The Geography of Trauma in Nova Scotia

by

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INTRODUCTION

Abstract

Injury is a leading contributor to Canada’s disease burden, accounting for over 15,000 deaths annually. Patients who receive care in designated trauma centers (TCs) have been shown to have a lower risk of trauma-related mortality, but these centers may not be accessible to large subsets of the population. This thesis uses geospatial and epidemiological methods with trauma registry data to assess the regional variation in trauma-related mortality in Nova Scotia and quantify the relationship between TC accessibility and trauma-related mortality. These analyses successfully identified clusters of high mortality risk and prolonged intensive care unit length of stay in the province. Additionally, poor access to TCs was found to be associated with an increased mortality risk for victims of motor vehicle collisions and penetrating injuries. Understanding the spatial variations in injury-related outcome can ultimately be used to inform trauma system organization and improve injury-related outcomes in Nova Scotia.

List of Abbreviations Used

CSD – CENSUS SUBDIVISION

DA – DISSEMINATION AREA

DALY – DISABILITY-ADJUSTED LIFE YEAR

EHS – EMERGENCY HEALTH SERVICES

GIS – GEOGRAPHIC INFORMATION SYSTEM

GPS – GLOBAL POSITIONING SYSTEM

ICD – INTERNATIONAL CLASSIFICATION OF DISEASE

ICU – INTENSIVE CARE UNIT

ISS – INJURY SEVERITY SCORE

HEMS – HELICOPTER EMERGENCY MEDICAL SERVICE

HRM – HALIFAX REGIONAL MUNICIPALITY

LZ – LANDING ZONE

MVC – MOTOR VEHICLE COLLISION

NS – NOVA SCOTIA

NSTP – NOVA SCOTIA TRAUMA PROGRAM

NSTR – NOVA SCOTIA TRAUMA REGISTRY

NTC – NON-TRAUMA CENTER

SES – SOCIOECONOMIC STATUS

SMR – STANDARDIZED MORTALITY RATIO

TC – TRAUMA CENTER

Chapter 1: Introduction

Introduction

There are relatively few issues in public health with the same pervasiveness and ubiquity as injury. Globally, injuries are responsible for 10% of all mortality, representing over 5 million deaths annually [1]. Although injuries are disproportionately concentrated in low-income countries, they affect every nation, social demographic and health sector [2]. Unfortunately, global estimates of the economic burden of injuries are nearly nonexistent, but reliable estimates for motor vehicle collisions (MVCs) have been generated and suggest their total costs amount to USD $518 billion annually [3]. As MVCs represent less than one third of all injuries, the true cost of injury globally is undoubtedly much higher [1].

In recent decades, policy-based interventions have been recognized as an effective means of addressing these high social and economic costs of injury [4]. The concentration of care at centers dedicated to the treatment of injured patients is one such policy that has had a significant impact on the mortality of patients cared for at these trauma centers (TCs) [5]. However, the reduced accessibility of resources concentrated at discrete, urban locations adds a geographic dimension to trauma care which remains relatively unstudied [6]. Understanding the relationship between trauma care access and mortality has important implications for healthcare resourcing, particularly in trauma systems predominated by rural injuries.

To further the understanding of how spatial access to TCs influences injury-related mortality, this study will combine spatial techniques based on Geographic Information Science (GIS) with the more traditional epidemiologic techniques of restriction and regression. By applying these methods to a retrospective database of severely injured patients, it will be possible to explore any observed associations between access to trauma care and mortality in the trauma system of the Canadian province of Nova Scotia (NS). Although a complete review of all relevant literature is beyond the scope of this thesis, the following sections will attempt to frame the subsequent chapters by providing a brief review of trauma care in Canada, and introduce the concept of access and how it can be quantified for use in epidemiologic research.

Injury Defined

Injury is traditionally defined as physical damage to the body through a sudden or brief transfer of energy, or through deprivation of heat or oxygen [7]. The transferred energy can be kinetic (MVCs, falls, assaults), thermal (burns, scalds), chemical (poisonings) or virtually any other type of energy capable of being acutely transferred to an individual. Injuries can be further classified based on presumed intent, with unintentional injuries representing nearly three quarters of the world's injury-related mortality [1]. These broad definitions of injury, encompassing entire spectrums of mechanisms and severity, contribute to the complex epidemiology of the disease. Study of injuries is further complicated by the regional variation in its epidemiology, suggesting context and mechanism-specific research is a justifiable approach to injury research [1]. This thesis explores issues related to the accessibility of trauma care by studying two distinct injury mechanisms, MVCs and penetrating injuries, defined by the International Classification of Disease (ICD) criteria.

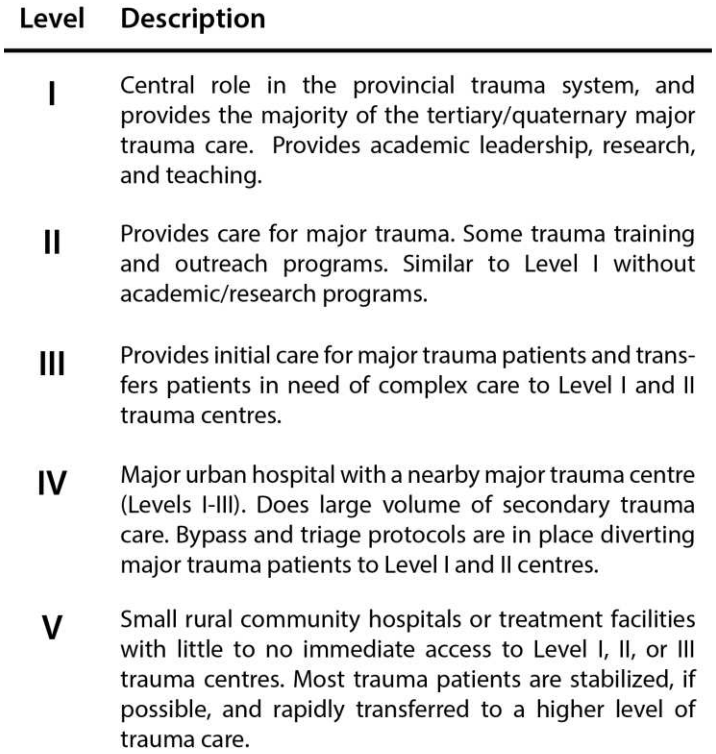
Burden of Trauma Care in Canada

In Canada, injury accounts for 6% of all mortality, representing over 15,000 deaths, and was the third leading cause of mortality in 2011 [8]. The costs associated with injury including medical care, rehabilitation, lost productivity and lost wages amount to nearly $20 billion per year, the fourth leading contributor to the economic burden of disease in Canada [9,10]. Injury accounts for more potential years of life lost than any other cause of death in Canada due to its high prevalence among younger demographics [11]. In addition to lost life years, there is a significant amount of disability associated with injury, making disability-adjusted life years (DALYs) an important metric to quantify injury burden. The Global Burden of Disease study estimates 1,972 disability-adjusted life years per 100,000 Canadians were attributable to injury in 2013, more than all communicable diseases combined [1]. Among all injury related deaths, falls are the most common mechanism (26%) followed by suicide (23%), MVC (15%) and poisoning (10%) [8].

Structure of Trauma Care in Canada

The landscape of Canadian trauma care has evolved substantially over recent years but maintains adherence, like most medical services, to the guiding principles of the Canada Health Act (public administration, comprehensiveness, universality, portability and accessibility)[12]. Despite ambulance services remaining excluded from this act, access to urgent and essential care is mandated by law for all Canadian citizens or landed immigrants. Although Canadian trauma care is federally guided through legislation and non-governmental accreditation bodies such as Accreditation Canada and the Trauma Association of Canada, it is funded and overseen by the individual provinces and territories, which are charged with developing their own standards and systems for trauma care delivery. Consequently, the structure of trauma care varies by province and territory, and each system has been developing to serve the specific region's unique geography and population and attaining different standards and levels of maturity. Despite the regional differences in Canadian trauma care, an understanding of the optimal management of the injured patient is evolving and robust, province-wide trauma systems are increasingly being adopted.

In NS, trauma care is coordinated through the Emergency Health Services (EHS), which in turn is overseen by the Minister of Health and Wellness. Currently trauma care in NS is regionalized, principally being provided at one adult level I centre (QEII Health Sciences Centre, Halifax Infirmary site), and one pediatric level I centre (IWK Health Centre), with support from eight level III trauma centres (Cape Breton Regional Hospital, St. Martha's Regional Hospital, Aberdeen Hospital, Colchester Regional Hospital, Cumberland Regional Health Care Centre, Valley Regional Hospital, Yarmouth Regional Hospital and South Shore Regional Hospital) (Figure 1-1) [13]. Mandated by the provincial government in 1997, the EHS developed an integrated provincial trauma program with the goal of facilitating the provision of optimal trauma care by providing leadership in injury prevention and control, education, research and trauma system development [14]. The implementation of formal trauma systems has revolutionized care of the injured patient and represents one of the major advancements in trauma care in recent decades [15].



Level	Description
I	Central role in the provincial trauma system, and provides the majority of the tertiary/quaternary major trauma care. Provides academic leadership, research, and teaching.
II	Provides care for major trauma. Some trauma training and outreach programs. Similar to Level I without academic/research programs.
III	Provides initial care for major trauma patients and transfers patients in need of complex care to Level I and II trauma centres.
IV	Major urban hospital with a nearby major trauma centre (Levels I-III). Does large volume of secondary trauma care. Bypass and triage protocols are in place diverting major trauma patients to Level I and II centres.
V	Small rural community hospitals or treatment facilities with little to no immediate access to Level I, II, or III trauma centres. Most trauma patients are stabilized, if possible, and rapidly transferred to a higher level of trauma care.

Figure 1-1 Description of the capabilities of the various tiers of trauma centers as outlined by the Trauma Association of Canada

The Nova Scotia Trauma Registry

The Nova Scotia Trauma Registry (NSTR) is one of the only population-based trauma registries in Canada. Maintained by the Nova Scotia Trauma Program as a quality assurance and research tool, this registry has been utilized in several peer-reviewed publications and policy briefs [79]. It captures data on all major traumas in NS, defined by the Canadian Institute of Health Information, National Trauma Registry definition (an appropriate ICD external cause of injury code and an injury severity score (ISS) > 11). Penetrating injuries with an ISS >9 are also included along with deaths within 24 hours of injury and trauma team activations. Annual re-abstracting audits are conducted on 10% of all entries. Since 2005, injury location data has been collected by prehospital personnel using Global Positioning Systems (GPS) and can be linked to the demographic and clinical data within the NSTR. The analyses for this thesis were conducted primarily using these two datasets.

Trauma Systems

Although 50% of deaths related to trauma result from catastrophic injuries and are likely only avoidable with primary and secondary prevention initiatives, the remaining 50% are potentially preventable with well-coordinated post-injury care [16]. Trauma systems, conceptualized as coordinated, geographically defined efforts designed to deliver the full range of care were developed, in part, to facilitate timely transport and treatment of injured patients and evidence for their effectiveness continues to accrue. One multicenter study conducted on a US population demonstrated a 25% reduction in the risk of death for moderate-severely injured patients treated at a TC compared to a non-trauma centre (NTC) [17]. Another US study also found TC care of injured patients to be associated with a significant mortality reduction compared to NTC care, and demonstrated the use of TCs to be associated with a cost of between $746 and $2815 per life year saved. The authors argue that this is considerably more cost-effective than other accepted interventions such as dialysis, coronary artery bypass grafting, and breast cancer treatment [18].

Several Canadian studies have come to similar conclusions. Studies from Quebec have consistently demonstrated decreases in mortality associated with regionalization and TC care [19–21]. Other studies based in NS found an increase in seriously injured patients admitted to TCs following implementation of the NS trauma program, but the authors were unable to detect more than a trend towards decreased mortality [22,23]. Perhaps the most compelling evidence for TC efficacy comes from a meta-analysis by Celso et al [5] that included 14 North American studies conducted on a variety of trauma systems. The authors concluded that TC care of injured patients was associated with a 15% decreased odds of death compared to NTC care. Clearly TC care is important in the treatment of injured patients, but determining how demographically and geographically diverse patient populations access TCs following injury remains an area of ongoing research, and a matter of social justice for a universal healthcare system.

Trauma Care Access

Inadequate access to essential public services was identified by the Whitehead report to be one of the seven main determinants of health differentials [24]. Inequitable access to services within a population is avoidable. Differences in health outcomes related to avoidable causes are unjust, and therefore an ethical concern as much as a political one [24]. Quantifying health inequities and consequent outcomes is necessary for developing policy aimed at equitable healthcare delivery and is largely the goal of this thesis [25]. Healthcare access is a multidimensional construct based on the interaction between healthcare systems and individuals [26]. Although a variety of frameworks have been proposed in the literature to aid in the conceptualization of access [27–29], one such framework, proposed by McIntyre and colleagues, distills access into three fundamental dimensions: availability, affordability, and acceptability [26]. By framing access as a geographic and socio-demographic construct, it becomes clear that the spatial relationship between a patient and a healthcare service is only one component of access, but study of this component has previously revealed startling population-level inequalities [30,31]. For the purposes of this thesis, access will be described in terms of its spatial (availability) and non-spatial (affordability, acceptability) components [32]. Although this thesis will focus on spatial access to TCs, the relevant work on non-spatial access to trauma care will be briefly discussed.

Socio-demographic factors have been repeatedly shown to contribute to the incidence of injury, and its consequent morbidity and mortality. In the US, trauma has been identified as one of the leading contributors to the higher mortality observed in the African-American population and individuals with fewer years of education [33]. Various indicators of socioeconomic status have also been identified as independent risk factors for trauma-related morbidity and mortality in several independent studies [34–36]. A meta-analysis by Haider et al identified insurance status, used as a marker for socioeconomic status, and race as being significantly associated with death following injury [37]. Although racial and socioeconomic disparities are possibly exaggerated by the unique structure of the US healthcare system, Canadian evidence supports racial disparities in injury-related incidence and mortality. A study by Karmali et al found Aboriginal populations of Alberta to be at a 3.7 fold increased risk of sustaining severe trauma, and a two-fold increased risk of dying compared to a reference population [38]. Despite the contributions of these non-spatial factors to the burden of injury, the expansive Canadian geography and heterogeneous population distribution makes spatial access to injury care another important contributor to injury-related outcome, and the focus of this thesis.

Trunkey and Baker classically described a tri-modal distribution of deaths following major injury [39,40]. Both studies suggested 50-60% of deaths occurred within minutes following injury, and were the result of catastrophic, non-survivable injuries. Although late deaths, occurring days after injury, have decreased substantially with improvements in post-injury care, the fraction of deaths occurring between one hour and 24 hours after injury has remained largely unchanged at 25-30% [41–43]. These deaths are potentially preventable with prompt transport to definitive care, and represent the population likely to benefit from improvements in spatial access to care.

In efforts to reduce the proportion of preventable deaths following major injury the concept of the “Golden Hour” was popularized in the 1970s. This adage implied that for optimal outcomes, an injured patient has 60 minutes from the time of injury to receive definitive care [44]. Although the heterogeneity of injury severities makes this rule non-generalizable, considerable evidence exists suggesting short prehospital intervals are associated with improved survival [21,45]. Sampalis et al demonstrated that prehospital times greater than 60 minutes were associated with a threefold increase in the odds of dying, and the same group subsequently identified shorter prehospital intervals as an independent predictor of improved survival [21,45]. This finding has been less robust in other trauma systems with two American studies reporting no survival advantage with shorter prehospital times [46,47]. Despite this disagreement, a recent meta-analysis identified shorter prehospital intervals to be associated with improved outcomes for patients with central nervous system injuries and hemodynamically unstable patients with penetrating injuries [48]. Although no complete assessment of the influences of prehospital times on outcomes has yet taken place in NS, some evidence exists that patients transported by air instead of ground have better outcomes [49]. Cumulatively, this evidence suggests that patients with better spatial access to TC care, and therefore shorter prehospital times, may have a survival advantage following major trauma. Additionally, individuals with poor spatial access to TC care may possess different behavioral risk factors compared to the general population such as seat belt use, substance misuse, or suicidal intent [50]. Consequently, defining the populations with poor spatial access to TC care is important to target interventions such as primary prevention programs, expanding TC infrastructure, or modifying prehospital transport protocols.

Geographic Information Systems

Few would argue that the spatial relationships between individuals and their environment have no impact on health. In fact, some of the very foundations of modern epidemiology can be traced to the mid-19th century work of John Snow, who successfully identified the source of a Cholera epidemic in the Soho neighborhood of London through the meticulous mapping of cases relative to local water sources [51]. However, it is only recently that technology has developed to the point where quantitative spatial analyses are receiving more widespread implementation in the fields of public health and epidemiology [52]. As spatial epidemiology remains unfamiliar to many audiences, a brief introduction to it's primary tool, the Geographic Information System (GIS), is warranted.

GIS is defined as an “automated system for the capture, storage, retrieval, analysis, and display of spatial data [52]” Fundamentally, a GIS is a software package comprised of a database of non-spatial information, a map or other spatial display, and a means to link the two together [6]. For the epidemiologist, GIS provides a means to quantify spatial relationships for the purposes of analyzing associations between location, environment and disease [52]. This has been aided by the increased access to GPS technology, which has provided an inexpensive means to add spatial information to datasets. The EHS has recognized the utility of this tool and now routinely collects GPS data on all ambulance responses in NS. By linking this data with the retrospective database of severely injured patients maintained by the NS Trauma Program, GIS can be used to display and study the distribution of trauma in NS.

The analysis that occurs within a GIS encompasses a variety of methods developed in geography, statistics and other disciplines. Although any method that analyzes and relates spatial information can be considered a form of spatial analysis, Gattrell and Bailey distill these types of analyses into three categories: visualization, exploratory data analysis, and model building [53]. Although there is considerable overlap between these categories, and none can be considered distinct, they provide a useful framework to discuss the breadth of the field.

Visualization is the process of displaying spatial information in a form that allows the rapid recognition of spatial patterns. Although John Snow's Cholera map is a classic example of this, the data management abilities of GIS allow for the creation of much more sophisticated, multilayered displays (Figure 1-2). A modern example of data visualization can be found in vector control programs. By overlaying layers containing data on population, precipitation, elevation, and vegetation it is possible to visualize the most suitable habitats for disease vectors and thereby target control programs such as pesticide deployment [54]. This thesis incorporates many different forms of visualization in each chapter, underscoring the techniques value in spatial epidemiology.

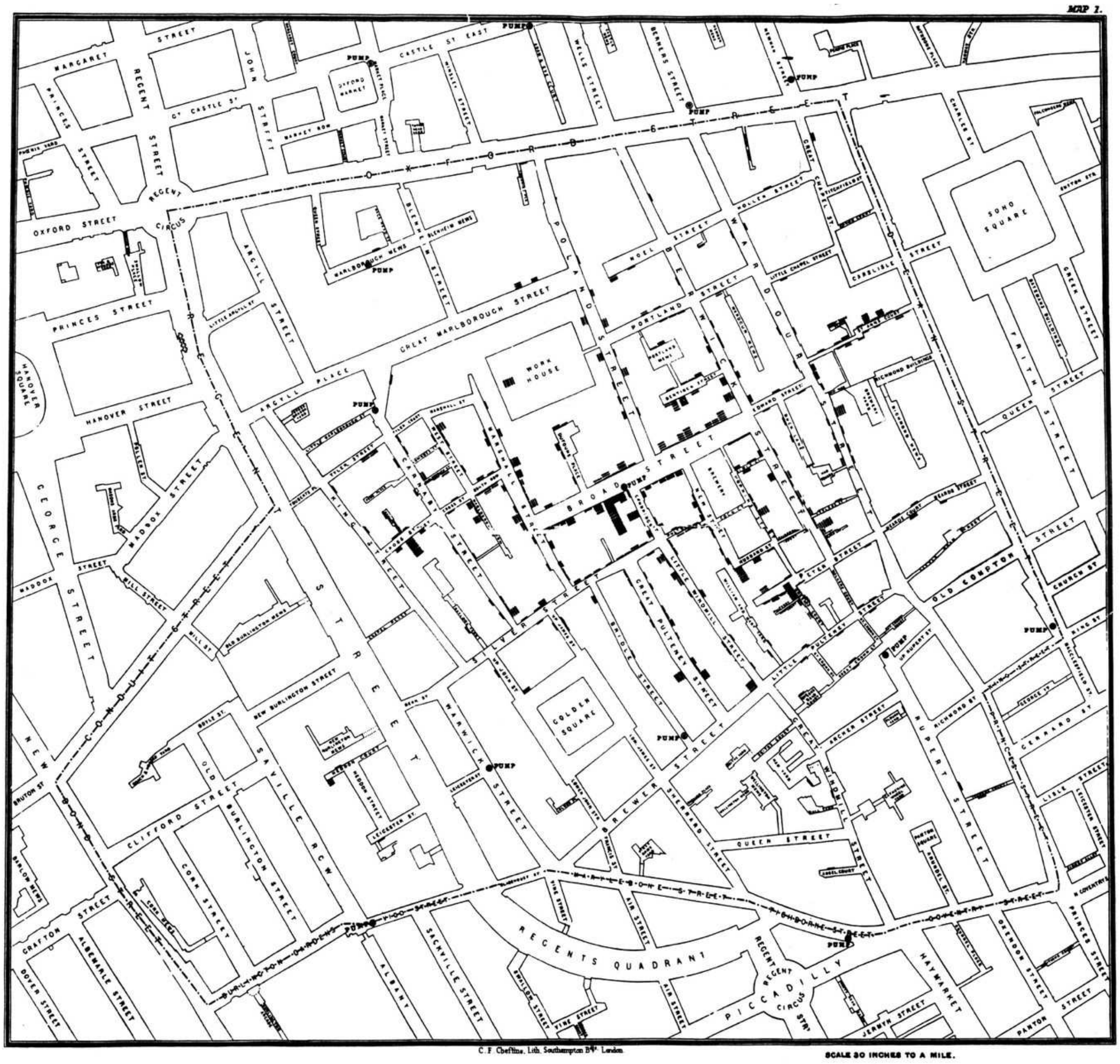


Figure 1-2: Original map by John Snow showing the clusters of cholera cases in the London epidemic of 1854, drawn and lithographed by Charles Cheffins.

The second form of spatial analysis is exploratory data analysis. These methods allow the analyst to explore data and identify spatial patterns which may ultimately lead to new hypotheses [52]. Among the more used exploratory methods are cluster detection techniques. These methods have been extensively used in infectious disease epidemiology to identify regions of geographically and/or temporally bounded occurrences which are unlikely to have occurred by chance [54,55]. Exploratory methods are also useful for searching for administrative areas of high disease prevalence. These methods can address issues of small numbers to smooth occurrence rates, as well as generate probability maps to display the statistical significance of rates [56]. Both cluster detection and Bayesian smoothing methods are employed in the first chapter of this thesis to illustrate the regional variation in adverse MVC-related outcomes.

Finally, GIS can also be used to generate data for input into more traditional epidemiologic models. An early example of this comes from a study of Lyme disease, where a GIS was used to generate variables such as slope and distance to a forest for subsequent incorporation into logistic regression models [57]. This is analogous to the second and third chapters of this thesis, where a model is built to quantify spatial access to trauma care for subsequent incorporation into logistic regression models. A review of all GIS-based modelling techniques is beyond the scope of this thesis, but a variety of methods have been developed to analyze all forms of spatial data [54]. Models designed to quantify access comprise only a subset of GIS-based modelling techniques, but since they are central to this thesis, the next section will discuss these models in further detail.

Measuring Access to Trauma Care

Spatial access to trauma care can be considered at the population level (potential access) or through studying service utilization (realized access). Several quantitative methodologies have been developed within GIS to measure both of these dimensions of spatial access and a thorough review of the topic has been published [58]. Measurements of potential access typically only requires knowledge of healthcare locations relative to population distributions, and is therefore easier to perform than assessments of realized access which require georeferenced utilization data [58].

Fundamental to all measurements of spatial access is the need to quantify the travel impedance between the population of interest and the health service, which can be defined in terms of travel distance or travel time [59]. In health research, travel impedance has most commonly been represented by straight-line (Euclidean) distances, but these representations of access fail to consider the potentially significant influence of topological barriers or transportation infrastructure [60,61]. Improvements in technology now allow representations of access to more closely resemble real world travel patterns by using transportation networks and speed limits to more accurately quantify travel distances and times [62].

Two data representations are possible with a GIS, and both can be utilized to quantify spatial access. Vector-based methods, known as "network" methods, represent roads or other transport infrastructure by a series of connected line segments linked to a database of attributes such as speed limits, road sizes or surfacing materials. An algorithm is then applied to identify the "least cost" route between a specified start and endpoint. In contrast, raster-based methods utilize a grid of a user-specified resolution to represent data. A travel cost can then be applied to each of these cells according to the geographic features contained within them. These "cost surfaces" can be built using combinations of road data, elevation data, or other geographic barriers, and provide the source information for algorithms designed to identify the travel times from source points (i.e. health centers) to all cells in the study area [59]. Both types of data representations have been used in studies of healthcare access previously, and no consensus exists on which method is most appropriate [59,63,64].

The first national-level assessment of potential access to level I or II trauma centres was an American study published by Branas et al [65]. These authors utilized a computerized resource allocation model to define the proportion of the population residing within 45 and 60 minutes of travel to a level I or II TC by either ambulance or helicopter [66]. The authors identified that 69% and 84% of all US residents had access to at least level II TCs within 45 and 60 minutes of injury, respectively [65]. A Canadian study by Hameed et al aimed to accomplish a similar objective utilizing a network method in a geographic information system (GIS) [15]. The results of the Hameed study were largely consistent with the American findings, with 77.5% of Canadians residing within 1-hour road travel time to a level I or II trauma centre. Estimates for NS were considerably lower than this with only 41.6% of the population within 1-hour drive time to the province's only level I or II adult TC [15]. These studies were not without their limitations, however. Using the location of residences as a surrogate for place of injury assumes injury is randomly distributed throughout the population, and that patients get injured at or near their homes. Both of these assumptions have been challenged [67,68]. Furthermore, both studies likely represent overestimates due to the exclusion of ambulance response times and scene times in their analyses. Finally, arbitrarily defined service areas and a lack of outcome information makes it difficult for such studies to be applied by policymakers.

To address some of these limitations, studies have been conducted specifically in injured populations. Lawson et al used similar GIS methods to those described previously, but conducted their analysis using the residences of only patients who died or were hospitalized following injury [69]. Their estimates were similar to those of Hameed et al, with 68.5% of injured persons living within 1-hour of a level I or II TC [69]. Other work has been done utilizing statistical methods to define realized access to TCs, overall providing concordant results with prior work [70,71]. However, the lack of spatial analysis makes it difficult to identify which populations have poor access to care. The first major study that combined spatial analyses using injury location data with adjusted statistical techniques was conducted by Crandall *et al* on an urban Chicago trauma system [72]. These authors identified a small, but significant survival disadvantage for individuals injured by a penetrating mechanism greater than 5-minutes from a TC after adjusting for age, gender, injury severity and socioeconomic status.

To date there have been no Canadian studies assessing access to care utilizing precise injury location data. This thesis aims to utilize georeferenced injury location data linked to a provincial trauma registry to define the potential and realized access to TC care for a severely injured retrospective cohort. Incorporation of clinical data from a comprehensive dataset will allow an adjusted evaluation of the association between access and outcome for victims of major trauma in NS. By identifying potentially worse outcomes following injury in populations with poorer spatial access to TC care, trauma program infrastructure could be expanded or transport protocols modified to address identified inequities.

Thesis Overview

This thesis will employ the spatial techniques described above on georeferenced data from the NS Trauma Registry to address three research questions:

1) Is there regional variation in injury-related outcomes in NS?

2) Is there regional variation in the accessibility of TCs in NS?
3) Is poor spatial access to TCs associated with an increased risk of injury-related mortality in NS?

The thesis document is organized into three chapters. The first chapter is an exploratory analysis of the regional variation in adverse injury-related outcomes in NS. Using cluster detection methods and Bayesian smoothing techniques, this chapter identifies areas at increased risk of adverse outcomes following motor vehicle collisions (MVCs). The second chapter develops and validates a model to quantify the spatial accessibility of trauma care in NS. Raster-based cost-distance methods are combined with a spatial interpolation to create a continuous surface of prehospital times for the province of NS. This model is then applied to the provincial population as well as a retrospective cohort of patients severely injured in MVCs to describe the accessibility of trauma care of these two populations. The final chapter uses this model to generate estimates of access for two cohorts of patients: those injured in MVCs and those injured by penetrating mechanisms. Logistic regression models are then built to identify if spatial access to level I or level III trauma care is associated with mortality in either of these cohorts. A formative discussion will follow specifying how the results of this thesis may influence the care of the injured patient in NS.

Chapter 2: Regional variation of injury-related outcomes in Nova Scotia

Introduction

Unintentional injuries are the fifth leading cause of death in Canada, accounting for greater than 10,000 deaths and $22.1 billion in direct and indirect costs annually [8,11]. Over a quarter of these deaths are related to transportation incidents, which alone account for $4.3 billion in annual total costs [8,11]. In addition to the economic costs, transportation incidents disproportionately affect individuals between 5 and 44 years of age, representing a further social cost related to premature mortality [73]. In recent years, the World Health Organization has recognized the growing morbidity and mortality associated with transportation incidents, particularly in low- and middle-income countries, and has made several recommendations on how member states should address this problem [73]. Included in these recommendations is the collection and analysis of reliable data to inform road safety planning and decision making [73]. Despite these recommendations, road safety remains understudied in many nations, including Canada.

As the majority of trauma-related deaths are immediate, and likely the result of catastrophic, non-survivable injuries, primary prevention of motor vehicle collisions (MVCs) is an important component of any mature trauma system [39,43]. Additionally, tertiary prevention strategies in the form of coordinated post-injury care have been reproducibly shown to be effective at reducing trauma-related mortality [17,74]. Due to the widespread implementation of these preventative strategies, recent years have seen declines in the rates of major injury and death related to MVCs in Canada [75]. However, injury-related mortality rates in Canada have previously been shown to vary geographically, suggesting that identifying areas at high risk of adverse injury-related outcomes is a potentially useful means of guiding the development of effective prevention and acute care policy [69]. For example, implementation and enforcement of traffic laws is a cornerstone of Canada’s MVC prevention strategy with current methods of enforcement largely based on penalizing individuals caught disobeying laws [75]. Seat belt use, speed limits and impaired driving laws have all been successful strategies in reducing MVC-related mortality [75]. As implementation and enforcement of laws requires the use of a limited supply of specialized equipment and/or personnel, it is inherently a geographic problem which could benefit from rational targeting strategies [6].

Delivery of post-injury care is a similar geographic problem. As injured patients often require time-sensitive interventions, individuals with poor access to definitive care may fare worse than individuals injured closer to centers with the resources and staffing required to care for injured patients [69,72]. Additionally, regional variations in institutional practices and protocols may result in clinically significant differences in the way injured patients are managed within a trauma system [76]. Use of spatial techniques to identify regions of poor trauma-related outcomes is a tool that can be used to identify these practice irregularities and improve care within a trauma system.

Due to a limited availability of injury location data linked to registries with relevant clinical outcome information, regional variation in MVC mortality has not been rigorously studied in Nova Scotia (NS). Accordingly, we undertook this study to explore the geographic patterning of adverse MVC-related outcomes in NS using a provincial, population based trauma registry linked to injury location data. Potential explanations for high-risk areas were subsequently explored.

Methods

Setting

NS is the second smallest province in Canada with an area of 55,284 km^2 [77]. The population of NS was estimated in the most recent 2011 census to be 921,727, which results in an average population density of 16.7 persons/km^2 [77,78]. This population is divided into 99 census subdivisions (CSDs) roughly corresponding to municipalities [78]. With a 2.3 fold higher proportion of rurally residing people than the national average, NS is also the third most rural province in the country [78]. This is interesting from a healthcare resourcing perspective because most of the specialized healthcare resources in the province are concentrated in the Halifax Regional Municipality (HRM), which occupies a 5,850 km^2 area on the province's south central coast [77]. Trauma care resources, for example, are heavily concentrated in the HRM, with the only adult and pediatric level I TCs located in this municipality. The level I TCs are supported by eight level III TCs located throughout the province (Figure 2-1). A comprehensive network of ground ambulances administered by Emergency Health Services (EHS) provides prehospital transportation to the majority of the major traumas in the province.

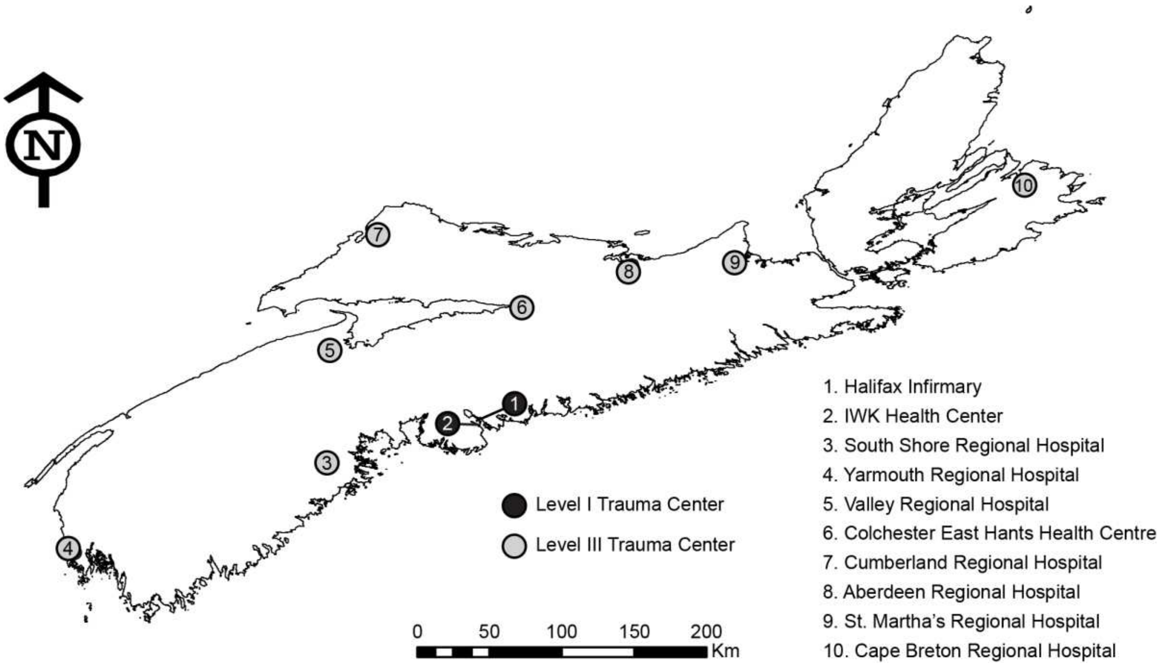


Figure 2-1: Locations of level I and level III trauma centers in Nova Scotia.

Study Data

All MVC-related injuries (ICD-10 V01 to V99) between January 2005 and December 2013 with an injury severity score (ISS) >11 were eligible for inclusion. Trauma team activations and prehospital deaths were similarly eligible for inclusion. Injury locations were obtained from the EHS, which records scene locations for all ground responses using global positioning systems (GPS). These data were linked to the Nova Scotia Trauma Registry (NSTR), a retrospective population-based database of all major traumas in NS, to obtain the demographic and clinical data corresponding to the injury location [79]. Individuals who were missing GPS coordinates or whose pickup location was inconsistent with the injury location were excluded. All duplicate entries were removed prior to analysis. Mortality data included prehospital as well as in-hospital deaths.

The locations of level I and level III TCs were obtained from a commercially available provincial dataset (CanMap, DMTI spatial, Markham, Ontario). The geographic boundary file for the census subdivisions was obtained from Statistics Canada [80]. All maps were generated using commercially available geographic information system (GIS) software (ArcMap, Esri, Redlands, CA).

Calculation of smoothed standardized mortality ratios

The point locations of all MVC-related deaths were aggregated to the CSD in which they occurred to obtain the observed number of deaths in each CSD, averaged over the eight-year study period. Direct age standardized mortality rates for MVCs were obtained using the 2011 Canadian residential population as the standard population and all transportation related deaths (ICD-10 V01 to V99) in the same year [8]. The expected number of MVC-related deaths in each CSD was then calculated using the age-specific mortality rates and the demographic structure of each CSD.

As area-based estimations demonstrate considerable instability in situations of small counts, Bayesian smoothing was applied to the standardized mortality ratios (SMRs) using the Besag, York and Mollié model [81]. This widely used method strengthens an area's risk estimate by incorporating prior information about the risk estimates in adjacent areas [54]. As smoothed SMRs are more stable and have corresponding uncertainty intervals, they are ultimately more informative to decision makers [82]. The resulting model produced a posterior distribution of the expected relative risk of mortality following MVCs for every CSD. The mean of the posterior distribution was taken as the best estimate of the SMR for each CSD and was plotted in a choropleth map using ArcMap. CSDs with a ⬅95% posterior probability of having an SMR greater than one were identified as "high risk" areas for MVC-related mortality compared to the national average. The model was run for 50,000 iterations following an initial burn-in of 1,000 iterations. Convergence was verified visually using traceplots and autocorrelation plots. Spatial dependency of the model's residuals was excluded using the Global Moran's I [83]. All Bayesian models were built using WinBUGS v1.4 [84]. Bivariate analyses comparing high and average risk CSDs were conducted using Stata v14.0 (Statacorp, College Station, TX).

Cluster Analysis of Outcomes following MVCs

Clustering of adverse outcomes following MVCs was evaluated using the Kulldorff spatial scan statistic within SatScan v9.4.2 [85]. This method constructs a series of ellipses of enlarging radii around each point location and tests the null hypothesis that the frequency of cases within the window is equivalent to the frequency of cases outside the window. Monte Carlo simulations are then conducted to compare the generated test statistic against a distribution of values generated under the null hypothesis [54]. Clustering of mortality, prolonged length of stay and prolonged ICU length of stay were evaluated using Bernoulli or ordinal models, where appropriate. For mortality, cases were defined as patients who died at any point in the prehospital setting or during their index hospital admission following injury, and controls were defined as those who survived to discharge. For the prolonged length of stay analyses, data were reclassified into quintiles. Hospital or ICU stays in the fifth quintile were defined as prolonged.

Potential explanations for clustering were sought through bivariate and multivariate comparisons between individuals within clusters and individuals outside of clusters using Stata v14.0. Bivariate comparisons were made using Fisher's exact test and Student's t-tests, where appropriate. Multivariate analyses were conducted using logistic regression.

Results

Study data

The general characteristics of the study population are illustrated in Table 2-1. Of the 1568 database entries, 77 were duplicates and 1304 (87.5%) were suitable for spatial analysis. Overall, victims were young and predominantly male. Twenty-five percent of the victims of MVCs died as a result of their injuries and individuals who died were, on average, more severely injured.

Table 2-1:Baseline characteristics of the study population.

Variable	MVC Frequency No. (%) or Mean ± SD	MVC Mortality No. (%) or Mean ± SD
Total	**1304**	**326 (25.0)**
Age (years)	39.4 ± 20.7	43.3 ± 22.7
Gender		
Male	896 (68.7)	241 (73.9)
Female	408 (31.3)	85 (26.1)
Injury Severity Score	27.4 ± 14.3	40.2 ± 18.6

Spatial distribution of MVC-related mortality risk

A choropleth map demonstrating the distribution of MVC-related mortality risk along with its associated probability map is illustrated in Figure 2-2. CSDs with a high probability of having an SMR greater than one are apparent in the northern region of Cape Breton Island. Notably, these CSDs contain or are adjacent to the Cabot Trail, one of the higher traffic tourist destinations in the province. Bivariate analyses demonstrated an increased rate of death in high risk CSDs (41.9% vs 24.2%, p=0.002) as well as higher mean ISS (31.8 vs 27.1, p=0.012) (Table 2-2). Additionally, deaths in high risk areas were more likely to occur in summer months (46.8% vs 31.0%, p=0.009) and more likely to occur in the prehospital setting (32.3% vs 15.4%, p<0.001). Review of the causes of death for the mortalities within high risk CSDs demonstrated that 38% resulted from multiple blunt injuries, 31% resulted from head trauma, 15% resulted from abdominal trauma, 8% resulted from chest trauma, and 8% resulted from other injuries.

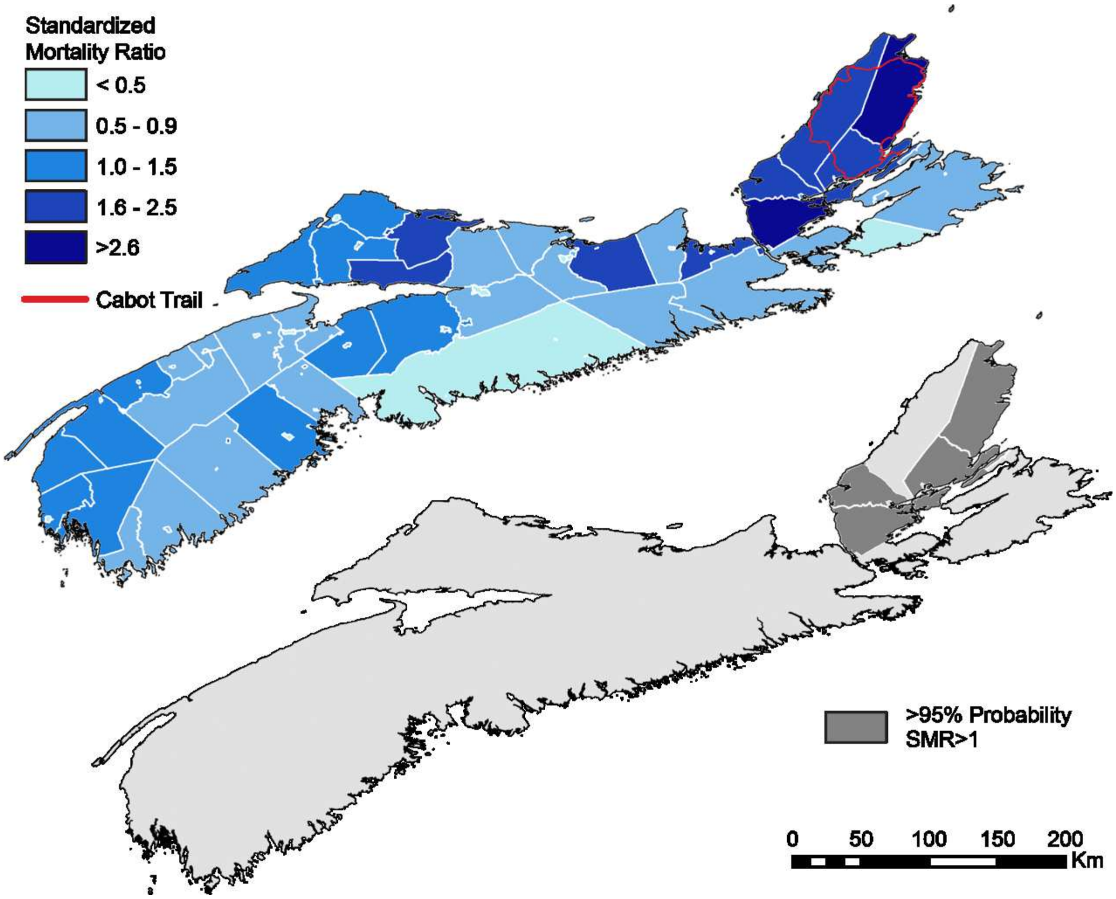


Figure 2-2: Choropleth map of smoothed standardized mortality ratios in Nova Scotia, by census subdivision. Associated probability map demonstrates areas with a greater than 95% probability that their corresponding standardized mortality ratio is greater than one.

Table 2-2: Bivariate comparisons of MVCs occurring in high risk versus average risk census subdivisions.

Variable	High Risk Areas	Non-High Risk Areas	P-value
Total	**62**	**1242**	
Unadjusted mortality (per 100 persons)	41.9	24.2	0.002
Age (years)	38.3	39.4	0.672
Gender			0.340
Male	46 (74.2)	850 (68.4)	
Female	16 (25.8)	392 (31.6)	
Injury Severity Score	31.8 ± 18.1	27.1 ± 14.0	0.012
Ejection	19 (30.7)	292 (23.5)	0.532
Highway	38 (61.3)	675 (54.4)	0.284
Summer Season	29 (46.8)	384 (31.0)	0.009
Scene Deaths	20 (32.3)	232 (15.4)	<0.001

Spatial Clustering of adverse outcomes for victims of MVCs

Using the Kulldorff spatial scan statistic, the spatial distribution of adverse outcomes was explored for victims of MVCs. Although no significant clustering of deaths or hospital length of stay was identified, one significant cluster of ICU length of stay (9 or more ICU days) was found around one level III TC (RR 5.36, p=0.003) (Figure 2-3). The characteristics of the cluster population are illustrated in Table 2-3. The patients within the cluster were overall comparable to the patients outside the cluster with respect to age, gender and injury severity, but patients within the cluster were more likely to have experienced complications (1.6 complications per patient within the cluster vs. 0.7 for patients outside the cluster, p=0.007) and more likely to be admitted to hospital prior to transfer to the center where they received definitive care (23.3% of patients within the cluster vs. 6.5% of the patients outside of the cluster).

Logistic regression analyses were subsequently performed to explore the potential relationship between admission to multiple centres and prolonged ICU length of stay. Cases identified within the cluster were excluded from these analyses to avoid the Texas sharpshooter fallacy (a form of bias resulting from when a correlation is hypothesized and tested using the same set of data). Following adjustment for gender, age, and injury severity, admission to multiple facilities was associated with a 2.3 fold increased odds of prolonged ICU length of stay (p=0.030) (Table 2-4).

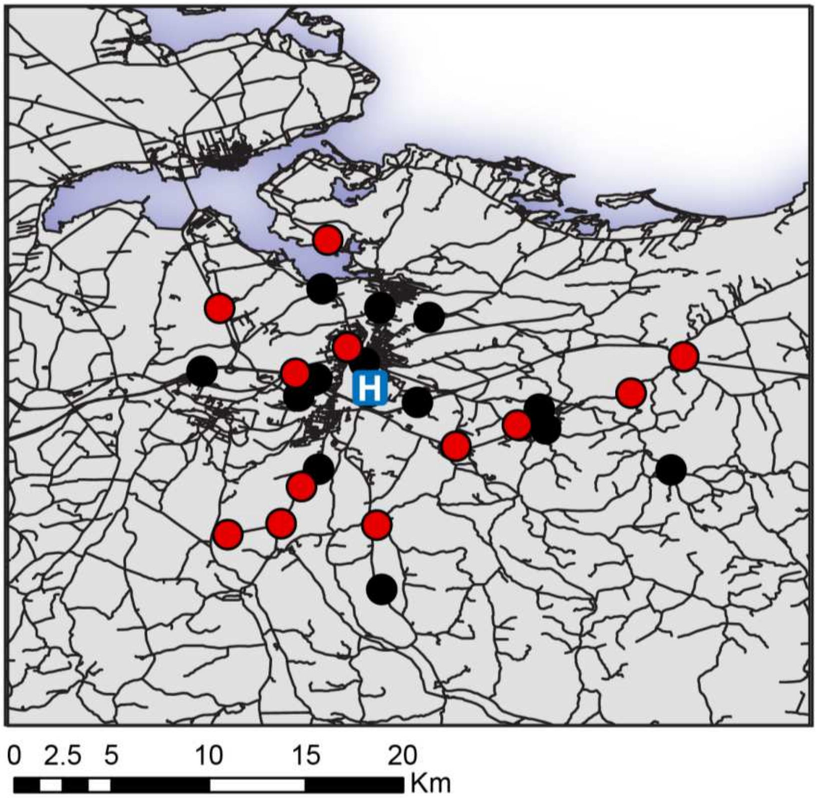


Figure 2-3: Results of Kulldorff spatial scan illustrating the locations of the cases in the cluster. Red symbols represent the locations of cases that experienced a prolonged ICU length of stay. Black symbols represent the cases that did not have a prolonged ICU length of stay

Table 2-3: Patient characteristics of the population within the cluster and the population outside of the cluster.

Variable	Cluster	Study Population	P-value
Total	**30 (2.3)**	**1,274 (97.7)**	
Unadjusted mortality (per 100 persons)	20.0	25.12	0.522
Age (years)	39.4 ± 20.2	39.4 ± 20.7	0.9976
Gender			0.807
Male	20 (66.7)	876 (68.8)	
Female	10 (33.3)	398 (31.2)	
Injury Severity Score	26.7 ± 10.3	27.4 ± 14.4	0.792
Length of stay	23.8 ±25.2	15.5 ± 25.6	0.0846
Number of Complications	1.6 ± 2.5	0.7 ± 1.6	0.0072
Admission prior to definitive care	7 (23.3)	83 (6.5)	<0.001

Table 2-4: Adjusted odds of prolonged ICU length of stay for victims of MVCs with ISS>11 between 2005 and 2013.

Variable	Adjusted OR (95% CI)	P-value
Prior admission	2.30 (1.08-4.93)	0.030
Male Gender	1.22 (0.76-1.96)	0.406
Age	1.00 (0.99-1.10)	0.406
ISS	1.05 (1.03-1.07)	<0.001

Discussion

This study demonstrates considerable spatial variation in the risk of adverse outcomes following MVCs in NS. The group of high risk CSDs identified on Cape Breton Island contain or are adjacent to some of the most popular tourist destinations in the province. This could potentially explain part of this finding as you would expect a tourist attraction to increase the traffic in an area above what would be expected from the area's residential population. This is supported by the preponderance of events during peak tourism times. However, the increased mortality risk, the higher ISS, and the higher likelihood of a scene death in these areas also suggests that the MVCs in these CSDs are more fatal relative to MVCs in other areas of the province. Notably, this region of NS is also home to half of the province's 16,000 Mi'kmaq First Nations; a disproportionate number for a region containing approximately 15% of the provincial population [8]. This is a potentially relevant association given the higher trauma-related mortality observed in aboriginal populations [38].

Although no clusters of increased mortality risk or prolonged hospital length of stay were found with a complementary methodology, one cluster of patients who experienced a prolonged ICU length of stay was identified. The colocalization of this cluster with one level III TC suggests that institutional practices may contribute to this finding. Notably, the patients within this cluster were over 3.5 times more likely to require transfer to a level I TC following initial admission at a level III facility. This association between ICU length of stay and initial mistriage remained robust in an adjusted model with the cluster excluded, suggesting it is a global association and not specific to the one identified cluster.

Spatial analyses are increasingly being used to identify regional variations in disease risk [54]. Additionally, by combining spatial data with clinical, demographic and environmental information, potential explanations for observed clustering can be explored. Although predominantly employed to detect clustering of infectious diseases, these methods are becoming frequently used in the study of noncommunicable disease distribution [55]. For example, work based in New South Wales, Australia has used both Bayesian and frequentist spatial methods to identify regions at increased risk of childhood burns [86,87]. Moreover, Liu and colleagues used the Kulldorff spatial scan statistic to identify spatial clustering of myelodysplastic syndromes in the eastern United States, and subsequently used the identified clusters to explore potential socio-demographic associations. In Canada, the Kulldorff spatial scan statistic has also been used to identify clusters of poor health-related quality of life following pediatric injury [88].

The advantages of using cluster detection techniques lie in their ability to detect areas of locally elevated risk, allowing for disease surveillance on finer spatial scales and, ultimately, more directly targeted health interventions [54]. A classic study by Mallonee and colleagues demonstrated how the use of surveillance data collected at a fine spatial scale could be used to successfully target a prevention intervention when they used detailed data on fire-related injury locations to inform a smoke alarm give-away program in an Oklahoma City neighborhood [89]. Although cluster detection methods have been previously employed to detect hot spots of MVCs or pedestrian injuries, there is currently a paucity of studies evaluating the distribution of MVC-related mortality over large geographic areas [90–93]. Furthermore, the utility of cluster detection studies on their own, without a corresponding investigation into potential explanations has been questioned [94]. Therefore, comprehensive datasets incorporating spatial, demographic and clinical data are required to undertake rigorous studies into the spatial variation of trauma-related mortality. Unfortunately, these datasets have limited availability in Canada.

By using two different techniques to evaluate the regional variation in several different outcomes following MVCs, we were able to identify potential intervention targets within the NS trauma system. The greater than expected number of MVC-related mortalities in four CSDs on Cape Breton Island make this area an important target for road safety campaigns such as evaluation of road design and speed limit enforcement programs, particularly during peak tourism times. Additionally, as these CSDs represent some of the areas with the poorest access to level I trauma care, ensuring the nearest level III TC has sufficient capacity to manage a wide range of traumatic injuries will be important for ongoing quality improvement. One specific consideration would be the addition of neurosurgical capacity to the Cape Breton Regional Hospital given that nearly a third of deaths in the high risk CSDs are a direct result of head trauma, and that neurosurgical interventions are among the most time sensitive for the injured patient [48].

The colocalization of a level III TC with a cluster of patients who experienced a prolonged ICU length of stay suggests regional practices may be contributing to this finding and warrants further investigation. Interestingly, the patients within this cluster were 3.6 times more likely to be initially admitted to an institution other than the one where they received their definitive care. Although this association could potentially be explained by reverse causation, with more critically ill patients requiring transfer and therefore more likely to experience a prolonged ICU length of stay, this is made less likely with the adjustment for injury severity and the observation of similar associations in other trauma systems [70] .

Reverse causation also doesn't explain the identified clustering of prolonged ICU length of stay around one level III TC. This finding is better rationalized by institutional variation in practices or protocols resulting in the observed geographic variation in the outcomes of injured patients. Such practice variability has been previously documented in another trauma system. A study by Gomez and colleagues identified significant variability in triage practices in Ontario by identifying several counties where patients had low realized access to trauma care despite being injured near designated trauma centers (TCs) [76]. Review of triage and referral practices within the province of NS, and particularly at the institution associated with the identified cluster, will be an important component of ongoing system evaluation to improve patient safety and reduce costs associated with prolonged ICU stays.

The use of precise injury location data is an advantage of this study compared to similar work with other injury mechanisms [86,87]. Although the relatively small number of MVCs prevent the use of more sophisticated geographically weighted regression techniques, the use of Bayesian smoothing limits the effect of small numbers on the estimated SMRs. Additionally, the use of a relatively stringent probability criterion of 95% limits the likelihood of a type 1 error. A further limitation of this study is the inclusion of only major traumas in the available dataset. This makes it impossible to calculate standardized incidence ratios, which would be useful in discerning between high mortality areas and high incidence areas. Despite these limitations, this study used two different techniques to identify two high risk areas which are potentially amenable to specific interventions.

Although spatial analyses such as this may be useful for the restructuring of primary and tertiary prevention resources, policy makers need to maintain awareness of the prevention paradox whenever interventions are focused on high risk areas [95]. Although the populations identified in this study were found to be at considerably increased risk of death or prolonged ICU stay, both populations represent a minority of MVC-related injuries in NS. Therefore, although high risk areas can be emphasized in any prevention intervention, province wide coverage and ongoing surveillance are necessary to ensure protection of the majority population and inform the shifting of resources when necessary.

Conclusions

Understanding the geographic variation in MVC mortality can contribute to the understanding of provincial transport safety and help identify high risk populations. Spatial analysis is a potentially useful means of studying this variation and identifying statistically meaningful areas at high risk of adverse MVC-related outcomes. The areas identified with an increased risk of adverse outcomes may be explained by a combination of behavioral factors such as seat belt use, vehicle speed, or use of impairing substances. Additionally, poor access to tertiary trauma services such as neurosurgical care as well regional institutional practices could be contributing independently to the association, and warrant further investigation. All of these factors are modifiable through the implementation of primary and secondary preventative strategies, and should receive specific attention in high risk areas.

Chapter 3: Potential Spatial Access to Trauma Care in Nova Scotia

Introduction

Injury is a major cause of mortality and health expenditure in Canada, accounting for over 15,000 deaths and $20 billion of direct and indirect costs annually [9]. Although the landscape of Canadian trauma care has evolved substantially over recent years, it maintains adherence, like all medical services, to the guiding principles of the Canada Health Act (public administration, comprehensiveness, universality, portability and accessibility) [12]. Resultantly, access to urgent and appropriate essential care is not only an expectation, but mandated by law for all Canadian citizens or landed immigrants.

Although Canadian trauma care is federally guided through legislation and non-governmental accreditation bodies such as Accreditation Canada and the Trauma Association of Canada, it is funded and overseen by the individual provinces and territories, which are charged with developing their own standards and systems for trauma care delivery [96]. Consequently, the structure of trauma care varies by province and territory, with each system developing to serve the specific region’s unique geography and population. Understandably, the diverse challenges of trauma care delivery in Canada have resulted in the provinces and territories attaining different standards and levels of maturity. This heterogeneity underscores the importance of ongoing evaluation at the provincial level to maintain high standards of trauma care across the country.

In Nova Scotia (NS), trauma care is coordinated through Emergency Health Services (EHS), which is overseen by the Minister of Health and Wellness. Currently, trauma care in NS is regionalized, with coordinated delivery throughout the entire provincial health authority. Acute care in NS is principally provided in the capital city of Halifax at one adult level I trauma centre (TC) (Halifax Infirmary), and one pediatric level I TC (IWK Health Centre), with regional support from eight level III TCs (Cape Breton Regional Hospital, St. Martha’s Regional Hospital, Aberdeen Hospital, Colchester Regional Hospital, Cumberland Regional Health Care Centre, Valley Regional Hospital, Yarmouth Regional Hospital and South Shore Regional Hospital). Mandated by the provincial government in 1997, the EHS developed this integrated provincial trauma program with the goal of facilitating the provision of optimal trauma care by providing leadership in injury prevention and control, education, research and trauma system development [79]. The implementation of formal trauma systems in North America has resulted in an estimated 15% decreased odds of death following injury, and represents one of the major advancements in trauma care in recent decades [5]. Although this approach helps ensure the optimal management of finite resources, it has the consequence of concentrating these resources at fewer locations. As accessing trauma care is required before survival benefits can be realized, measuring accessibility becomes an important component of trauma system evaluation and equitable healthcare delivery in Canada [97].

Healthcare access is a multidimensional construct based on the interaction between health systems and individuals [26]. Although a variety of frameworks have been proposed in the literature to aid in the conceptualization of access [27–29], one such framework, proposed by McIntyre and colleagues, distills access into three fundamental dimensions: availability, affordability, and acceptability [26]. By framing access as a geographic and socio-demographic construct, it becomes clear that the spatial relationship between a patient and a healthcare service is only one component of access. However, the expansive Canadian geography and inhomogeneous population distribution warrants careful study of these spatial relationships for diseases such as injury, which often require time sensitive treatments with discretely positioned resources [48].

Spatial access to trauma care in NS has been previously studied [15,69]. However, these studies have been limited strictly to population-level analyses examining access to the level I TCs and did not incorporate important trauma-related data into their estimates such as injury location and pre-scene time. To address the limitations of prior work in this area, the present study aims to develop a model to quantify spatial access to level I and level III trauma care in NS, and validate the model using a provincial database containing a retrospective cohort of patients severely injured in a motor vehicle collision (MVC). This model will subsequently be used to evaluate trauma care accessibility for the provincial population as well as the severely injured cohort.

As NS trauma care is comparable to many other provincial trauma systems, results of this study will likely be applicable to the broader Canadian context. Identifying areas of poor access to trauma care may make it possible to more effectively allocate trauma care resources in Canada.

Methods

Setting

NS is the second-smallest Canadian province by area (55,284 km^2) and 4th smallest by population (921,727 based on the 2011 census) [77]. Although this makes NS the second most densely populated province, approximately 40% of the population lives in the Halifax Regional Municipality (HRM), with the remaining 60% living in rural towns and villages [98]. This dichotomous geography is interesting from a trauma care perspective because of the relatively high proportion of rural trauma. Trauma care in NS is divided amongst eight level III TCs, one adult level I TC, and one pediatric level I TC [99]. Emergency medical services in NS, including dispatch and ground and air transport is administered by a single, fully integrated program with rigorous medical oversight. Ground-based prehospital transport is provided by a comprehensive network of ground ambulances deployed by a dynamic dispatch system designed to maximize provincial coverage at all times. Air-based prehospital transport is provided by the LifeFlight helicopter emergency medical service (HEMS) based at the province's international airport. This service is able to respond at any time, during favorable flying conditions. During daylight hours, the HEMS is able to respond directly to the scene, but during non-daylight hours a province-wide network of 73 night-rated landing zones (LZs) is utilized, in addition to ground ambulances to transport victims to these LZs (Figure 3-1).

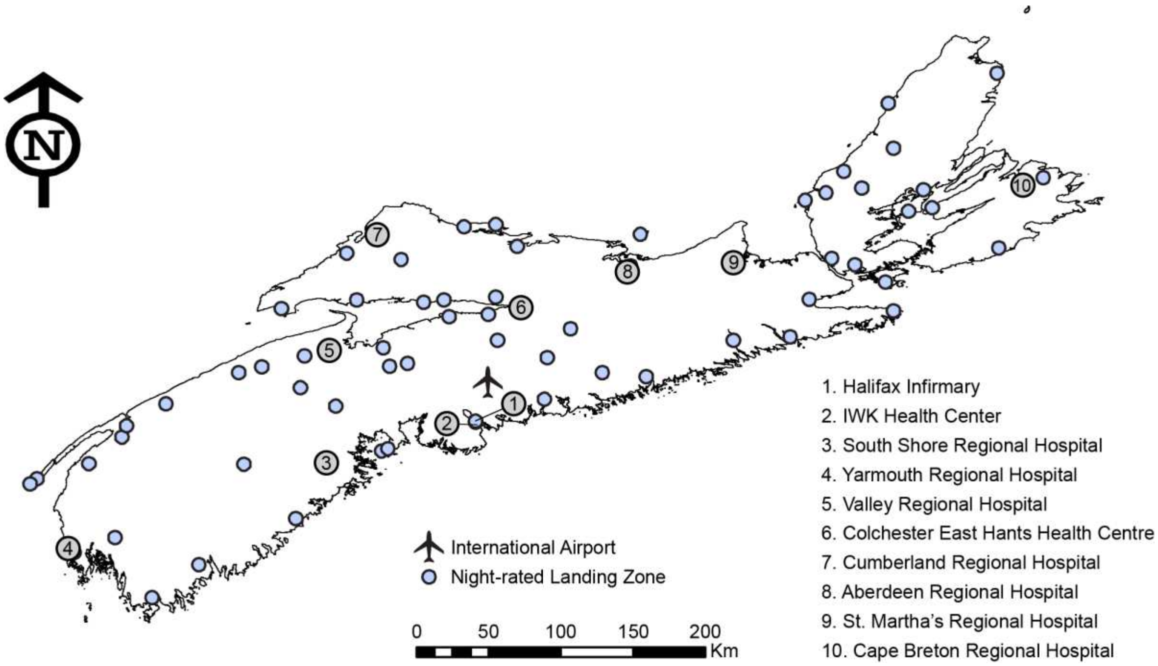


Figure 3-1: Locations of trauma centers and night-rated landing zones in Nova Scotia.

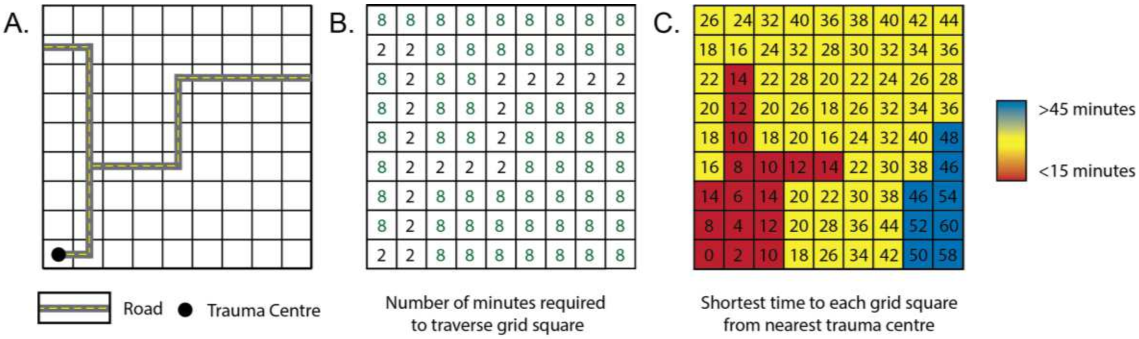
Study Data

Injury location and pre-scene interval data were obtained from the Nova Scotia Trauma Registry (NSTR) which is a population-based database of all major trauma cases in the province maintained and audited by the Nova Scotia Trauma Program (NSTP). The EHS (or the coroner in cases of scene deaths) records the coordinates of the pickup location of all victims using Global Positioning Systems (GPS). These data are abstracted into the NSTR along with prehospital time intervals collected automatically into the patient's electronic record. All trauma team activations or injuries with an injury severity score (ISS) >11 related to MVCs (ICD-10 V01 to V99) between January 1st, 2005 and December 31st, 2013 were eligible for inclusion. Individuals who were missing GPS coordinates or whose pickup location was inconsistent with the injury location were excluded. All duplicate entries were removed prior to analysis.

The provincial road network utilized in the spatial analyses was obtained from a commercially available dataset (CanMap, DMTI Spatial, Markham, ON). The locations of level I and level III trauma centers were also obtained from this dataset. The locations of all of LifeFlight's night-rated LZs, including the international airport which is juxtaposed to Halifax, were obtained from the EHS. Helicopter specifications and response time intervals for aeromedical transport were also obtained from the EHS. Commercially available geographic information system (GIS) software (ArcMap, Esri, Redlands, CA) was used for all geospatial analyses. Statistical analyses were performed using Stata v14 (StataCorp, College Station, TX).

Cost-Distance Analysis (Ground-based Travel)

Cost-distance analyses were performed to model travel times from all points in NS to the nearest level I TC or level III TC. This method calculates the accumulated travel cost in minutes associated with travelling across a surface from any point in the study area to specified destinations (i.e. trauma centres) (Figure 3-2). For use in these analyses, a $100m^2$ gridded cost surface was constructed using the provincial road network and each road segment's corresponding speed limit. Cells without a road were assigned a value corresponding to a speed of travel of 5 $km \cdot h^{-1}$ (i.e. the average speed of walking). As prehospital transport is expected to predominantly utilize established road networks, other barriers such as hydrologic features were not incorporated into the cost surface. The final outputs were continuous surfaces where the value of each cell corresponded to the time required to travel from that geographic location to the nearest level I TC or level III TC.



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26	24	32	40	36	38	40	42	44
18	16	24	32	28	30	32	34	36
22	14	22	28	20	22	24	26	28
20	12	20	26	18	26	32	34	36
18	10	18	20	16	24	32	40	48
16	8	10	12	14	22	30	38	46
14	6	14	20	22	30	38	46	54
8	4	12	20	28	36	44	52	60
0	2	10	18	26	34	42	50	58

Figure 3-2: Schematic representation of cost-distance analysis. A) 100m^2 grid surface overlain over entire study area. B) A cost surface is constructed, whereby each grid square is assigned a cost, in minutes, corresponding to the amount of time required to cross that grid square. C) Example of final output showing the time, in minutes, required to get from each cell to the nearest trauma centre using the “least cost” path. Values are assigned a color for cartographic representation.

Comparison of Potential and Revealed Post-Scene Times

Cost-distance models were validated for post-injury transport times by comparing the potential and revealed post-scene times for a cohort of patients severely injured in MVCs who were directly transported to the level I TC from the scene of injury using ground ambulances. Individuals with unknown post-scene intervals or injury locations were excluded. The potential post-scene time for each of these points was identified by extracting the value of the level I care cost-distance output associated with the point location of the MVC. The revealed post-scene time of each incident was retrieved from the NSTR. The association between the two intervals was illustrated graphically and analyzed statistically using linear regression.

Cost-Distance Analysis (Air-based Travel)

Using similar methods adapted from prior studies [100], cost-distance outputs were generated to model travel times associated with the HEMS. An additional 100m^2 gridded cost surface was constructed whereby each cell was assigned an impedance value corresponding to the average overland travel speed of the LifeFlight Sikorsky S-76 helicopter (250 km$\cdot$h^{-1}). This analysis was designed to model the most common response patterns for day and night activations, respectively:

1) A response to the scene of injury during the day with subsequent delivery to a level I TC
2) A response to a non-scene LZ at night, with subsequent delivery to a level I TC

Modelling scene responses during the day required the summing of two distinct cost-distance outputs:

1) The cost-distance output representing the travel time from the Halifax International Airport to all other points in NS
2) The cost-distance output representing the travel time from all points in NS to the Halifax Infirmary, the only adult level I TC in the province

An additional time of 10-minutes was added to each cell in the study area, representing the reported “wheels up” time of LifeFlight during daylight hours.

As daylight restrictions commonly prevent LifeFlight from landing at the scene of an injury, a non-daylight scenario was also modelled. This scenario was designed to simulate a

LifeFlight response from the Halifax International Airport, to a night-rated LZ, and ultimately to the level I TC during non-daylight hours. This similarly required the summing of two outputs:

1) The cost-distance output representing the travel times from Halifax International Airport to the night-rated landing zones
2) The cost-distance output representing the travel times from the night-rated landing zones to the level I TC

A travel time was assigned to each LZ by extracting from this output the values corresponding to the LZs' location. Each cell in the study area was then assigned to one night-rated LZ using a cost allocation algorithm. This algorithm allocated each cell to the nearest (least cost) night-rated LZ based on the provincial road network. An additional 60 minutes was added to each cell, representing the reported "wheels up" time of LifeFlight during non-daylight hours.

In both scenarios, the time between injury and HEMS activation was not modelled, as estimates of these time intervals were not available. Furthermore, it was assumed in both scenarios that the injured patient was waiting at the LZ at the time of arrival of the helicopter. As a result, both models represent conservative estimates of helicopter transport times in NS.

Potential Spatial Access to Trauma Care

Overlaying the cost-distance outputs on a population layer composed of census dissemination areas (DAs) allowed for estimates of the population-level potential spatial access to trauma care. DAs with an average travel time of ≤60 minutes were identified and expressed as a proportion of the total population of NS. Additionally, the average travel time of each DA was plotted with a frequency weight of the DA's corresponding population to determine the distribution of potential spatial access to trauma care for the population of NS. These estimates were made using the cost-distance outputs for all modeled transport scenarios (air transport and ground transport ± pre-scene times).

As a sensitivity analysis for ground responses, a 100m buffer was constructed around the entire provincial road network and used to identify and extract only the grid squares located within 100m of a road. The average value of these squares for each DA was then determined to generate a more liberal estimate of access. Because large open areas located away from roads have the potential to erroneously inflate estimates of travel time, this change excludes these areas by assuming the entire population of NS lives within 100m of a road.

Overlaying the point locations of major traumas related to MVCs over the ground-based cost-distance outputs allowed for estimates of potential spatial access to trauma care for a cohort of patients admitted into the NS trauma program. The predicted travel time corresponding to the point location of each injury was extracted from the cost-distance outputs and plotted graphically.

Testing for Spatial Autocorrelation of Pre-Scene Times

The Global Moran's I tool was used to determine if the location where an MVC occurred was associated with the observed pre-scene time [83]. This test is a widely used statistical means of detecting relatedness among adjacent points in a study area. The results of the analysis are interpreted against a null hypothesis that the attributes being evaluated are randomly distributed among the features in the study area [83].

Spatial autocorrelation of pre-scene time was further explored through the creation of a semivariogram. Semivariograms plot distance against a measure of variance to visually display evidence of spatial autocorrelation. As spatial dependency implies near features are more similar than distant features, the variance of attributes is expected to increase as the distance between features increases. Although this method does not generate a test statistic to compare results against a null hypothesis of complete spatial randomness, it has the advantage of generating additional data pertaining to the nature of spatial relationships such as the range of distances over which spatial dependency is observed and measures of non-spatial variation within the data [54,101].

The point locations of all MVCs occurring during the study period were plotted. The pre-scene interval recorded in the NSTR was included as an attribute of each feature and used as the attribute of interest in the Global Moran's I and semivariogram construction. A Gaussian model provided the best fit to this data based on assessments of several error parameters. Data with no recorded pre-scene time were excluded.

Pre-Scene Time Spatial Interpolation

To generate a continuous surface of pre-scene time estimates across the entire study area, spatial interpolation was performed using the Kriging method [102]. This method applies an algebraic function to the modeled semivariogram to generate spatial weights for each feature. Using these weights, estimates of the value of the attribute of interest can be estimated at each grid cell of the study area. This method generated a continuous, smoothed, 100m^2 grid surface of pre-scene time estimates for incorporation into estimates of population-level prehospital times.

Results

Study Data

Between January 1st, 2005 and December 13th, 2013 a total of 1568 trauma patients injured in MVCs were eligible for inclusion. Following the exclusion of duplicates and entries with missing or inconsistent injury locations, 1304 trauma cases were suitable for spatial analysis (Figure 3-3). All hospitals and helicopter LZs were successfully geolocated.

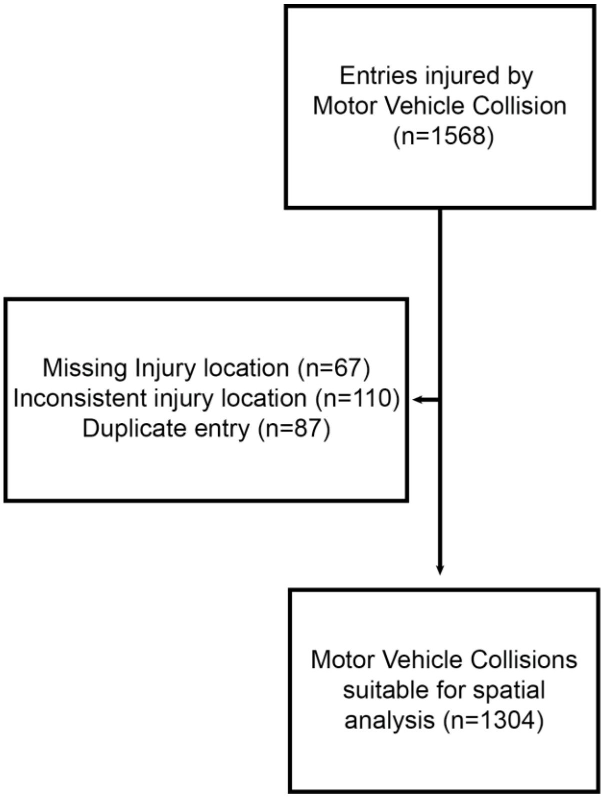

Figure 3-3: Flowchart of study population.

Potential Population-Level Access to Trauma Care in NS via Ground Transport

The cost-distance analysis of ground-based travel time to trauma care in the province of NS is illustrated in Figure 3-4. Expectedly, regional variation in travel time to the level I TC is evident, with the majority of the NS landmass further than 60-minutes of driving time from the level I TC. Level III TCs are more readily accessible, with most points in the province within 60-minutes of driving time to one of these facilities. Following amalgamation of the cost-distance outputs with a census-derived population layer at the level of DAs, it was determined that 45.9% and 93.1% of the population resides within 60 minutes of a level I TC and level III TC, respectively (median time to level I TC: 67.7 minutes; median time to level III TC: 15.4 minutes). As a sensitivity analysis, this calculation was repeated using only pixels within 100m of a road. Overall, the results were highly comparable to the original analysis, with 46.4% and 94.2% of the population living within 60-minutes of a level I TC and level III TC, respectively. The distributions of potential spatial access to level III and level I trauma care are shown in Figure 3-5.

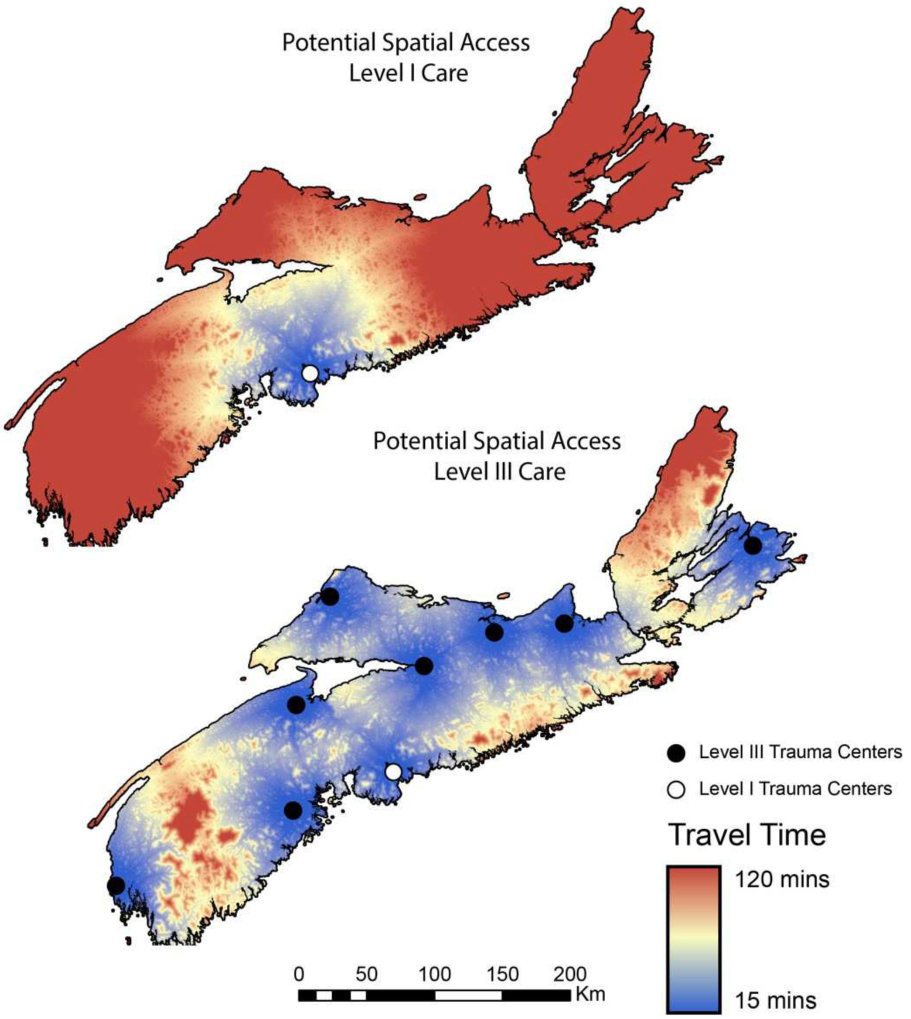

Figure 3-4: Results of ground-based cost-distance analysis illustrating the potential spatial access to level III and level I trauma care for Nova Scotia.

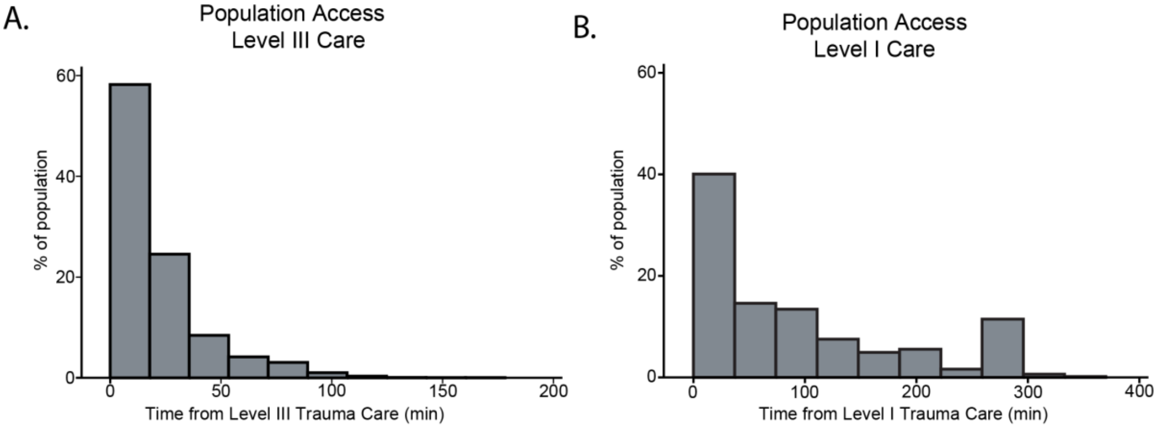

Figure 3-5: Population-level potential spatial access to trauma care in Nova Scotia by ground-based travel. A) Potential spatial access to level III trauma care for the population of Nova Scotia. B) Potential spatial access to level I trauma care for the population of Nova Scotia.

Validation of Potential Spatial Access Model

To determine the accuracy of the cost-distance analysis output in predicting revealed post-scene times, the documented post-scene times of all individuals transported directly from the scene to level I care were plotted against the post-scene times predicted from the cost-distance analysis for the same injury location. The results of this comparison are depicted graphically in Figure 3-6. Following the exclusion of entries with missing data and entries with predicted post-scene times >60 minutes, 290 observations remained for analysis. Linear regression ultimately demonstrated a near 1:1 relationship between the two time intervals (β 1.05, $p<0.001$, forced intercept of 0), supporting the validity of the model for the study population.

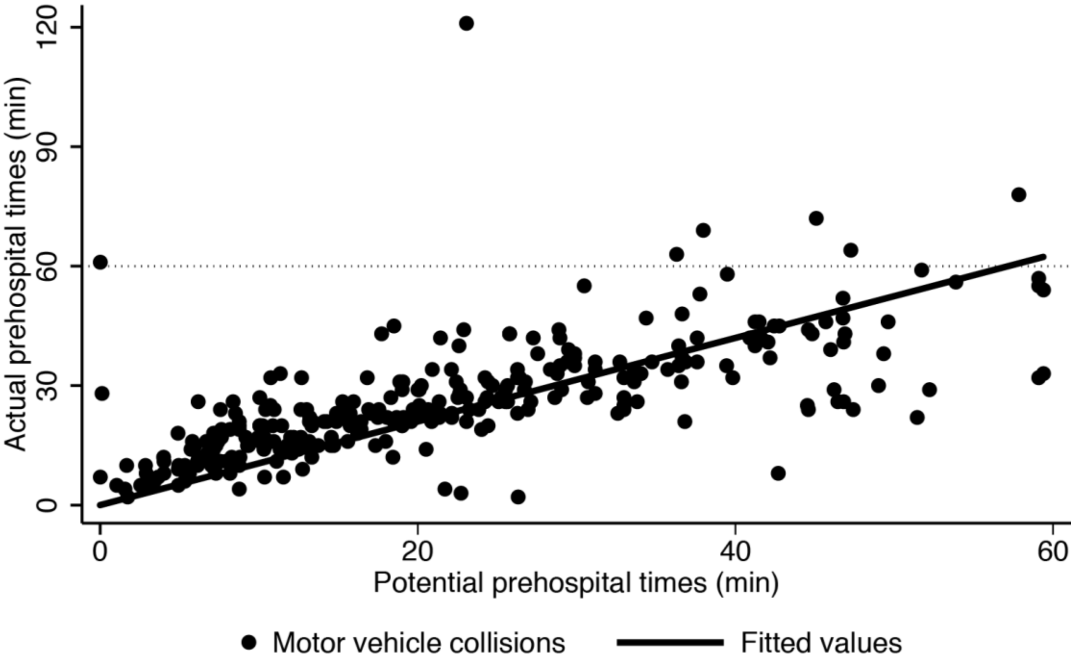

Figure 3-6: Scatterplot with fitted line depicting the relationship between predicted and revealed post-scene time. Analysis is based on 290 observations where a victim had a predicted post-scene time <60 minutes and were transported directly from the scene to level I care.

Pre-Scene Time Spatial Interpolation

The Moran's I test was used to determine if there was any evidence of pre-scene time spatial dependency within the study sample. Of the 1304 MVC victims suitable for spatial analysis, pre-scene times, defined as the time interval between activation and arrival on the scene, were available for 1222 individuals (93.7%). There was strong evidence of spatial autocorrelation within this sample (Moran's Index 0.88, $p<0.001$). To better visualize this spatial dependency and facilitate Kriging interpolation, a semivariogram was constructed (Figure 3-7). This model demonstrated a range of 32.3 kilometers over which events exhibited some level of spatial autocorrelation.

A continuous surface of predicted pre-scene time was created using the Kriging method (Figure 3-8). This model illustrates the localization of shorter predicted pre-scene intervals around TCs, with longer pre-scene times associated with the more remote areas of the province's interior such as Kejimkujik National Park. The fairly narrow range of predicted pre-scene times between 5 and 35 minutes suggests the province is fairly uniformly serviced by the EHS.

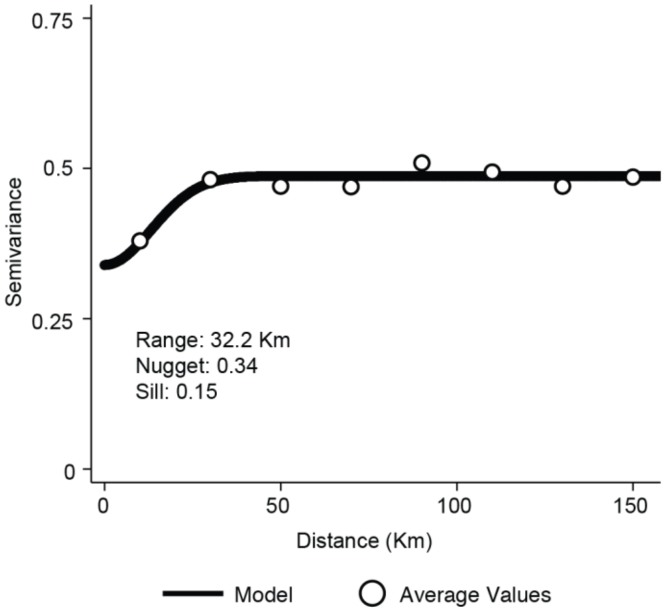

Figure 3-7: Semivariogram illustrating the spatial autocorrelation of pre-scene times for motor vehicle collisions in Nova Scotia between 2005 and 2013.

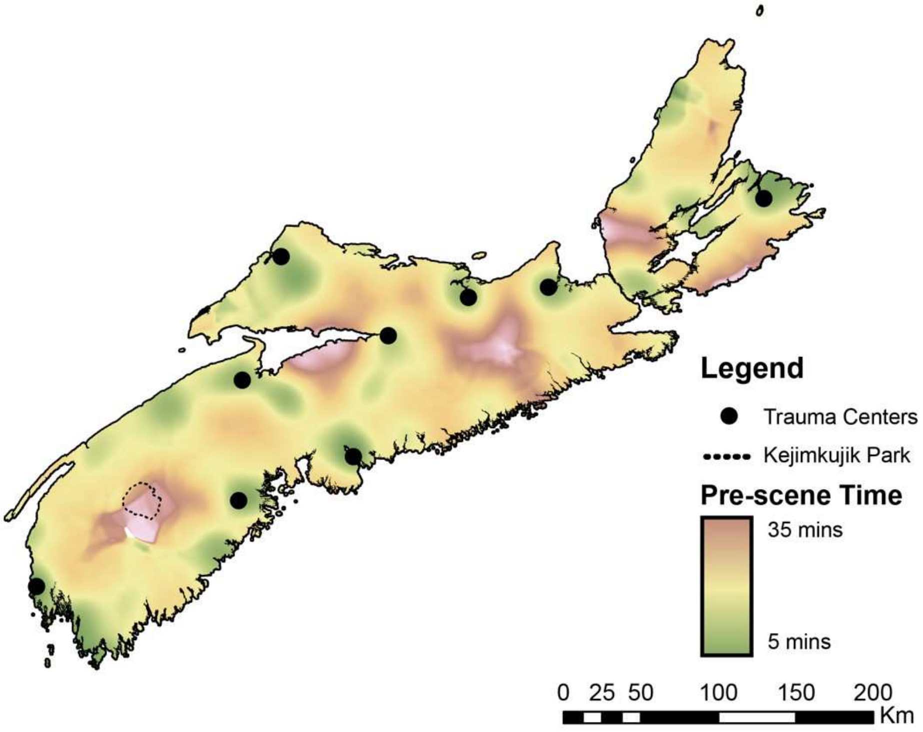

Figure 3-8: Interpolation of Pre-Scene Times in Nova Scotia. Data represents results of a Kriging interpolation modeled on the documented pre-scene times of 1304 patients injured in MVCs.

By combining this spatial interpolation with the cost-distance outputs illustrated in Figure 3-4, a model of both pre-scene and post-scene times was generated. This combined model was amalgamated with the census-derived population layer to generate population-level potential spatial access estimates with consideration to both the pre-scene and post-scene intervals. As longer predicted pre-scene times were generally associated with less populated areas, the incorporation of this interval into the model did not drastically alter the population-level access to trauma care. Overall, access to a level III TC within 60-minutes decreased from 93.1% to 88.1%. Similarly, access to the level I TC decreased from 45.9% to 42.7%.

Potential Population-Level Access to Trauma Care in NS via Rotor Wing Aeromedical Transport

The cost-distance analyses of air-based travel time to level I trauma care in the province of NS are illustrated in Figure 3-9. Regional variation in access is again demonstrated, with the western portion of the NS peninsula and Cape Breton Island having poorer access to level I care via LifeFlight. When the population layer is overlaid on the cost- distance output for daylight responses, it was determined that 59.4% of the NS population is deliverable to the level I TC within 60-minutes of travel time (median travel time to level I TC: 47.1 minutes). This represents an additional 123,000 people with access to a level I TC within this interval relative to ground ambulance responses. Access is considerably lower during non-daylight hours due largely to the 60-minute response time required for these activations (median travel time to level I TC: 96.0 minutes) (Figure 3-10). However, some benefit is observed for populations with the lowest spatial access to care with time to level I care for the 90th percentile being reduced from 275 to 216 minutes.

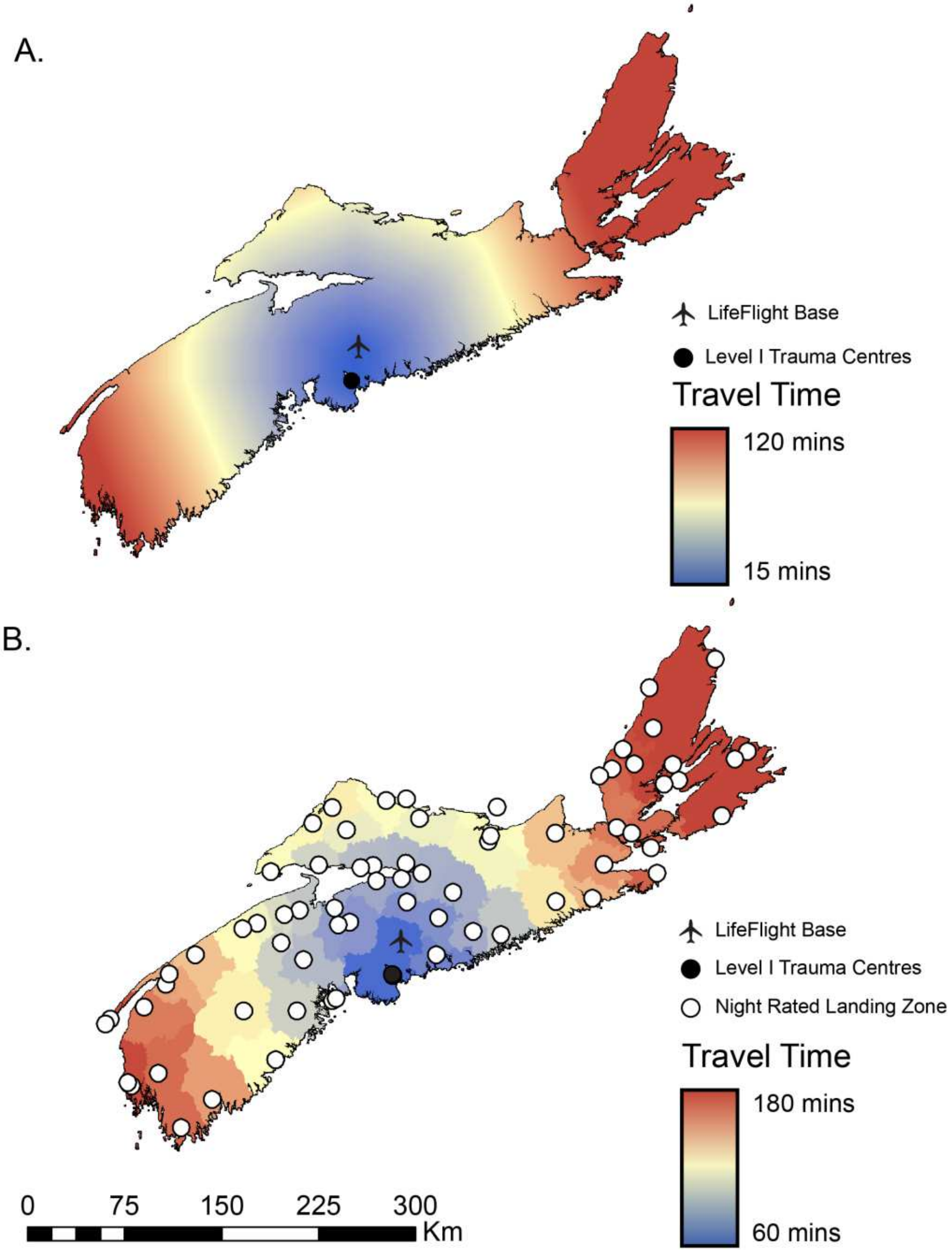

Figure 3-9: Results of air-based cost-distance analysis illustrating the potential spatial access to level I trauma care via LifeFlight. A) Cost-distance analysis for daylight hours. B) Cost-distance analysis for non-daylight hours via night-rated landing zones.

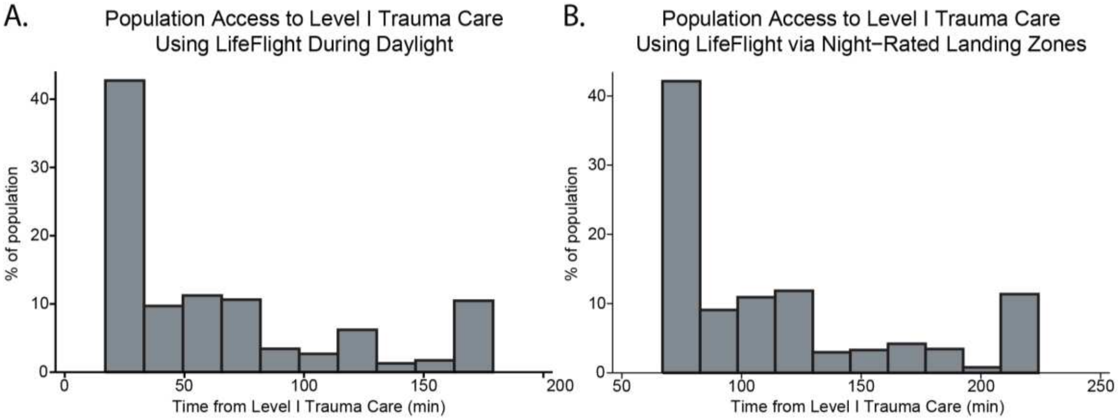

Figure 3-10: Population-level potential spatial access to trauma care in Nova Scotia by air-based travel. A) Potential spatial access to level I trauma care for the population of Nova Scotia during daylight hours. B) Potential spatial access to level I trauma care for the population of Nova Scotia during non-daylight hours.

Potential Spatial Access to Trauma Care in NS for Victims of MVCs

By plotting the locations of major traumas resulting from MVCs and extracting the ground-based transport time predicted in the cost-distance analysis for that location, it was possible to determine the potential spatial access to trauma care for a cohort of severely injured patients. The results of this analysis were lower compared to the population-level analysis with 36.0% and 91.6% of the population being injured within 60-minutes of a level I TC and level III TC, respectively (median time to level I TC: 81.7 minutes; median time to level III TC: 19.3 minutes). The distributions of predicted travel times are shown in Figure 3-11. The locations of MVCs corresponded closely with the population density of census DAs (Figure 3-12).

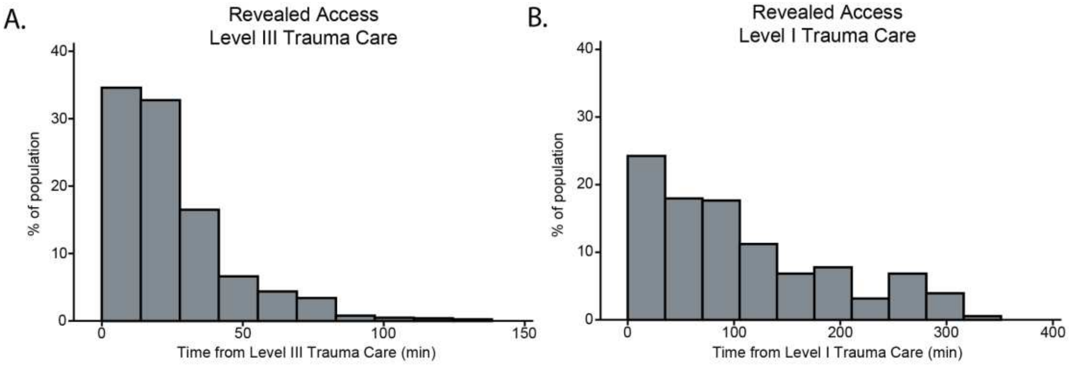

Figure 3-11: Population-level potential spatial access to trauma care by ground-based travel for victims of motor vehicle collisions in Nova Scotia. A) Potential spatial access to level III trauma care for victims of motor vehicle collisions in Nova Scotia. B) Potential spatial access to level I trauma care for victims of motor vehicle collisions in Nova Scotia.

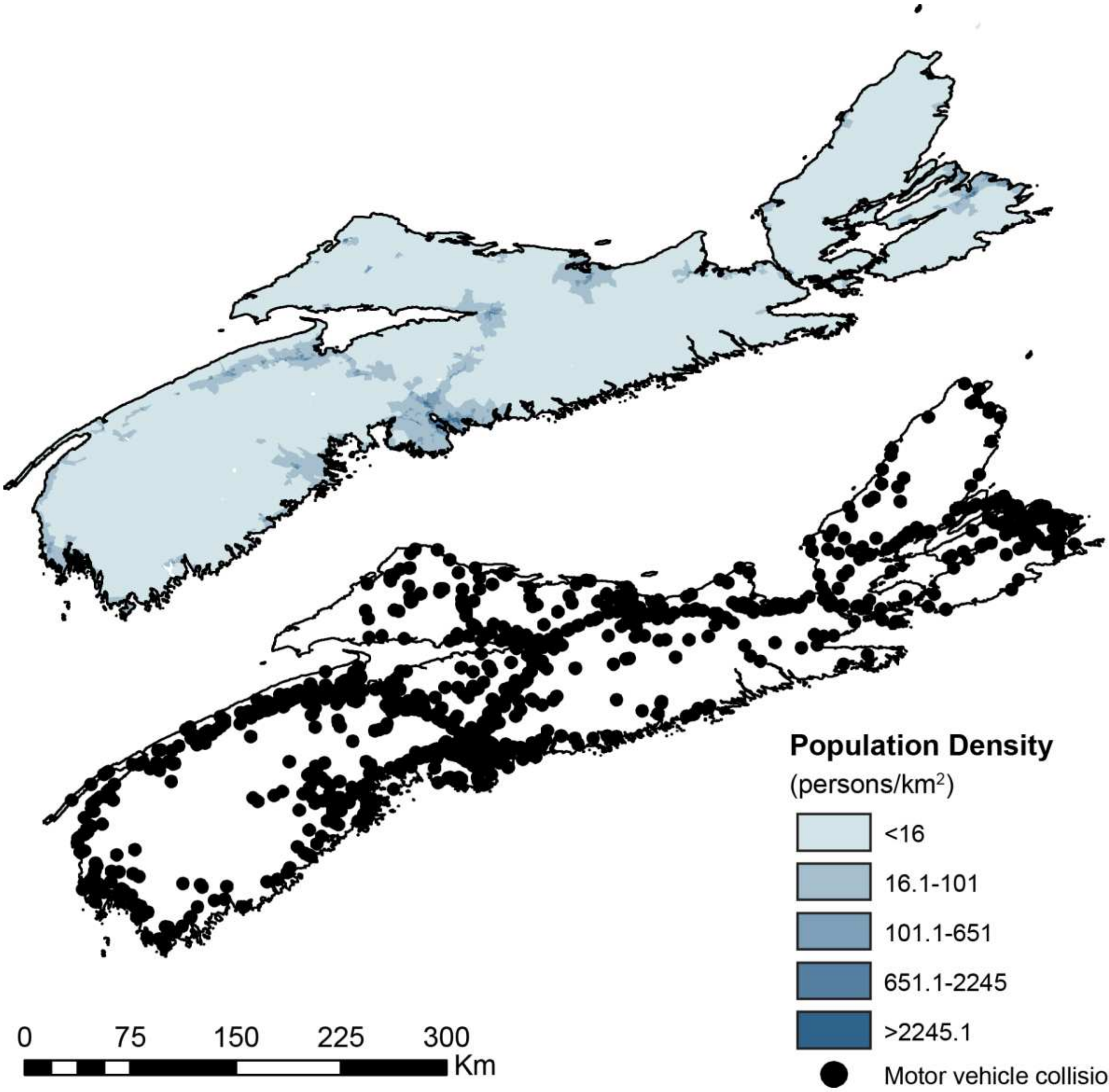

Figure 3-12: Maps of Nova Scotia demonstrating a close relationship between population density and the locations of motor vehicle collisions.

Discussion

Spatial access to trauma care can be considered at the population level (potential access) or through studying service utilization (revealed access). The first national-level assessment of potential access to level I or II trauma centres was an American study by Branas et al [65]. These authors utilized a computerized resource allocation model to define the proportion of the population residing within 45 and 60 minutes of travel time to a level I or II TC by either ambulance or helicopter [65,66]. The authors identified that 69% and 84% of all US residents had access to at least level II TCs within 45 and 60 minutes of injury, respectively [65]. A Canadian study by Hameed et al aimed to accomplish a similar objective utilizing a network analysis method in a GIS [15]. This method incorporates road attributes such as speed limits and intersections to arrive at a predicted travel time for a given section of road between a defined start and endpoint. This method has been suggested as one of the preferred GIS-based methods for assessing access as it incorporates barriers such as water bodies and mountain ranges that are ignored in estimates based on Euclidean distances [61]. The results of the Hameed study were largely consistent with the American findings, with 77.5% of Canadians residing within 1-hour of road travel time to a level I or II TC. Estimates for NS were considerably lower than this with only 42% of the population within 1-hour of driving time to the province's only level I or II adult TC [15]. A subsequent study by Lawson et al attempted to evaluate potential spatial access to trauma care for a Canadian cohort of severely injured patients based on their residential postal codes [69]. Their results were largely consistent with the Hameed study, with 41% of severely injured Nova Scotians residing within a 1-hour driving time to a level I or II TC.

Although these studies provide useful insights into the spatial accessibility of trauma care in NS, they are not without their limitations. First, using the location of residences as a surrogate for place of injury assumes injury is randomly distributed throughout the population and that patients get injured at or near their homes. Both of these assumptions have been challenged [67,68,103]. Furthermore, these studies likely represent overestimates of spatial access due to the exclusion of ambulance response times in their analyses. Finally, exclusion of level III trauma centres from the study models and the use of arbitrarily defined 60-minute service areas make it difficult for these studies to be applied by policymakers in NS.

The present study represents a comprehensive descriptive analysis of the spatial accessibility of trauma care in NS. Using GIS-based methods, we were able to demonstrate nearly ubiquitous population-level potential spatial access to level III TCs within 60-minutes of driving time. Population-level access to level I care was considerably lower, with 54% of the NS population residing greater that 60-minutes of driving time from the provincial level I TC. These figures remained consistent when pre-scene times were incorporated into the model. Although the population-level accessibility of the level I TC was marginally improved with the utilization of HEMS, the benefit was limited to daytime responses. The predicted accessibility advantage of utilizing LifeFlight at night was restricted to the population with the lowest access to the level I TC, largely in the eastern region of Cape Breton Island. Lastly, we demonstrate that the distributions of MVCs is comparable to the population distribution of NS, but median predicted travel times for this cohort to the level I TC and level III TCs are 20% and 25% longer, respectively. This is not an unexpected finding given that high-speed roadways are typically located outside of population dense areas, but provides further evidence of the inaccuracies associated with using residence locations to measure access in a trauma system predominated by MVC-related injuries.

Although not previously applied to evaluations of trauma care access, cost-distance analyses and spatial interpolation have been used to estimate spatial access and interpolate driving times [104–107]. These methods have the advantage of providing estimates over a continuous surface, allowing for rapid visualization of trends. The dynamic dispatch system employed in NS and the lack of availability of ambulance locations at the time of response prevented the use of more traditional routing methods to estimate pre-scene times. Although low data point densities limit the accuracy of spatial interpolation, the high concentration of MVCs in population dense areas allowed for reasonable population-level estimates. Additionally, the time between injury and HEMS activation was not modelled in either of the LifeFlight models, and it was assumed in both scenarios that the injured patient was waiting at the LZ at the time of arrival of the helicopter. As a result, both models represent conservative estimates of helicopter transport times in NS.

Importantly, the results obtained using these methods are largely consistent with the previous work on access to trauma care that was performed in NS [15,69]. However, without outcomes data for the injured cohort it is impossible to determine if spatial access to the level I TC or level III TCs influences mortality following injury. This data will be important for further improvements to trauma care organization in NS. Although previous work by Lawson et al did demonstrate an increased likelihood of death in individuals with poorer access to the level I TC in NS, the analysis used in this work was based on the residential postal codes of all major trauma victims and was not statistically adjusted for relevant confounding variables [69]. Additionally, because timely access to neurosurgical capacity is known to influence outcomes following traumatic brain injury, and these services are only available at the level I TC in NS, evaluating the level I TC and level III TCs independently will be important in NS [48,108].

Conclusions

This study confirms the low potential spatial access to the level I TC in NS. However, the high accessibility of level III TCs suggests these centres need to play a significant role in NS trauma care. Ongoing maintenance and expansion of these centers' capacity will be an important component of trauma care improvement in the province. Particular attention needs to paid to Yarmouth and Cape Breton Regional Hospitals as these centres are located in the areas of the province with the lowest access to the level I TCs. Ensuring these facilities have the capacity and resources to provide high-quality emergency care is important for ensuring equality of access to trauma care in the province.

Importantly, this study suggests that LifeFlight has limited utility for the majority of the population at night. Further research will be needed to determine which populations of injured patients benefit most from the use of this service with particular attention to traumatic brain injuries given the limited neurosurgical capability outside of the level I TC. Cost effectiveness analysis may be a useful tool in quantifying the utility of this service for specific populations.

Evaluating specifically how spatial access to the level I TC and level III TCs influences the mortality of injured patients will be another important component of ongoing research.

Chapter 4: Association between spatial access to trauma care and mortality for victims of major trauma in Nova Scotia

Introduction

Injury represents one of the largest causes of healthcare expenditure in Canada, accounting for over $20 billion in direct and indirect costs annually [9]. Although injury results in over 15,000 deaths each year, the majority of injuries are low severity and require no specialized inpatient care [9]. In response to this wide spectrum of injury severities, inclusive trauma systems have been built in many jurisdictions to match the patient needs with the appropriate health facility resources [97]. Preferentially triaging severely injured patients directly to specialized, high volume TCs has been consistently shown to result in lower mortality, with a recent meta-analysis estimating a 15% decreased odds of death in these patients [5]. Meanwhile, triaging less severely injured patients to lower volume centers reduces the resource strain on higher level facilities [97,109]. Although the regionalization of post-injury care has resulted in survival benefits for the patients who are cared for in designated centers, it has had the added consequence of concentrating specialized resources in a few discrete locations.

Healthcare access, defined as the degree of fit between the patient and the health system, is a relevant concept to policymakers because poor access may negatively influence healthcare utilization [29]. Although many frameworks have been proposed to aid in the conceptualization of access, one such framework proposed by Penchansky and Thomas distills access into five dimensions: availability, accessibility, accommodation, affordability, and acceptability [26,27,29]. More simply, access can be categorized by spatial (accessibility, availability) and non-spatial factors (affordability, acceptability, accommodation) [58]. By framing access as a geographic and socio-demographic construct it is clear that the spatial relationship between a patient and a healthcare service is only one component of access. However, the expansive Canadian geography and heterogeneous population distribution warrants careful study of these spatial relationships for diseases such as injury, which often require time sensitive treatments with discretely positioned resources [48].

Inadequate access to essential public services was identified by the Whitehead report to be one of the seven main determinants of health differentials [24]. Although variable spatial accessibility is understandable for any discretely positioned health service, ethicists argue that this variability is unjust when it is avoidable and results in differential outcomes. Given the significant resource investment required to maintain TC readiness, understanding how spatial access to trauma services influences outcome becomes important for ensuring optimal trauma system organization [110]. Measuring inequities in access and the resulting health outcomes is a key component of the framework developed by Asada, designed to quantify health inequities, and is the primary objective of this thesis [25].

One Canadian study has previously demonstrated that poor spatial access to trauma care results in lower TC utilization rates following major injury [76]. Additionally, variability in the spatial accessibility of Canadian TCs has been previously demonstrated [15,69]. However, the relationship between spatial access to TCs and mortality following major trauma remains unclear. This study uses injury location data linked to a retrospective database of severely injured patients to evaluate the relationship between mortality and spatial access to TCs in Nova Scotia (NS).

Methods

Setting

NS, located on Canada’s eastern coast, is the second smallest province in the country by area [77]. With a population of 921,727 based on the 2011 census, NS is also the second most densely populated province in Canada [78]. Despite the relatively high mean population density, 40% of the population of NS is concentrated largely in the Halifax Regional Municipality (HRM), with the remaining individuals living in more rural areas [78]. This is important from a care delivery perspective because of the potentially high number of people with poor spatial access to resources concentrated in the HRM. Trauma care in NS is divided amongst eight level III TCs, one adult level I TC, and one pediatric level I TC [99]. Both level I TCs are situated within the HRM. A comprehensive network of ground ambulances administered by the Emergency Health Services (EHS) provides prehospital transport to the majority of the major traumas in the province.

Study Data

Demographic and clinical data, as well as injury locations, were obtained from a retrospective database of major trauma maintained by the Nova Scotia Trauma Registry (NSTR). The NSTR is one of the only population-based trauma registry in Canada, capturing data on major traumas from all TCs across NS [79]. The EHS (or the coroner in cases of scene deaths) records the coordinates of the pickup location of all victims using Global Positioning Systems (GPS). These data can be abstracted into the NSTR. All traumas with an injury severity score (ISS) >11 related to Motor Vehicle Collisions (MVCs) (ICD-10 V01 to V99) or with an ISS >8 related to a penetrating mechanism (ICD-10 W25, W26, W32-34, W45, X72-74, X78, X93-95, X99, Y22-24) between January 1st, 2005 and December 31st, 2013 were eligible for inclusion. Individuals who died in the 24 hours following injury, or who required a trauma team activation were also included. Entries that were missing GPS coordinates or had a pickup location that was inconsistent with the injury location were excluded. All duplicate entries were removed prior to analysis.

The provincial road network utilized in the spatial analyses was obtained from a commercially available dataset (CanMap, DMTI Spatial, Markham, ON). The locations of level I and level III TCs were also obtained from this dataset. Commercially available geographic information system (GIS) software (ArcMap, Esri, Redlands, CA) was used for all geospatial analyses. Statistical analyses were performed using Stata v14 (StataCorp, College Station, TX).

Cost-Distance Analysis

Cost distance analyses were performed to model travel times from all points in NS to the nearest level I or level III TC. This method calculates the accumulated travel cost in minutes associated with travelling across a surface from any point in the study area to specified destinations (i.e. trauma centres). For use in these analyses, a 100 m^2 gridded cost surface was constructed using the provincial road network and each road segment's corresponding speed limit. Cells without a road were assigned a value corresponding to a speed of travel of 5 km·h^{-1} (i.e. the average speed of walking). As prehospital transport is expected to predominantly utilize established road networks, other barriers such as hydrologic features were not incorporated into the cost surface. The final outputs were continuous surfaces where each pixel corresponded to the time required to travel from that geographic location to the nearest level I or level III TC. Further details of the model development and validation are discussed in the previous chapter.

Potential Spatial Access to Trauma Care

Overlaying the point locations of major traumas related to MVCs or penetrating mechanisms over the cost distance outputs allowed for estimates of potential spatial access to trauma care for a cohort of patients admitted into the NS trauma program. The predicted travel time corresponding to the point location of each injury was extracted from the cost distance outputs and incorporated into the statistical models.

Statistical Model Building

Logistic regression models of mortality were estimated using age, gender, socioeconomic status (SES), and injury severity score (ISS) as covariates. All covariates were defined *a priori* based on previously identified associations. SES was defined using the Vancouver Area Neighbourhood Derivation Index (VANDIX). The VANDIX is a census-based proxy for population health status developed for use as an area-based measure of SES [111]. Each patient was assigned the VANDIX score corresponding to the census dissemination area (DA) of their residential postal code. The most deprived quintile was defined as low SES. In instances where residential postal codes were unavailable, the location of injury was used as a proxy for place of residence. The outcome of interest was mortality, either in-hospital or χ^2 test, where appropriate. Subset analyses were performed on patients who survived long enough to receive some form of post-injury care to better delineate the potential impacts of post-injury care on the observed associations. Spatial autocorrelation of model residuals was excluded using the Global Moran's I.

Results

Study data

Between January 1st, 2005 and December 13th, 2013 a total of 1568 MVCs and 243 penetrating traumas were eligible for inclusion. Following the exclusion of duplicates and entries with missing or inconsistent injury locations, 1304 MVC entries and 231 penetrating trauma entries remained that were suitable for spatial analysis. A flowchart illustrating the flow of data is illustrated in Figure 4-1. All TCs were successfully geolocated.

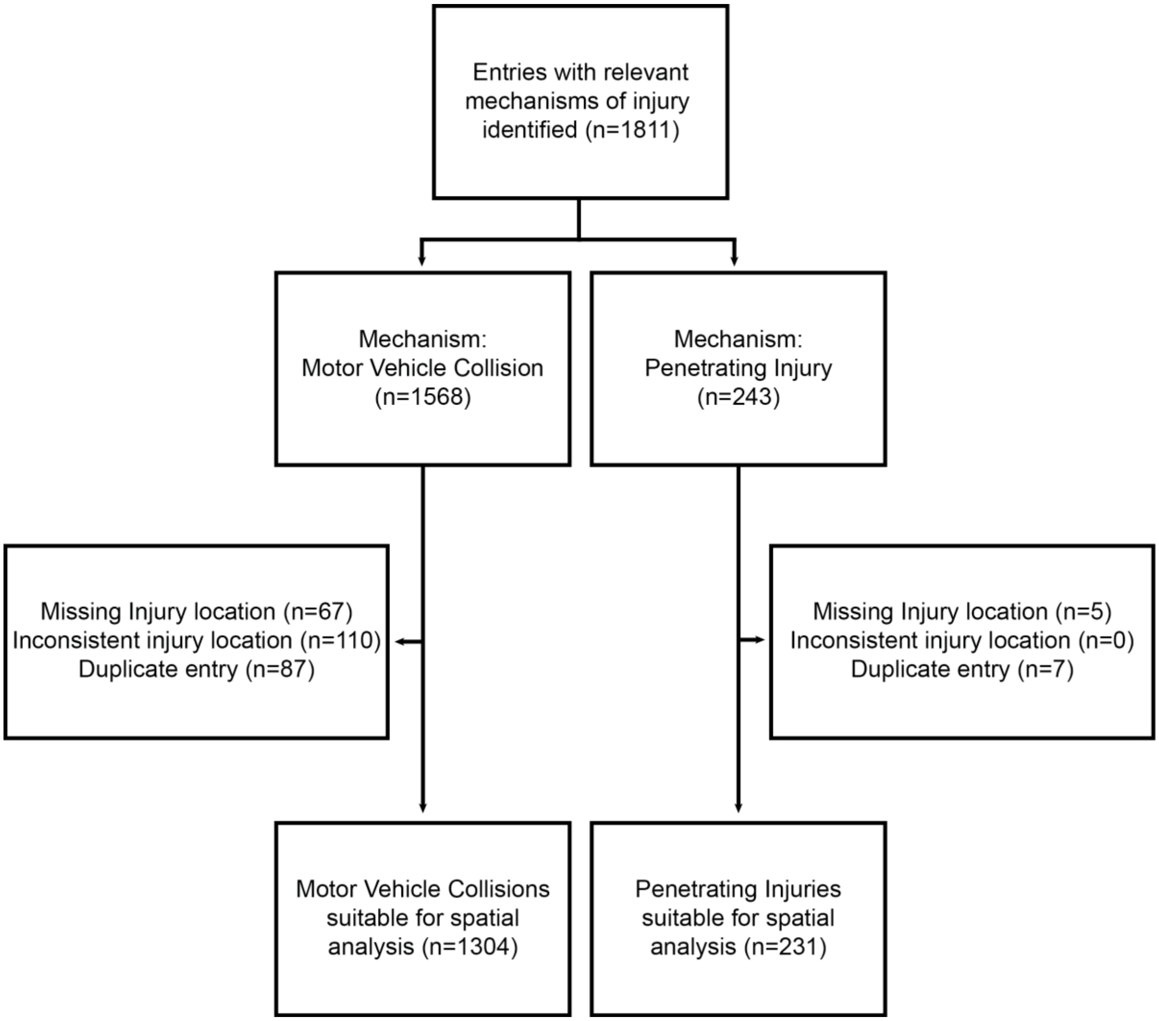

Figure 4-1: Flowchart of study population

There were no missing outcomes data in either cohort. Injury location data was missing for 12.5% of MVCs and 2.1% of penetrating injuries. A comparison of cases with and without reliable injury location data is illustrated in Table 4-1 and Table 4-2. Individuals injured in MVCs with missing injury location data were more likely to die (36.4% vs. 25.0%, p=0.001) and more likely to be male (78.6% vs. 68.7%, p=0.006). The two groups did not significantly differ in age, injury severity or SES. Similarly, individuals injured by a penetrating mechanism with missing injury location data were more likely to die as a result of their injuries (100% vs. 56.3%), but differences in mortality and all other covariates failed to reach statistical significance.

Table 4-1: Missing data analysis for MVC cohort. Data represented as N(%) or mean ± SD.

Variable	Available injury location	No available injury location	p-value
Total	**1304**	**187**	
Unadjusted mortality (per 100 persons)	25.0	36.4	0.001
Age (years)	39.4 ± 20.7	41.1 ± 19.7	0.293
Gender			0.006
Male	896 (68.7)	147 (78.6)	
Female	408 (31.3)	40 (21.4)	
Injury Severity Score	27.3 ± 14.3	28.7 ± 17.4	0.233
Low SES	271 (20.8)	58 (22.0)	0.073

Table 4-2: Missing data analysis for penetrating injury cohort. Data represented as N(%) or mean ± SD.

Variable	Available injury location	No available injury location	P-value
Total	**231**	**5**	
Unadjusted mortality (per 100 persons)	56.3	100	0.051
Age (years)	44.6 ± 20.3	55.4 ± 7.1	0.237
Gender			0.206
Male	217 (93.9)	4 (80.0)	
Female	14 (6.1)	1 (20.0)	
Injury Severity Score	28.9 ± 17.8	25.6 ± 3.7	0.681
Low SES	78 (33.8)	2 (40.0)	0.771

Potential spatial access to trauma care in NS via ground transport

The cost distance analyses of ground-based travel time to trauma care in the province of NS are illustrated in Figure 4-2. These analyses identified significant regional variation in travel time to the level I TCs, with the majority of the NS landmass further than 60-minutes of driving time from the level I TCs in the province. Level III TCs are more readily accessible, with most points in the province within 30-minutes of driving time to one of these eight facilities. By plotting the locations of major traumas resulting from MVCs and extracting the ground-based transport time predicted in the cost distance analysis for that location, it was possible to determine the potential spatial access to trauma care for the cohort of severely injured patients. Overall, 64.0% and 29.7% of MVC entries were injured >60-minutes from a level I TC and >30-minutes from a level III TC, respectively (median time to level I TC: 81.7 minutes, median time to level III TC: 19.3 minutes). Similarly, 57.1% and 26.8% of penetrating trauma entries were injured >60 minutes from a level I TC and >30 minutes from a level III TC, respectively (median time to level I TC: 68.9 minutes, median time to level III TC: 15.3 minutes).

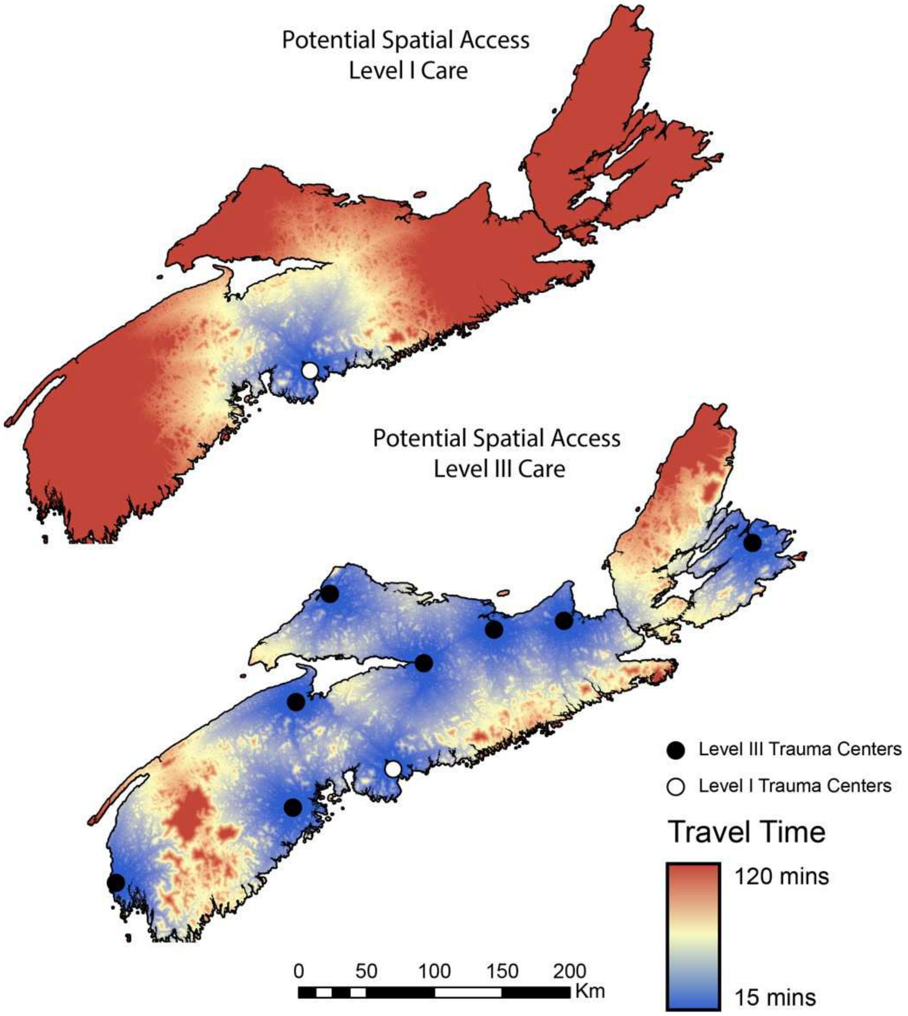

Figure 4-2: Results of cost distance analysis illustrating the potential spatial access to level I and level III trauma care for Nova Scotia

Influence of Spatial Access to Trauma Care on Patient Outcomes

Logistic regression analyses were conducted to determine the influence of spatial access to trauma care on outcomes. The general characteristics of the study population are illustrated in Table 4-3 and Table 4-4. Overall, victims of both injury mechanisms were young and predominantly male. Twenty-five percent of the victims of MVCs died as a result of their injuries compared to 57.2% of the victims of penetrating trauma. Individuals who died were more severely injured on average in both groups.

Table 4-3: Baseline characteristics of study participants injured in MVCs.

Variable	MVC Frequency No. (%) or Mean ± SD	MVC Mortality No. (%) or Mean ± SD
Total	**1304**	**326 (25.0)**
Age (years)	39.4 ± 20.7	43.3 ± 22.7
Gender		
Male	896 (68.7)	241 (73.9)
Female	408 (31.3)	85 (26.1)
Incident within 60 minutes of level I care		
Yes	469 (36.0)	112 (34.4)
No	835 (64.0)	214 (65.6)
Incident within 30 minutes of level III care		
Yes	917 (70.3)	209 (64.1)
No	387 (29.7)	117 (35.9)
Injury Severity Score	27.4 ± 14.3	40.2 ± 18.6
Low SES	329 (21.9)	96 (26.0)

Table 4-4: : Baseline characteristics of study participants injured by a penetrating mechanism.

Variable	Frequency No. (%) or Mean ± SD	Mortality No. (%) or Mean ± SD
Total	**231**	**130 (56.3)**
Age (years)	44.6 ± 20.3	54.3 ± 17.5
Gender		
Male	217 (93.9)	126 (96.9)
Female	14 (6.1)	4 (3.1)
Incident within 60 minutes of level I care		
Yes	99 (42.9)	36 (27.7)
No	132 (57.1)	94 (72.3)
Incident within 30 minutes of level III care		
Yes	169 (73.2)	83 (63.9)
No	62 (26.8)	47 (36.2)
Injury Severity Score	28.9 ± 17.8	35.0 ± 19.6
Low SES	78 (33.8)	41 (52.3)

Influence of Potential Spatial Access on Patient Outcomes Following MVCs

An unadjusted comparison of individuals injured ≤60 minutes or >60 minutes of predicted driving time from level I care is illustrated in Table 4-5. The unadjusted mortality rates between the two groups did not significantly differ. Overall, 25.6% of patients injured greater than 60-minutes from level I care died from their injuries compared to 23.8% of patients injured less than 60-minutes from a level I TC. The two groups were fairly comparable, with the exception of pre-scene times (p=0.0001) and scene-times (p=0.0002), which were slightly longer among individuals with poorer access to care.

Table 4-5: Unadjusted comparison of victims of MVCs injured >60 minutes or ≤60 minutes from level I trauma care.

Variable	Level I care >60 minutes No. (%) or Mean ± SD	Level I care ≤60 minutes No. (%) or Mean ± SD	p-value
Total	**835 (64.0)**	**469 (36.0)**	
Unadjusted mortality (per 100 persons)	25.6	23.8	0.483
Age (years)	37.9 ± 19.5	40.2 ± 21.3	0.0535
Gender			0.9264
Male	573 (68.6)	323 (68.9)	
Female	262 (31.4)	146 (31.13)	
Injury Severity Score	27.2 ± 13.9	27.5 ± 15.0	0.7289
Low SES	206 (24.8)	65 (14.3)	<0.001
Prehospital times			
Pre scene time	15.3 ± 11.0	12.9 ± 8.9	0.0001
Scene Time	32.3 ± 22.16	27.9 ± 16.8	0.0002
Post scene time	31.4 ± 119.4	25.2 ± 14.3	0.1748
Extrication time	35.8 ± 22.6	32.0 ± 17.7	0.2362
On-scene death	133 (15.9)	60 (12.8)	0.1226
Ejection	242 (30.5)	115 (25.2)	0.048

Bivariate analyses comparing the groups injured in MVCs >30 minutes or ≤30 minutes of predicted driving time from level III trauma care are illustrated in Table 4-6. The unadjusted mortality rate was higher for individuals injured >30 minutes from level III care (30.2/100 persons vs. 22.8/100 persons, p=0.0051). The pre-scene, post-scene and on-scene intervals were all higher in the group injured >30 minutes from level III care (p<0.001 for all). The probability of on-scene death was also higher for individuals injured greater than 30 minutes from level III care (20.9 vs 12.2%, p=0.0001). Lastly, individuals injured greater than 30 minutes from level III care were 52% more likely to be ejected from the vehicle (p<0.0001).

Table 4-6: Unadjusted comparison of victims of MVCs injured >30 minutes or ≤30 minutes from level III trauma care.

Variable	Level III care >30 minutes No. (%) or Mean ± SD	Level III care ≤30 minutes No. (%) or Mean ± SD	p-value
Total	**387 (29.7)**	**917 (70.3)**	
Unadjusted mortality (Per 100 persons)	30.2	22.8	0.0051
Age (years)	39.3 ± 20.8	39.4 ± 20.6	0.8989
Gender			0.047
Male	281 (72.6)	615 (67.1)	
Female	106 (27.4)	302 (32.9)	
Injury Severity Score	27.7 ± 14.0	27.2 ± 14.4	0.6020
Low SES	117 (30.3)	154 (17.1)	<0.001
Prehospital times			
Pre scene time	18.6 ± 12.8	12.7 ± 8.6	<0.0001
Scene Time	35.5 ± 22.4	28.8 ± 19.3	<0.0001
Post scene time	35.4 ± 25.5	26.8 ± 31.3	<0.0001
Extrication time	35.8 ± 20.9	33.6 ± 20.5	0.6036
On-scene death	81 (20.9)	112 (12.2)	0.0001
Ejection	122 (31.5)	189 (20.6)	<0.0001

Following a multivariable analysis, lack of potential spatial access to level I care under 60-minutes was not found to be associated with an increased risk of death after adjustment for the *a priori* identified confounding variables of age, gender, ISS and SES (OR 1.13, p=0.452) (Table 4-7). However, potential spatial access to level III trauma care greater than 30-minutes was found to be associated with a 66% increased odds of dying following an MVC after adjustment for the same confounding variables (OR 1.66, p=0.045) (Table 4-8). Importantly, this finding was not found when on-scene deaths were excluded from the analysis, suggesting differences in post-injury care are unlikely to explain the observed association (OR 0.93, p=0.781).

Table 4-7: Adjusted odds of mortality for victims of MVCs with an ISS>11 injured greater than 60-minutes from level I trauma care between 2005-2013.

Variable	Adjusted OR (95% CI)	P-value
Level I care > 60 minutes	**1.13 (0.82-1.57)**	**0.452**
Male Gender	1.47 (1.05-2.06)	0.026
Age	1.02 (1.01-1.03)	<0.001
ISS	1.11 (1.09-1.12)	<0.001
Low SES	1.25 (0.87-1.80)	0.222

Table 4-8: Adjusted odds of mortality for victims of MVCs with an ISS>11 injured greater than 30-minutes of predicted travel time from level III care between 2005-2013.

Variable	Adjusted OR (95% CI)	P-value
Time to level III care		**0.045**
<10 minutes	**reference**	
10-20 minutes	**1.02 (0.65-1.60)**	
20-30 minutes	**1.13 (0.70-1.82)**	
>30 minutes	**1.66 (1.09-2.52)**	
Male Gender	1.45 (1.03-2.04)	0.034
Age	1.02 (1.02-1.03)	<0.001
ISS	1.11 (1.09-1.12)	<0.001
Low SES	1.19 (0.83-1.71)	0.352

Influence of Potential Spatial Access on Patient Outcomes Following Penetrating Injuries

For penetrating injures, the unadjusted mortality rate was significantly higher for individuals injured >60-minutes from level I TCs (71.2 per 100 persons vs. 36.4 per 100 persons, p<0.001) and for individuals injured >30-minutes from level III TCs (75.8 per 100 persons vs. 49.1 per 100 persons, p<0.001). Patients injured >60 minutes from level I TCs were more likely to present initially to a level III TC (p<0.001). Individuals injured further from level I or level III TCs were also more likely to be older, experience longer prehospital intervals, and be of a low socioeconomic status (all p<0.01) (Table 4-9, Table 4-10).

Table 4-9: Unadjusted comparison of victims of penetrating trauma injured >60 minutes or ≤60 minutes from level I trauma care.

Variable	Level I care >60 minutes	Level I care ≤60 minutes	P-value
Total	**132 (57.1)**	**99 (42.9)**	
Unadjusted mortality (per 100 persons)	71.2	36.4	<0.001
Age (years)	49.2 ± 19.6	38.5 ± 19.7	<0.001
Gender			0.2682
Male	126 (95.5)	91 (91.9)	
Female	6 (4.6)	8 (8.1)	
Injury Severity Score	30.6 ± 17.9	26.6 ± 17.5	0.0796
Prehospital times			
Pre scene time	20.9 ± 41.4	11.15 ± 10.7	<0.001
Scene time	28.5 ± 21.2	16.4 ± 23.0	<0.001
Post scene time	27.1 ± 25.9	13.6 ± 8.7	<0.001
On-scene death	80 (60.6)	33 (33.3)	<0.001
Low SES	54 (40.9)	24 (24.2)	0.008
Level III presentation	23 (46.0)	4 (6.1)	<0.001

Table 4-10: Unadjusted comparison of victims of penetrating trauma injured >30 minutes or ≤30 minutes from level III trauma care.

Variable	Level III care >30 minutes	Level III care ≤30 minutes	P-value
Total	**62 (26.8)**	**169 (73.2)**	
Unadjusted mortality (Per 100 persons)	75.8	49.1	<0.001
Age (years)	52.0 ± 20.5	41.9 ± 19.6	<0.001
Gender			0.2452
Male	60 (96.8)	157 (92.9)	
Female	2 (3.2)	12 (7.1)	
Injury Severity Score	30.9 ± 17.8	28.2 ± 17.8	0.3163
Prehospital times			
Pre scene time	25.9 ± 18.8	13.4 ± 35.5	0.0037
Scene time	34.3 ± 23.8	18.6 ± 21.3	<0.001
Post scene time	44.7 ± 31.3	13.8 ± 8.7	<0.001
On-scene death	39 (62.9)	74 (43.8)	<0.001
Low SES	32 (51.6)	48 (28.4)	0.004
Level III presentation	4 (19.05)	23 (24.21)	0.612

Following adjustment for age, gender, SES, and ISS, being injured by a penetrating mechanism >60-minutes of predicted travel time from level I care remained independently associated with a worse outcome (OR 3.14, p=0.005) (Table 4-11). Similarly, injury >30-minutes from level III trauma care was independently associated with an over 3-fold increased odds of dying after adjusting for the same confounding variables (OR 3.43, p=0.039) (Table 4-12). Notably, these associations remained when on-scene deaths were excluded (OR 4.35, p=0.042 for level I care >60-minutes; OR 3.48, p=0.058 for level III care >30-minutes).

Table 4-11: Adjusted odds of mortality for victims of penetrating trauma with an ISS>11 injured greater than 60-minutes from level I trauma care between 2005-2013.

Variable	Adjusted OR (95% CI)	P-value
Time to level I care		**0.005**
<30 minutes	**reference**	
30-59.9 minutes	**2.97 (0.59-14.81)**	
60-120 minutes	**3.14 (1.25-7.91)**	
>120 minutes	**4.47 (1.86-10.71)**	
Male Gender	1.54 (0.35-6.84)	0.570
Age	1.06 (1.04-1.08)	<0.001
ISS	1.06 (1.03-1.10)	<0.001
Low SES	0.84 (0.40-1.80)	0.658

Table 4-12: Adjusted odds of mortality for victims of penetrating trauma with an ISS>11 injured greater than 30-minutes from level III trauma care between 2005-2013.

Variable	Adjusted OR (95% CI)	P-value
Time to level III care		**0.039**
<10 minutes	**reference**	
10-20 minutes	**1.53 (0.65-3.62)**	
20-30 minutes	**2.96 (0.86-10.21)**	
>30 minutes	**3.43 (1.37-8.59)**	
Male Gender	1.47 (0.36-6.08)	0.595
Age	1.06 (1.04-1.08)	<0.001
ISS	1.07 (1.03-1.10)	<0.001
Low SES	0.88 (0.41-1.87)	0.738

Influence of Revealed Prehospital Times on Patient Outcomes Following Injury

Further analyses were conducted to explore the relationship between documented prehospital times and patient outcomes following injury. Prehospital time was defined as the arithmetic sum of the pre-scene, scene, and post-scene times. Scene deaths were excluded from the analysis. Although there was a trend towards a proportional relationship between prehospital time and outcome for victims of penetrating trauma, this failed to reach statistical significance (p=0.638) (Table 4-13). The relationship between prehospital time and patient outcome for victims of MVCs was inversely proportional and remained strongly significant in the adjusted analysis (Table 4-14). Importantly, 26% of MVCs and 51.7% of penetrating injuries were missing values for at least one prehospital time interval.

Table 4-13: Adjusted odds of mortality for victims of penetrating trauma with an ISS>11 for various total prehospital times. Scene deaths were excluded from the analysis.

Variable	Adjusted OR (95% CI)	P-value
Prehospital Time		0.638
<30 mins	Reference	
30-60 mins	0.70 (0.14-3.43)	
>60 mins	1.58 (0.33-7.54)	
Male Gender	0.34 (0.05-2.11)	0.246
Age	1.06 (1.02-1.10)	0.001
ISS	1.04 (0.99-1.09)	0.145
Low SES	2.53 (0.72-8.86)	0.147

Table 4-14: Adjusted odds of mortality for victims of MVCs with an ISS>11 for various total prehospital times. Scene deaths were excluded from the analysis.

Variable	Adjusted OR (95% CI)	P-value
Prehospital Time		<0.001
<30 mins	Reference	
30-60 mins	0.35 (0.16-0.79)	
>60 mins	0.21 (0.09-0.48)	
Male Gender	1.21 (0.77-1.93)	0.403
Age	1.03 (1.02-1.04)	<0.001
ISS	1.12 (1.10-1.14)	<0.001
Low SES	0.96 (0.57-1.60)	0.870

Discussion

This study has demonstrated that patients severely injured in areas with poorer spatial access to the NS trauma program have an increased risk of death following injury by both penetrating and MVC-related mechanisms. Importantly, the magnitude of the association and the potential explanations underlying it are modified by the injury mechanism. Understanding how the behaviors, injury severities or the post-injury care of rurally injured patients differs from those of the general population is necessary to explain the observed associations and design strategies to redress them.

Regionalization of trauma care has become standard practice over the past two decades. It has been consistently demonstrated that caring for the injured patient in a designated TC is associated with a survival advantage [17,21]. Similarly, initial referral to non-trauma centers (NTCs) has been found to confer a survival disadvantage regardless of eventual transfer to designated TCs [70]. Field triage guidelines have therefore been developed, which stipulate that an injured patient should be transported directly to a designated TC irrespective of the facility's proximity to the injury location [112]. Despite these guidelines, field triage in some trauma systems remains subjective [113]. In NS, initial triage to a NTC is rare, but poor spatial access to level I TCs relative to level III TCs could potentially result in a survival disadvantages for severely injured patients as a result of an increased likelihood of being inappropriately triaged to a centre lacking the necessary resources to provide definitive care [71,76].

In addition to field triage, minimizing the time interval between injury and receipt of definitive care, popularized as the "golden hour", has been another tenet of post-injury care for several decades. Two early studies from a Canadian trauma system identified significant survival benefits in patients with shorter prehospital times [21,45]. Several studies since, conducted on a variety of patient subsets and in multiple geographic locations, have failed to replicate this finding. Most notably, a large North American prospective cohort study by Newgard and colleagues evaluated nearly 150 emergency medical systems servicing over 50 TCs and failed to demonstrate any survival advantage with shorter prehospital times [47]. More recently, a systematic review by Harmsen and colleagues evaluated 20 studies from several trauma systems and concluded that shorter prehospital intervals confer survival benefits only for patients with central nervous system injuries, and hemodynamically unstable patients injured by penetrating mechanisms [48]. As longer prehospital times are typical for patients injured in rural areas, these data suggest the presence of a potential rural disadvantage for subsets of patients injured in remote areas [16,50,114].

Both triage practices and prehospital transport times are potentially spatially dependent constructs that are, in part, dependent on the geographic relationship between the location of injury and the spatial locations of designated TCs. By combining spatial analyses with more traditional epidemiologic techniques, this study aimed to evaluate possible associations between spatial access to trauma care and mortality in a mature, Canadian trauma system. For victims of MVCs, it was determined that spatial access to level I care was not associated with mortality in this retrospective cohort of over 1300 severely injured patients. However, being injured >30 minutes of driving time from level III trauma care was found to be associated with a 66% increased odds of dying. This association was not related to post-scene transport times or post-injury care as evidenced by the loss of association when scene deaths were excluded. The increased probability of ejection events following MVCs in more remote areas suggests behavioral patterns such as seatbelt use may be at least partly responsible for this association. Additional factors related to collision velocity or the built environment may also partly explain this association given the more rural locations of many high speed roads, but this was not testable with the available dataset. Preventative public health campaigns are therefore potentially more effective at redressing this inequality than any changes to trauma care infrastructure. In this cohort, prehospital time was paradoxically inversely associated with survival (as seen in Figure 4-14). Prehospital time is related to the institution the patient is initially brought to and the urgency of initial transport. These are both largely related to the clinical stability of the patient. As this could serve to introduce bias into analyses, prehospital time should not be used as a proxy for access in a tiered trauma system such as the one in Nova Scotia.

For victims of penetrating trauma, poor spatial access to both level III and level I trauma care was associated with an increased risk of death after adjustment for age, gender, injury severity and SES. The robustness of this finding following the exclusion of on-scene deaths suggests differences in post-injury care or prolonged post-scene transport times are potential contributors to this result. Patients injured in areas with poorer access to trauma care were more likely to experience longer prehospital intervals and more likely to present initially to level III TCs. Although no statistically significant relationship was identified between prehospital time and outcome in this dataset, low power, missing data and the potential for this time interval to be subject to observer bias could potentially be confounding any association.

Lawson et al have previously evaluated the association between potential spatial access to trauma care for a retrospective cohort of injured Canadians [69]. In addition to identifying that 68% of severely injured Canadians reside within 60-minutes of driving time to a level I or level II TC, they also described increased mortality for patients with poorer spatial access to higher level trauma care. Importantly, these authors utilized residential postal codes as a surrogate for injury location. In trauma systems dominated by blunt mechanisms, this surrogate is potentially inaccurate [68]. Furthermore, the unadjusted nature of the statistical analysis limited the ability of the authors to elucidate any potential explanatory or confounding factors underlying their findings. This is important given the potential for rurally injured individuals to have additional risk factors for adverse outcomes such as lower SES or more severe injuries [50,115]. Some of the first trauma-related spatial analyses that incorporated multivariable statistical models was conducted by Crandall and colleagues in urban Chicago [72]. These authors demonstrated that victims of firearm-related penetrating trauma had a 23% increased odds of death if injured greater than 5-minutes from a TC, after adjusting for several relevant confounding variables. However, the urban setting and specific population of this study provides little generalizability to a rural trauma system.

This study provides some of the most robust Canadian evidence to date of the influence of poor spatial access to trauma care on mortality for victims of MVCs or penetrating injuries. The use of precise injury location data as well as a mechanism-specific and adjusted analysis results in more useful results compared to some prior studies. Using these approaches, it was possible to determine that the impact of spatial access on outcome is dependent on injury mechanism in the NS trauma system. Additionally, the incorporation of scene deaths into the dataset reduces any influence of the survivor bias typically observed in registry-based studies.

This study does have several limitations that require consideration. First, this study represents data from one provincial trauma system. Although the epidemiology of injuries is comparable to other systems across Canada, systemic differences in post injury care remain possible and results will require replication in a geographically and politically distinct system. Additionally, incorporation into the comprehensive dataset utilized in this study requires presentation to the provincial trauma system. Therefore, it is possible to miss patients who present to, and are definitively cared for, at a NTC. The prevalence of this is estimated to be less than 1.5% of major traumas. Data accuracy and completeness also need to be considered in secondary data (registry) studies. Although individuals without injury location data were more likely to die, the proportion of missing data was only 12% and unlikely to introduce significant bias into the results. The accuracy of injury location data collected by the EHS has not been externally validated and relies on personnel manually indicating when they arrive on scene. However, an available field denoting the reliability of the coordinates helps avoid the inclusion of inaccurate data in the analysis.

Conclusions

Injury affects millions of people worldwide annually and is one of the foremost public health problems affecting the health of Canadians. This burden of injury is exacerbated by the difficulties of delivering care with finite resources in the expansive Canadian geography. Understanding how the accessibility of trauma care influences the outcomes of injured Canadians is therefore vitally important to improve the universality and equity of Canadian healthcare.

This study has demonstrated that level III TCs are vital to the accessibility of trauma care in Nova Scotia. Furthermore, we have demonstrated that the association between access and mortality is modified by the mechanism of injury, and that explanations for these associations are not confined to either the pre-injury or post-injury environment. These results imply that the accessibility of level I care is not a protective factor for victims of MVCs, suggesting that level III care is capable of receiving the vast majority of these patients. Additionally, as differences in post-injury care may be partly responsible for the association between access and outcome for victims of penetrating trauma, ensuring readiness of prehospital personnel and level III TCs will be important in redressing this inequality. Specific attention should be paid to reducing prehospital intervals for these patients. This may be effectively accomplished through the education of prehospital personnel and the direct triage of rurally injured patients to the nearest TC.

Future research should focus on replicating these results in a geographically distinct trauma system with a different regulatory environment, and on identifying specific pre- and post-injury factors responsible for differences in outcomes for rurally injured patients.

Chapter 5: Conclusions and Recommendations

With over 15,000 deaths per year and $20 billion in annual healthcare expenditure, injury represents one of the foremost problems in Canadian public health practice [9,116]. Compounding the problem's magnitude is the difficulty in providing emergency, time-sensitive treatment in an expansive, sparsely populated country such as Canada. As specialized trauma care in the form of TCs exist predominately in urban settings, rurally injured populations may have compromised access to life saving treatment. In the context of Canada's universal healthcare system, preventable disadvantages related to access are contrary to the accessibility criteria of the Canada Health Act and must be carefully researched and redressed. This thesis explores the spatial properties of trauma in Nova Scotia, with specific emphasis on three key research questions:

1) Is there regional variation in injury-related outcomes in NS?
2) Is there regional variation in the accessibility of TCs in NS?
3) Is poor spatial access to TCs associated with an increased risk of injury-related mortality in NS?

Answering these questions may aid in the identification of populations at high risk of adverse injury-related outcomes and ultimately may prove useful for the optimization of trauma care delivery in the province. The following discussion will reflect on these research questions with reference to the data presented in the prior chapters. It will conclude by suggesting meaningful areas for future research and policy recommendations based on the findings.

Regional variation in injury-related outcomes

Aggregation of data in geographic areas is a commonly used means of displaying trends visually [54]. However, when aggregating a low number of observations, these simple methods can often give misleading results. Additionally, without estimates of uncertainty such as confidence intervals, it is difficult to ascertain which regional variations are remarkable. This study used Bayesian techniques to statistically evaluate regional variations in MVC-related outcomes. By smoothing SMRs for the province's CSDs, a region of high risk on Cape Breton Island could be identified where there were more MVC-related mortalities than would be expected given the population of the area. By evaluating the MVCs within this region, potential explanations for this finding could be identified such as tourist traffic and a higher incidence of severe collisions. Additionally, these CSDs contain some of the highest numbers of Aboriginals in the province; a population known to be at increased risk of adverse injury-related outcomes. These are all potentially valuable findings for prevention planning and improving equitable healthcare delivery in NS.

Using complimentary methods, MVC-related outcomes were further explored to identify “hot spots” or clusters of adverse events such as deaths or prolonged hospital lengths of stay. These cluster detection methods aim to ascertain if an area has a higher number of events of interest than would be expected based on the number of MVCs in the same area. Although mortality and hospital length of stay were found to be statistically homogenous throughout the province, one cluster of prolonged ICU length of stay was identified surrounding a level III TC. When this cluster was investigated, a high proportion of the events were admitted to the level III TC prior to transfer to a level I facility. Although this is simply an association, it remained robust in an adjusted statistical analysis of the entire cohort and suggests the potential for a causative relationship between the level of hospital where a patient is initially admitted and their subsequent ICU length of stay. This finding should not be used to undermine the importance of level III TCs within the NS trauma system, but to emphasize the importance of early transfer of patients who require level I care.

Together these finding illustrate that adverse MVC-related outcomes are not simply related to local population counts or the frequency of events. Other factors such as victim behaviors or post-injury care practices must therefore be contributing to the spatial variation in these adverse events. Poor access to TC care is one potential contributor and warrants investigation due to its importance within a universal healthcare system.

Variation in Access to TC care

Before the impact of spatial access on TC care on adverse injury-related outcomes can be evaluated, a reproducible and valid means of quantifying access is necessary. Although documented prehospital time is one potential surrogate for access, it could not be exclusively used in this dataset due to a high number of missing values. Additionally, use of this surrogate is potentially biased by prehospital decisions related to the urgency of the case or the stability of the patient, which would compromise the detection of an association between access and outcome. This thesis uses geospatial methods to develop a model of TC access for the province of NS and validates it using data from the NSTR. By treating access as a continuous variable, distributions of access could be constructed for the population of NS as well as a cohort of patients injured in MVCs. The analysis demonstrated that access to level I TCs was considerably lower than the national average; a finding that is consistent with prior work. However, the analysis additionally demonstrated that access to level III TCs within 30-minutes was nearly ubiquitous, underscoring their importance for the accessibility of the NS trauma system.

Using these same methods, models of access using aeromedical transport instead of ground-based transport were constructed. These analyses demonstrated that use of LifeFlight transport modestly improves the accessibility of level I care, but this benefit is largely limited to daylight responses. Due to the 60-minutes delay between activation and take-off at night, access advantages are only realized for the populations with the worst access to level I care in the province. This finding underscores the limited utility of LifeFlight in realizing access advantages for the majority of the population. However, before recommendations aimed at improving the accessibility of a trauma system can be made, an understanding of the relationship between access and outcomes is required.

Relationship between TC accessibility and outcome in NS

By combining geospatial models of access with logistic regression models, it is possible to make estimations of the association between access to TCs and mortality in NS. Following these analyses, it was determined that poor access to level I care conferred no increased mortality risk for victims of MVCs. Although poor access to level III TCs was associated with a 66% increased risk of death following an MVC, this association is lost when scene deaths were excluded suggesting pre-injury or injury-related factors are underlying the finding.

Contrary to MVCs, access to TCs for victims of penetrating injuries is strongly associated with mortality. In this cohort of over 200 patients, poor access to level I and level III TCs was associated with a >2.5 fold increased risk of mortality. This relationship remained strong when scene deaths were excluded, suggesting that post-injury factors such as transport time or receiving facility readiness may explain part of this relationship.

Contributions to the literature

In addition to providing further evidence of the spatial variability of injury-related outcomes, this study significantly expands our understanding of the relationship between access and mortality for victims of trauma in Canada. Using a model methodologically distinct from prior studies, this study reaffirms that the majority of the population of NS lacks access to level I TCs within 60-minutes. However due to the depth of information collected within the NSTR, this study also demonstrates that the relationship between TC access and mortality is more complicated than that originally postulated by Lawson et al, with the nature of the relationship being modified by the injury mechanism and potentially other injury-related factors [69].

Although longer prehospital times are typically the concern for patients with poor access to TCs, this study illustrates that individuals with poor access to TCs represent a unique population that differs demographically, socioeconomically and behaviorally from the general population of NS. Therefore, although individuals with poor access to TCs typically experience a longer prehospital interval, additional variables are expected to be contributing to their outcomes. As there was no increased risk of mortality for MVC victims with poor access to TCs following exclusion of scene deaths, it is clear that prehospital transport times are not contributing to the observed association. However, the robustness of the association in victims of penetrating trauma who survive to hospital suggests post-injury care practices are potentially important in this population. It is noteworthy that the penetrating trauma victims with poor access to TCs experienced a prehospital interval approximately twice as long as patients with better access. The plausibility of this relationship being causative is supported by prior studies which identified worse outcomes in victims of penetrating trauma with poorer access to trauma care or longer prehospital times [72,114].

Limitations

Although this study represents a robust analysis of the spatial distribution of injury in NS, several limitations need to be considered before the findings can be generalized. Importantly, this is a retrospective study based on registry data. In addition to the caution required before applying the conclusions prospectively, causative relationships cannot be definitively established. Additionally, this study was conducted in a single trauma system with a relatively low number of observations. Drawing widespread conclusions on the relationship between access to TCs and outcomes will require replication of these findings in a geographically distinct trauma system with a different regulatory environment and a larger patient cohort. Importantly, missing data within the trauma registry has the potential to introduce bias into the observed results. Although the likelihood of this is low given the limited missing data, it cannot be excluded as a possible source of bias. Finally, the year of injury was not adjusted for in this analysis due to the relatively low number of events over the 8-year study period. Although no radical policy shifts occurred during this time, subtle temporal trends cannot be excluded as a potential additional source of bias.

Due to a higher amount of missing data for other variables within the NSTR, factors such as prehospital time and anatomical location of injury could not be completely accounted for in the adjusted analyses resulting in the potential for residual confounding to underlie the observed associations. Similarly, injury time was not available or accurate for the majority of entries, preventing the inclusion of discovery times in the analysis. As it is conceivable that the interval between injury and EHS activation is longer for rural injuries, discovery times are a potentially important, spatially dependent variable that may significantly reduce the accessibility of care for rurally injured patients.

Future research

The value of spatial modelling in epidemiology lies in its ability to generate hypotheses by uncovering spatial associations. It is extremely important to emphasize that poor access to TCs is not synonymous with prolonged prehospital times. Although there is a co-linearity between these two variables, individuals with poor access to TCs represent a unique population which differs demographically and behaviorally from the general population. Understanding specifically how these populations differ and how these differences relate to survival following injury will be an important component of ongoing research. As an example, a detailed investigation into seatbelt use or impaired driving behaviors in more rural areas may result in findings which can successfully be used in preventative campaigns. Furthermore, investigating the relationship between prehospital time and outcome using a much larger cohort of Canadian patients injured by penetrating mechanisms will be useful in determining how this variable contributes to the observed associations between access and mortality. Lastly, this study exclusively investigated mortality, but it will be important to measure the effects of TC access on other outcomes such as hospital length of stay, disability and quality of life as this could also have important implications for trauma care delivery in NS.

Policy recommendations

Despite the limitations of this study, it is possible to make several policy recommendations informed by the results and the methodology. Importantly, this study demonstrates the utility of spatial analysis in the monitoring and evaluation of a provincial trauma system. Incorporating these methods into ongoing evaluation will be useful in detecting any changes in the spatial epidemiology of trauma in NS and for informing the shifting of resources when necessary. Additionally, this application of GIS is not limited to trauma and should be investigated for incorporation into the planning of other emergency services such as cardiac and stroke care.

The high mortality area identified on Cape Breton Island should be included in ongoing prevention campaigns, particularly in the summer months. However, recognizing that this area represents the minority of injury-related fatalities, prevention campaigns should still be focused province-wide with an emphasis on rural populations given their observed increased mortality risks. These campaigns should involve a market research component aiming to understand the behaviors and perceptions of rural populations with respect to MVC risk factors. Additionally, given the low access to neurosurgical care experienced by patients injured on Cape Breton Island generally, consideration should be given to expanding the acute neurosurgical capacity of the province to this area pending the outcome of careful cost-benefit analyses

A focused investigation of the identified level III TC at the center of the cluster of patients who experienced a prolonged ICU length of stay should also be conducted. As there are potentially practice patterns at this facility explaining why so many of these patients required transfer to the province’s tertiary ICU following admission. More generally, transfer protocols should be improved to reflect the consequences of the undertriage of patients requiring care at the level I TCs.

As there was no survival advantage experienced by MVC victims with access to the level I TCs, the utility of LifeFlight for these victims needs to be questioned. It is possible that this service confers a survival benefit for population subsets such as those requiring acute neurosurgical care, or victims of penetrating trauma, but this is currently unclear and wasn’t specifically investigated in this study. Careful scrutiny of this service will be required to determine which geographic locations and injuries experience large enough benefits from improved level I TC access to justify the cost of this service. Additionally, due to the small population that experiences access improvements from the utilization of LifeFlight at night, limiting the service to daylight only responses or improving non-daylight response times is necessary for continued justification of the service. Adding additional LifeFlight assets in the more remote regions of the province is one potential means of accomplishing this, but would require careful economic evaluation prior to implementation.

Finally, the level III TCs in the province have been demonstrated to play a crucial role in the accessibility of trauma care. These TCs should therefore be staffed and resourced in accordance with this finding to ensure their readiness to manage all traumas, but particularly penetrating injuries. Furthermore, coordinated efforts to reduce prehospital times for victims of penetrating trauma are necessary. Whether through education of prehospital personnel or through increased utilization of level III TCs, improvements in access to TCs for victims of penetrating injuries would potentially result in a significant survival advantage for this population and should be a major focus of ongoing trauma system improvement.

Closing remarks

Prompt access to emergency care following injury has been one of the major tenets of trauma care for decades. Descriptive studies employing geospatial methods have added support to this by demonstrating an increased mortality in trauma patients with poor access to trauma care. Using novel methods and adjusted analyses, this study demonstrates that the relationship between access to trauma care and mortality is more complicated than initially thought and dependent on a myriad of aggravating and alleviating factors. Improving trauma care for rurally injured patients will require more than simply decreasing the time between injury and receipt of care. Use of carefully designed, local studies will be necessary to leverage political will and justify the costs associated with ongoing trauma care improvements.

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