Spatial Epidemiology of Child and Youth Injury

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Ofer Amram

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B.A. (Geography), Simon Fraser University, 2009

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Approval

Name: **Ofer Amram**

Degree:

Title: **Spatial Epidemiology of Child and Youth Injury**

Examining Committee: **Chair:** Meghan Winters
Assistant Professor, Faculty of Health Sciences

Nadine Schuurman
Senior Supervisor
Professor
Geography Department
Simon Fraser University

Michael Friger
Co- Supervisor
Professor
Faculty of Health Sciences
Ben-Gurion University

Natalie Yanchar
Supervisor
Associate Professor
Faculty of Medicine
Dalhousie University

Valorie Crooks
Supervisor
Associate Professor
Geography Department
Simon Fraser University

Martin Andresen
Internal/External Examiner
Associate Professor
School of Criminology
Simon Fraser University

John Tallon
External Examiner
Clinical Professor
Departments of Emergency Medicine
University of British Columbia

Date Defended/Approved: August 18, 2015

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Abstract

Injury is one of the leading causes of death amongst Canadian children. Every year, it is estimated that approximately 25000 children will be hospitalized because of unintentional injuries – of these 25000, nearly 400 are likely to die. However, not all children are equally at risk. Studies have shown that children from socio-economically deprived families are at higher risk of morbidity and mortality as a result of injuries. In fact, despite a steady decrease in total rates of injury within the Western world, the difference in rates of pediatric injury between rich and poor has actually broadened in recent decades. In addition, injury has been shown to have a geographical gradient, whereby populations residing in rural areas experience worse outcomes compared to urban dwellers. This is primarily attributable to the reduced access to pediatric trauma centres amongst rural populations, as rapid access to pediatric trauma centres have been shown to produce superior outcomes with severely injured patients. This dissertation encompasses an analysis of pediatric trauma centre access and socioeconomic status within specific regions of Canada and Israel. Its two principal objectives involve: 1) an analysis of the geographical distribution of major traumas within the child and youth population; and 2) an assessment of the effectiveness of pediatric trauma systems in dealing with these injuries within both of the countries under observation. On a more granular level, the project aims to describe the hotspots for child and youth injury, to identify disadvantaged populations and high risk injury mechanisms and patterns, and to explore the barriers that impede access to appropriate care in both of the study regions. It is also intended to improve the methodology available to researchers in dealing with locational error within injury data. The results will assist decision makers in prioritizing the delivery of health care services and will help direct scarce prevention-related public health resources to high risk populations.

Keywords: Pediatric Injuries; Access to Care; Social Determinants of health; Spatial analysis

Dedication

To my wife, Marilyn, and my two girls, Eyden and Ma'ayan

With love…..

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Chapter 1.

Introduction

1.1. Overview

Injuries are the leading cause of death amongst Canadian children, with similar trends found in other developed countries (Birken, Parkin, To, & Macarthur, 2006). Despite this, injury research receives relatively little attention when compared to research on other illnesses. This may be partly due to the many different triggers for injuries and partly due to the misconception that injuries are difficult to prevent and that preventative measures lie outside the domain of health care (Mock, Quansah, Krishnan, Arreola-Risa, & Rivara, 2004; R. J. McClure, M. Stevenson, & McEvoy, 2004). For the purpose of this dissertation an injury is defined as a trauma caused by an external factor.

In order to understand the extent of this issue and to be able to how and where injuries occur and precisely which populations are being affected (R. J. McClure control, prevent and treat injuries more effectively, health professionals need to know et al., 2004). For pediatric populations, this entails identifying the geographic distribution of pediatric injuries and determining whether there is a link between the location of these injuries and the environmental and social indicators that might influence them. Identifying injury location also allows for a better understanding of the relationship between distance to and/or type of care and injury outcomes.

This project seeks to fill a gap in the current understanding of pediatric injuries within both Canada and Israel. Beginning with an overview of pediatric injury, pediatric trauma systems, health geography and spatial epidemiology, the project then goes on to outline the research questions and objectives. This overview is followed by the four papers that make up the body of the dissertation.

1.2. Research Objectives and Challenges

The burden of childhood trauma, both financially and in terms of lives lost and altered, is enormous, warranting a closer investigation of pediatric injury patterns, causes and health care delivery mechanisms. The aim of this dissertation is to provide an in-depth investigation of pediatric injuries within Canada and Israel in order to improve care and tailor prevention and access to care strategies to this population. More specifically, this research seeks to: (1) provide an overview of spatial access to pediatric trauma centres in Canada and to examine the impact spatial access has on outcomes; (2) provide an in-depth look at the geographical distribution of major traumas within the British Columbia child and youth population, describing the hotspots for child and youth injury within this region and identifying disadvantaged populations and high risk injury mechanisms and patterns; (3) examine the relationship between spatial access to trauma centres and injury outcomes in different geographical settings (4) examine how locational error in injury research impacts results and provide methods of minimizing those errors.

The international scale of this research introduces several challenges. First, the different geographical areas and various populations included within the study, result in datasets that are large and heterogeneous. This heterogeneity is brought about by the differences in local characteristics (e.g. weather patterns and culture) that affect injury mechanisms within the two different countries of study (Israel and Canada). Second, as there is no accepted standard for injury data collection between the two countries, the study design must be engineered to account for these differences.

1.2.1. Research Questions

Four main research questions, each to be addressed within its own chapter, will serve as guides for this study. These questions are listed in order below:

1. What is the potential spatial access of pediatric populations sustaining injuries to pediatric trauma centres within Canada?

2. What is the relationship between spatial access and patient outcomes?

3. Are children with lower socio economic status (SES) more likely to be injured? If so, are certain injury mechanisms more prevalent in children of lower SES?

4. To what extent does locational error in injury research impact results? What are the best ways to minimize these errors?

1.3. Study Sites and population

This project was conducted across different regions of Canada and Israel. Within Canada, the research was primarily situated within the Greater Vancouver area of British Columbia. Greater Vancouver, located within Western Canada, is home to approximately 2.3 million people with a relatively high income. It is also the site of the BC Children's Hospital, the largest pediatric trauma center in the province. This hospital treats injured children from the Greater Vancouver region as well as most of the rest fof the province, except for the very south east corner. British Columbia is a very large province, covering 944,735 square kilometers. Its geography is wide-ranging and diverse, encompassing rugged mountains, populated islands and remote towns, and presents a challenge to the equitable provision of health care services, including trauma care. Within Canada, this project also examined access to care in the Maritime province of Nova Scotia. Nova Scotia has a geographical area of 55,238 square kilometres and a population of close to 1,000,000 people, being much smaller than British Columbia in both size and population. The IWK Health Centre, located in Halifax, the province's capital and largest city, is the only pediatric hospital in the Maritimes.

Within Israel, the project is focused upon the Southern region of the country, also known as the 'Negev'. This region, that is primarily rocky desert, is the least densely populated region in the country and covers more than half of Israel's landmass. The bulk of the population within the Negev region is concentrated in the North around the largest city of Beer Sheva. Beer Sheva, is home to Soroka Hospital, that has a pediatric trauma center and which provides trauma services to the entire region. The total population of the Negev is estimated at over 700,000 people, of which 73% are Jewish.

The remainder are primarily Bedouin of Muslim decent. The stark differences between these two populations in terms of culture and SES provide an interesting backdrop against which to explore both trauma care access and injury mechanisms and rates.

Although the bulk of the research within this dissertation focused on children aged 0-18, some of the analyses used children in the 0-15 age range as this was the only data available.

1.4. Conceptual Framework

In terms of conceptual framework, this thesis draws from the two closely aligned fields of health geography and spatial epidemiology. Both deal with health issues from a geographical perspective however health geography takes a more theoretical and qualitative approach while spatial epidemiology emphasizes the use of spatial data and is more quantitative in nature. The following section will briefly describe both disciplines, before proceeding to outline the concepts that help shape the framework for this dissertation.

1.4.1. Health Geography

Health geography focuses on well-being rather than strictly on the presence or absence of illness (Fleuret & Atkinson, 2007). It employs theories from social science based on the promotion of social justice, the distribution of wealth (Marx) and theories of equality/inequality. It takes a contextual rather than compositional approach to health, by examining the social and environmental determinants of health rather than relying solely on individual factors or characteristics. (Dorn, 2010; Fleuret & Atkinson, 2007)

Health geography employs many methods and theoretical frameworks in its interpretations, including therapeutic landscapes, accessibility, embodiment, foodscapes and social and environmental determinants of health (Allison, 2002; E. Hall, 2000; Luginaah, 2009; Panelli & Tipa, 2009; Ricketts, 2010). These methods are helpful in providing a more comprehensive picture of the processes contributing to particular health outcomes within society and enable a focus on how and why particular outcomes are occurring as opposed to simply where they are occurring. This, in turn, can assist in the identification of methods to minimize disparities at different levels (local, regional, global) within society (R. Kearns, & Collins, D., 2010). For example, if a walkability study determines that there is a correlation between walkable neighborhoods and positive health outcomes within the population, a health geographer can then try to determine how to increase walkability in the target neighborhoods. This might be done by increasing the number of pedestrian walkways and improving the connectivity between them, or alternatively, by providing more open space and better lighting so as to enhance the perceived safety of the neighbourhood (Leslie et al., 2007). By addressing how and why particular outcomes occur, health geography research can also provide decision makers with methods to enhance population health through long term and preventative measures. Such measures are useful in that they can be applied to large segments of the population and can therefore be cost effective. In this sense, the role of space (where things happen) and place (how they happen) are both crucially important to the understanding of population health (Curtis & Rees Jones, 1998; R. Kearns, & Collins, D., 2010; R. Kearns & Moon, 2002).

1.4.2. Spatial Epidemiology

Geography is a discipline that aims to identify and explain structure and process in space. Much of geographic research concerns itself with the processes and behaviors of humans and the environment (Moore & Carpenter, 1999). Epidemiology, on the other hand, is the study of the distribution of determinants of disease within the population, focusing on the frequency and distribution of disease. Spatial epidemiology links the two disciplines in "…the study of spatial variation in disease risk or incidence."(Ostfeld, Glass, & Keesing, 2005). The relationship between space and health is longstanding as evidenced within the Hippocratic treatise "Air, Waters and Places", written almost 2400 years ago (Krieger, 2003). A more recent example comes from John Snow, who, in 1854, showed the importance of space and disease distribution by mapping cholera cases in London to their source where they were clustered around a water supply. In this particular case, Mr. Snow managed to stop the outbreak by shutting off the water source. Another example, from the 1950s, is that of Burkitt's lymphoma. By identifying clusters of jaw tumors occurring in children in a particular equatorial region in Africa, Denis Burkitt, was able to isolate the first cases of a tumor caused by a virus (Moore & Carpenter, 1999). Spatial epidemiology's main objective is to analyze two types of data: case-event data (point) and regional summary data (aggregated data), which typically lead to dot maps and choropleth maps, respectively. However, epidemiology is also concerned with the identification of unknown risk factors, that may be either environmental (air pollution, radiation, magnetic fields, etc.) or socioeconomic (Berke, 2004).

Despite its importance within the field of Geography, spatial data has been less well utilized by epidemiologists (Graham, Atkinson, & Danson, 2004; Jacquez, 2000). This has changed recently as a result of rapid developments in geographic information systems (GIS) and increasing data availability (Rushton, 2003). A GIS is an "integrated set of computer hardware and software tools to capture, store, edit, organize, analyze and display spatially-referenced data" (Moore & Carpenter, 1999). GIS is used to integrate data of different formats (raster format and vector format) and to combine those data sources to map a phenomenon (Graham et al., 2004).

The use of GIS has grown rapidly within the last two decades, accompanied by improvements in data acquisition techniques and, more importantly for epidemiology, the development of several new methods of spatial analysis (MJ, 2004). This has allowed epidemiology researchers to conduct spatial analysis that goes beyond the simple mapping of disease (Moore & Carpenter, 1999). Spatial analysis is "the ability to manipulate spatial data into different forms and to extract additional meaning as a result. It encompasses a variety of methods and procedures developed in different disciplines" (MJ, 2004). There are three different categories of spatial analysis: visualization, exploratory spatial data analysis and model building. An additional category, not normally associated with spatial analysis, but which uses many of the same techniques, is that of accessibility. This type of analysis generally examines the spatial accessibility to services and uses location allocation models to provide better service.

This dissertation draws from two concepts that are present in both health geography and spatial epidemiology. The first is the concept of accessibility and the second is based upon the social determinants of health.

Access to health services

Adequate access to health care services is paramount to population health and wellbeing and is one of the most researched subjects in public health. However, the definition of access is somewhat complex as it can mean different things to different people. For example, for an anthropologist, an examination of the social factors (e.g. language, gender) affecting access to health services may be of more importance, while for a geographer, the spatial aspects of access (e.g distance, density) may receive greater emphasis (Khan & Bhardwaj, 1994). According to the Canada Health Act, “persons must have reasonable and uniform access to insured health services, free of financial or other barriers. No one may be discriminated against on the basis of such factors as income, age, and health status” (Act, 1985). This definition highlights the many dimensions of access to care as well as the complexity and difficulty of understanding how access to care impacts population health.

Measures of health service access can be grouped into two distinct categories; spatial access and non-spatial access (Aday & Andersen, 1974; Khan & Bhardwaj, 1994). Spatial access is often measured in terms of distance to a particular facility or service, or alternatively, in terms of the time it takes to get to a particular health care facility. There are also different ways to determine spatial access. For example, measures of distance to the nearest health care facility may take into account either physical distance (e.g. kilometres) or driving time (20 minutes), or might quantify the number of facilities within a given area. Measures of non-spatial access, on the other hand, use non-geographical factors to determine access. Such factors are typically personal (for example, those experienced as a result of cultural differences), financial or organizational (like long waiting lists) in nature (Brown, McLafferty, & Moon, 2009; Khan & Bhardwaj, 1994). In reality, however, access to health care is a multi-dimensional process that incorporates both spatial and non-spatial components (Gulliford et al., 2002).

When measuring access to trauma centers, the analysis is somewhat simplified as many of the non-spatial factors that may impede or facilitate access do not play a major role. Factors like language and income, for example, are typically less of a barrier in emergency than in non-emergency situations. On the other hand, spatial factors, like distance to the nearest trauma centre, may play a greater role in an emergency situation.

Social determinants of health

A variety of social processes play a role in the health outcomes of both individuals and communities as a whole (Marmot & Wilkinson, 2005). Collectively, such factors are defined as social determinants of health, and typically include factors such as levels of education and income, employment, food security, availability of shelter, and so on. (World Health Organization, 2008). Research has consistently shown that socioeconomic factors have an impact on the health and well-being of the population. For example, poverty has been shown to contribute to increased mortality rates from cardio vascular disease and diabetes (Raphael, 2001; Yu & Raphael, 2004). Poverty is also related to food insecurity that can, in turn, lead to a number of nutrition-related health problems (Wilkinson & Marmot, 2003). In conclusion, socioeconomic factors play a powerful role in shaping the health of individuals and contribute to the health and well-being of society as a whole. In order to increase health equity, social economic policies need to improve the living conditions of those adversely affected and provide for the more equitable distribution of power and resources.

Building a framework

This thesis takes concepts from health equity and combines these within a spatial model intended to identify populations that are either at high risk of injury or that have limited access to trauma care services. Once identified, these concepts are used to explore the factors that contribute to increased risk of injury and to isolate the factors that may impede access to care. Figure 1-1 illustrates how these concepts are combined within the conceptual framework.

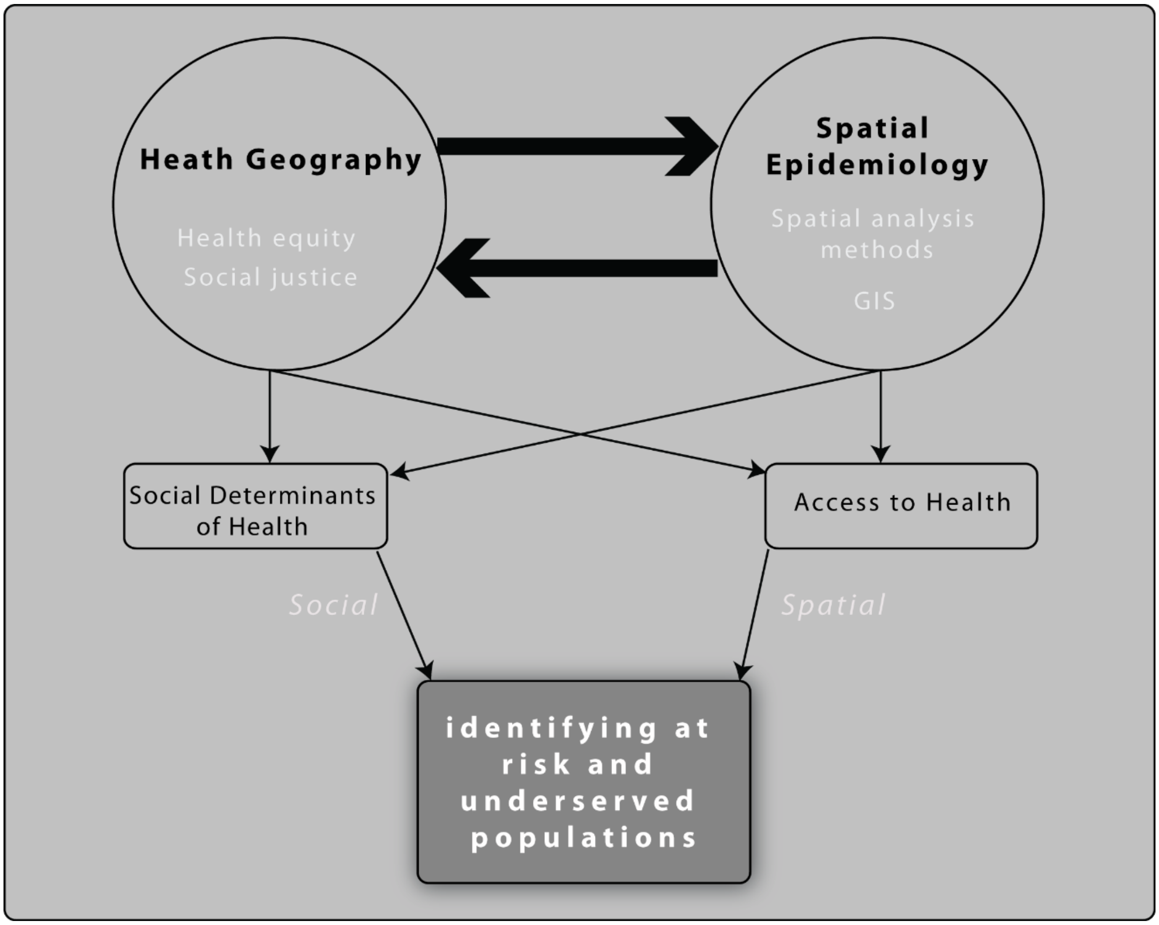

Figure 1-1 Conceptual Framework
The figure illustrates the conceptual framework that guides the thesis. Theoretical concepts from health geography were used to guide the spatial methodological development. Using a framework that combines access to care with social determinants of health provides a unique means of identifying at risk and underserved populations.

1.5. Literature Review

1.5.1. Pediatric Injury

While injuries are the fifth leading cause of death in Canada, they are the leading cause of death within pediatric populations (Statcan, 2012). Every year, it is estimated that 400 children will die from injury with an annual direct and indirect cost estimated at 19.8 billion (SafeKidsCanada, 2006). Worldwide, there are more deaths from injury in the first four decades of a person's life than from any other cause (Hameed et al., 2010). There is no doubt that the burden of injury to society is tremendous.

Over the last 5 decades, there has been a 50% decline in childhood injuries within Canada – as is the case in many other countries in the developed world. However, although the absolute number of injuries has declined, researchers have shown that the prevalence of injury is substantially higher amongst those of lower socioeconomic status (SES) (Birken et al., 2006; Catherine S Birken, 2004). At the same time, some studies have shown the inverse, indicating that children with relatively high SES are experiencing higher rates of injury (Potter et al., 2005). These inconsistencies highlight the need for a more detailed investigation of pediatric injury and its correlates.

The relationship between socio- economic status and Pediatric injury

The bulk of the research conducted in the area of SES and pediatric injury, concludes that children of low SES are more susceptible to injury (Catherine S Birken, 2004; Cubbin & Smith, 2002b; Potter et al., 2005). This is particularly true in urban areas and for specific types of injuries, such as burns or pedestrian injuries (Catherine S Birken, 2004; Dougherty, Pless, & Wilkins, 1990). There are several reasons for this: for example, children with low SES typically live in older, less well-maintained homes and are, therefore, more often exposed to environmental hazards such as lead poisoning and house fires (Cubbin, LeClere, & Smith, 2000; Cubbin & Smith, 2002b). In addition, children in these areas may not have access to injury preventing equipment like home smoke alarms or bicycle helmets. At the neighborhood level, urban playgrounds in low SES areas tend to be located in high traffic areas where pedestrian injuries are more likely (Powell, Ambardekar, & Sheehan, 2005). Low levels of education are also associated with increased risk of injury (Soubhi, Raina, & Kohen, 2004). As education has been shown to increase with income level, parents with lower SES may be less aware of injury prevention strategies than those with higher levels of education/income. Children with low SES are also less likely to be supervised by an adult which can in turn lead to increased risk of injury (Schwebel & Gaines, 2007). Roberts et al examined the likelihood of mortality from injuries and found that children in impoverished homes in England were 1.89 times more likely to die from fire than children from high SES homes. At the same time, these children were 1.47 times more likely to die from pedestrian injury, 1.46 times more likely to die from fall injury and 1.36 times more likely to die from poisoning injury (Roberts, 1997). An American study using the same socioeconomic parameters found that children in Boston and Philadelphia were 2.6 times more likely to die from house fire. Two Canadian studies came to a similar conclusion, indicating that children in poorer neighbourhoods were far more likely to die as a result of pedestrian injuries, house fires, falls and drowning than were children in higher SES neighbourhoods (Faelker, Pickett, & Brison, 2000; Gilbride, Wild, Wilson, Svenson, & Spady, 2006). An examination of injury severity shows a similar trend. For example, a study in Ontario demonstrated that children from low SES homes were 1.75 times more likely to be admitted to hospital for home injuries, 1.37 times more likely to be admitted for sports injuries and 1.42 times more likely to be admitted for fall injuries (Faelker et al., 2000).

Adolescent injuries

The relationship between injuries and SES is unclear for adolescents. In addition, adolescent injuries tend to have different mechanisms and causes than those occurring amongst younger children. Although sport-related injuries are typically associated with adolescents of higher socioeconomic status (as they are more likely to participate in sport activity), adolescents with low SES are more likely to be injured in street crime and neighborhood violence (Simpson, Janssen, Craig, & Pickett, 2005). However, the relationship between SES and injury in adolescence has not been firmly established. In fact, a large Canadian study, which examined more than 11329 Canadian adolescents (Pickett et al) determined that there is no clear relationship between SES and injury (Pickett, Garner, Boyce, & King, 2002; Williams, Currie, Wright, Elton, & Beattie, 1997).

Gender

It is well established that boys are at higher risk for injury than girls. For example, a Canadian survey of adolescents (age 11-16) conducted by Simpson et al, found that 59.1% of males were injured as opposed to 50.1% of females (Simpson et al., 2005). Other studies show the same propensity (Gilbride et al., 2006). There are several sociological and behavioral reasons for this, the primary one being that boys tend to engage in activities of higher risk (e.g. physical sports) than girls.

1.5.2. Pediatric Trauma Systems

As with adult trauma systems, pediatric trauma systems have undergone rapid development in recent decades (Morrison, Wright, & Paidas, 2002). Trauma systems, when operating appropriately, are designed to seamlessly integrate the various stages of care of injured patients, beginning with the pre-hospital phase with identification and stabilization of patients, through to transport, arrival and care at hospital, and finally to rehabilitation (Nirula, Maier, Moore, Sperry, & Gentilello, 2010). While patients that are critically injured require rapid transport to a trauma centre, either directly from the scene or after stabilization in a local facility those with less serious injuries can receive their definitive care in a non-trauma facility. The process of determining which patients are critically injured and where they should go is known as triage. Triage plays a key role within trauma systems, impacting not only the quality of care for a particular patient but also the capacity of the trauma system as a whole (Engum et al., 2000). For example, if a non-critical patient were to be triaged as critical and sent to a trauma hospital (in a process known as overtriage), the patient would consume resources that could otherwise be used by a patient who was actually in need of critical care (J. S. P. Sampalis et al., 1997). Triage scoring systems are typically quite simple as their sole purpose is to determine whether or not a patient requires trauma service. There are several types of triage scoring systems: some are age specific and are used specifically for pediatric patients, while others are more general and can be used with patients of any age (Marcin & Pollack, 2002).

In 1999, the American College of Surgeons Committee on Trauma declared that care for injured children “may be optimally provided in the environment of a children’s hospital with a demonstrated commitment to trauma care” (Junkins Jr, O'Connell, & Mann, 2006). Additional research has suggested that children with severe injuries should be sent to Pediatric Trauma Centers (PTCs) or, at minimum, be treated within a trauma center where a pediatric surgeon is present (Junkins Jr et al., 2006). The creation of Pediatric Trauma Centers within the last three decades was brought about in recognition of the fact that children have unique characteristics and that injured children may require specialized care (Petrosyan, Guner, Emami, & Ford, 2009). In the US, the number of PTCs has grown from 37 in 1997 to 65 in 2009. However, in 2009 only 10%

of all injured children in the US were treated in PTCs, up from 3% in 1997 (Petrosyan et al., 2009). It has been shown, that PTCs provide care to injured children that is superior to that of Adult Trauma Centers (ATCs) (Hulka, 1999). Advantages of PTCs include the provision of specialized pediatric services along with access to pediatric trauma research, institutional commitment to care of the injured child and family-centered care paradigm of pediatric health centres in general education. However, as PTCs are very scarce, decisions as to where best to transport pediatric patients can be quite challenging. This is even more complex in remote areas, where US figures show that approximately 40% -70 % of children die prior to arrival at a center capable of providing appropriate care (Acosta et al., 2010). In addition, in some locations the scarcity of PTCs makes it necessary to provide care to injured children at non-trauma centers or at adult trauma centres (Junkins Jr et al., 2006).

Where should pediatric patients be sent?

Several studies have analyzed health outcomes for pediatric patients treated in PTCs as compared with ATCs (Densmore, Lim, Oldham, & Guice, 2006; Keller & Vane, 1995; Petrosyan et al., 2009; Douglas A. Potoka et al., 2000). A summary of these studies, most of which were conducted in the United States, is provided below. To date, no comprehensive study on pediatric trauma systems has been completed in Canada, although studies on outcomes of specific injury patterns have shown marked advantages of PTCs over ATCs for the child sustaining major injuries (Macdonald & Yanchar,2012).

Densmore et al analyzed approximately 80,000 cases of pediatric trauma from 27 different American states and found that children treated in PTCs had significantly lower mortality rates than those treated in an ATC or in an ATC with a children’s unit. In addition, the length of stay was much higher for children treated in both regular ATCs and ATCs with children’s units, than it was for children treated in PTCs, even though the mean Injury Severity Score (ISS) scores of the injured children in the participating hospitals were not significantly different. As a result, the author concluded that severely injured children were much better off being treated in a PTC (Densmore et al., 2006). A search of the literature, failed to find studies that examined the relationship between spatial access to pediatric trauma centers and injury outcomes.

Although the studies outlined above show a distinct improvement in outcomes for pediatric patients treated at PTCs, an assessment of quality of care must include factors additional to survival rate. To this end, several studies have also examined the effect of choice of operative procedure (operative vs non operative) upon key pediatric injuries. This research has generally found a positive relationship between choice of treatment and survival rates, patient outcomes and even cost savings (in terms of length of stay in the hospital). The injury types highlighted below have been shown to have much better outcomes when treated at PTCs.

Abdominal injuries

More than 90% of all pediatric injuries are blunt abdominal trauma injuries with the most commonly injured organs being the spleen and liver (Petrosyan et al., 2009). In recent years the management of children with blunt abdominal trauma has changed significantly and several studies have reported differences in such management between PTCs and ATCs (Root et al., 2000). Historically, operative resection was felt to be the standard of care for injured spleens for concern of ongoing bleeding or delayed rupture. Non-operative management of blunt splenic injuries was first introduced in the 1970s at the Hospital for Sick Children in Toronto (Douglas & Simpson, 1971). Since then it has become widely used, as preserving the spleen is paramount in maintaining childrens' immunecompetence, with significant risk of postsplenectomy sepsis and increased septic morbidity after splenectomy (Petrosyan et al., 2009).

A study by Potoka et al. showed that spleen and liver injuries had much higher rates of survival when treated in PTCs rather than ATCs. The authors concluded that these differences in survival rates were the result of greater success with non-operative management in PTCs(Douglas A. Potoka et al., 2000). Several other studies have shown similar results. For example, a study by Macdonald and Yanchar found that splenic operations were performed on only 2.3% of children treated in PTCs as compared to 11.7% of children treated in ATCs (Macdonald & Yanchar,2012).

Head and neck injuries

Approximately 75% of injury related deaths in pediatric patients are a result of Traumatic Brain Injury (TBI), making it the most common cause of mortality in this population (Petrosyan et al., 2009). Although several studies have compared outcomes for children with TBI treated at PTCs as opposed to ATCs, the results have been inconclusive (J. R. Hall, Reyes, Meller, Loeff, & Dembek, 1996). Potoka et al demonstrated that children with TBI treated at a PTC or an ATC with a commitment to pediatric trauma care had a 21% mortality rate, while those treated at an exclusive ATC had a mortality rate of 31%. Neurosurgical procedures had mortality rates of 13.5% and 24% for PTCs and ATCs respectively. Some authors also theorize that children's outcomes may be better at PTCs due to the lack of social support ATCs provide to this subset of the population (J. R. Hall et al., 1996; Peters et al., 2000; Petrosyan et al., 2009; Douglas A. Potoka et al., 2000).

1.6. Dissertation Structure

The dissertation will be made up of nine chapters. The introductory chapter will provide the reader with an overview of the field of pediatric injury while describing the objectives of the dissertation, the issues affecting pediatric injury within Canada and the ways in which the dissertation will attempt to address them. The next seven chapters will comprise the body of the dissertation. Consisting of four individual papers (chapters 2, 4, 6, and 8), each to be published independently, these chapters collectively aim to answer the research questions outlined in section 1.2.1 above. The final chapter will conclude the dissertation by summarizing and discussing the results of the four papers.

Appended below is an outline of the four papers that will make up the body of the dissertation. Each outline indicates the purpose of the paper, and provides an overview of the data and methodology to be used.

The first of the four papers is included within Chapter 2. Divided into two parts, the first part of this chapter examines spatial accessibility to pediatric trauma centres across Canada and provides a quantitative analysis of the level of trauma centre accessibility in each province. The second part of this chapter focuses on two Canadian provinces, British Columbia and Nova Scotia, and examines the impact of spatial access on injury outcomes within those locations. This is the first study to examine the impact of geography on access to pediatric trauma care within Canada and provides a detailed explanation of the use of GIS in assessing spatial accessibility to pediatric trauma centres.

Chapter 4 examines the relationship between pediatric traumatic brain injury (TBI) and socioeconomic status (SES) within Greater Vancouver. Using spatial analysis, areas with high rates of injury were first identified and mapped. Census data were then used to determine the characteristics of the population residing in those hotspots. As the final step in the process, the injuries were further examined to determine whether the causes were unique to the hotspot populations. The resulting map provides a clear overview of the hotspots for pediatric TBI and highlights clusters of injury by cause.

Chapter 6 describes a study that took place within the Negev region of Southern Israel. This study incorporates methodologies used in the previously described papers to examine the relationship between spatial access to Soroka Pediatric Hospital and patient outcomes (reflected by length of stay in hospital). This study also included a temporal analysis intended to assess the impact of seasons on access. Additionally, the study examined differences in rates and causes of pediatric injury between the two dominant populations within the region (Jewish and Bedouin). As this is the first time that pediatric injury has been analyzed in this way, this paper also hypothesizes as to why such discrepancies exist within these populations.

The final paper, included within Chapter 8, examines the error propagated by using place of residence as a proxy for place of injury in injury research. This paper uses a large TBI dataset that includes locations for both place of injury and place residence at the postal code level. Using both types of locational data, the paper aims to provide researchers with insight into how locational error impacts the results of both accessibility studies and hotspot identification. The chapter’s conclusion also recommends methods to minimize such errors.

Chapter 2.

Assessing Access to Pediatric Trauma Centers in Canada and the Impact of the Golden Hour on Injury Outcome

This paper will be submitted prior to the date of defense: Journal: Injury Prevention, Authors: Ofer Amram, Nadine Schuurman, Ian Pike, Michael Friger and Natalie L Yanchar

2.1. Abstract

INTRODUCTION:

Within Canadian pediatric populations, injuries are the leading cause of death and a leading cause of morbidity, with an annual monetary cost of $5.1 billion (SafeKidsCanada, 2006). Trauma systems have been established across North America to provide comprehensive injury care and to lead injury control efforts. However, not all populations have equal access to trauma care services. The objective of this study is to assess the impact of geographical access to Pediatric Trauma Centers (PTCs) on patient outcomes and to determine spatial access to PTCs in two regions of Canada.

METHOD(S):

Hospital administration datasets from British Columbia (BC) and the Nova Scotia (NS) trauma registry were used to assess the impact of spatial access on injury outcomes (Consolidation File (MSP Registration & Premium Billing). V2., 2011; Discharge Abstract Database (Hospital Separations). V2, 2011). To determine spatial access to PTCs across Canada, a list of level 1 and 2 PTCs was identified through direct communication with provincial representatives of the Trauma Association of Canada.

RESULTS:

In Nova Scotia, for injuries within 60 minutes of PTC, the median length of stay was 4 days, while for those outside of 60 minutes, this value increased to 7 days (Figure 2-1). In BC, this difference is smaller with a median stay of 3 days within 60 minutes and 5 days outside 60 minutes driving time of a PTC. Approximately 65% of the pediatric population resides within one hour of a PTC.

CONCLUSION:

This paper highlights differences in injury outcomes associated with variations in access. However, further investigation is needed to determine the influence of other factors on outcomes such as severity and type of injury, age and/or gender.

2.2. Introduction

Worldwide, there are more deaths from injury in the first four decades of a person's life than from any other cause (Hameed et al., 2010). By way of response, trauma systems have been established across North America to provide comprehensive injury care and to lead injury control efforts. Unfortunately, however, not all populations have equal access to trauma care services.

Pediatric Trauma Centers (PTCs) were developed in response to a recognition that children have unique characteristics and that injured children may require specialized care (Petrosyan et al., 2009). In 1999, the American College of Surgeons` Committee on Trauma declared that care for injured children "may be optimally provided in the environment of a children's hospital with a demonstrated commitment to trauma care" (Junkins Jr et al., 2006). Other research suggests that children with severe injuries should be sent to a PTC or, at minimum, be treated within a trauma center where a pediatric surgeon is present (Junkins Jr et al., 2006). In the US, the number of PTC's grew from 37 in 1997 to 65 in 2009. However, they are still very scarce when compared to adult trauma centers (ATCs). In fact, in 2009 only 10% of all injured children were treated in PTCs, up from 3% in 1997 (Junkins Jr et al., 2006; Petrosyan et al., 2009). It has been shown that the care provided to injured children by PTCs is better to that of adult trauma centers (Densmore et al., 2006; Douglas A Potoka, Schall, & Ford, 2001; Douglas A. Potoka et al., 2000).

In Canada, PTCs are defined as pediatric tertiary care facilities "with facility with a full array of medical specialties and ready access to advanced medical technology….Medical staff and hospital resources are dedicated and/or prioritized to the care of the major pediatric trauma patient ensuring rapid access to required care in a preplanned system of care" (Trauma Association of Canada, 2011). The advantages of PTCs include the provision of specialized pediatric services and rehabilitation in addition to access to pediatric trauma research, education, prevention strategies and commitment to family-centred care. In order to estimate the availability of trauma resources among the population, trauma studies typically use the widely accepted 'golden hour' concept (which suggests that survival rates improve when care is given within the first hour after sustaining major traumatic injury) (Hameed et al., 2010). Using the one hour driving time parameter, a US study estimated that close to 84% of US residents have access to trauma centers providing definitive care (Branas et al., 2005). A similar study in Canada, found that 77.5% of Canadians live within a one-hour drive of a trauma center (Hameed et al., 2010). This type of research can be focused to measure the accessibility of specific sub populations (e.g. children) in terms of access to specialized facilities like pediatric trauma centers. Such information will allow an estimation of the proportion of the population with poor accessibility to specialized trauma care, and will enable the introduction of prevention strategies intended to reduce injury rates in those locations.

The objective of this study is to examine the impact of geographical access to PTC's on patient outcomes in 2 Canadian settings and to determine spatial access to PTCs across Canada.

2.3. Methods

2.3.1. Injury Data

Hospital administration datasets from of British Columbia (BC) and the Nova Scotia (NS) trauma registry were used to assess the impact of spatial access on injury outcomes (Consolidation File (MSP Registration & Premium Billing). V2., 2011; Discharge Abstract Database (Hospital Separations). V2, 2011). These two Canadian provinces are situated at either extremes of Canada and have relatively mature trauma systems, Each has a single level I PTC which serves as the hub of the provincial pediatric trauma system (Evans, Tallon, Bridge, & Nathens, 2014; Simons et al., 2002). Each provincial dataset provided case-level data including the Injury Severity Score (ISS) (calculated using ICD10 codes), the patient's place of residence at the six-digit postal code level, gender, age, treatment hospital and length of hospital stay (used as a proxy measure of injury outcome). It also included details as to whether the patient was directly or indirectly (seen at another hospital firs and then transferred) admitted to the PTC and geographic location of the PTCs, ATCs and non-trauma hospitals for each province.

To determine spatial access to PTCs across Canada, we first identified a list of level 1 and 2 PTCs from across the country through direct communication with provincial representatives of the Trauma Association of Canada. Population counts for each dissemination area (DA) were obtained from the 2006 Canadian census conducted by Statistics Canada (C. Canada, 2006). Population variables (namely, the number of residents ages 0-15) were taken from the census at the dissemination area (DA) level. Each DA is typically composed of neighboring streets that host somewhere between 400 and 700 residents. Because of differences in population density across different communities, DA-level data is highly accurate in urban areas but is less accurate in more rural settings.

2.3.2. Driving Time Calculation and Population Estimation

All location data (including patient place of residence and location of PTC's across Canada) was geo-coded using DMTI GeoPinPoint (Spatial, 2011a). For the injury data sets, driving time between the patient's place of residence and the hospital was calculated using the network analyst function in ArcGIS. The driving time variable for each injury incident was then added to the data set.

Also using the ArcGIS network analyst, a one hour driving time catchment was created around each PTC in order to estimate accessibility. Estimation of the population count (for patients aged 0 – 19) both inside and outside of the one hour driving time catchment were established by joining the population weighted centroid of each DA within 2500m of a road segment. Network Analyst allows for relatively accurate estimations of travel time as it provides turn-by-turn calculations while taking into account road speed limits. A more detailed explanation of this methodology can be found in previous publications (Cinnamon, Schuurman, & Crooks, 2008; Schuurman, Crooks, & Amram, 2010). The DMTI road data set was used to supply the road network data. This data provides uniform coverage across the Canada and is suitable for use with Network Analyst.

2.3.3. Analysis

In order to examine whether a relationship existed between access to PTC and injury outcome, all injured patients treated at a PTC in either BC or NS were selected. The average length of stay at the PTC was then determined for all injured patients who live within and outside of 60 minutes driving time of the PTC. Separate but identical analyses were conducted for the two provinces.

2.4. Results

2.4.1. Spatial access and length of stay at the hospital

Nova Scotia

There were 347 moderate to severe (ISS ≥ 12) injuries in Nova Scotia between the years 2001-2010. Eighty-five per cent of these were treated at the IWK Health Centre, the only level I PTC in the province. The remainder t were treated in other hospitals across the province, none of which are strictly pediatric. Of the injuries treated at IWK, almost 100% of those within a 60 minute drive of the hospital were directly admitted; of those more than 60 minutes away, 84% were directly admitted. For those within 60 minutes of IWK, the median length of stay was 4 days, while for those outside of 60 minutes, this value increased to 7 days (Figure 2-1). An independent-samples t-test was conducted to compare length of stay at the hospital for those within 60 minutes and outside 60 minutes and a significance different was found ($p = 0.01$). Gap in length of stay clearly increased as the severity of the injury increased (Table 2-1).

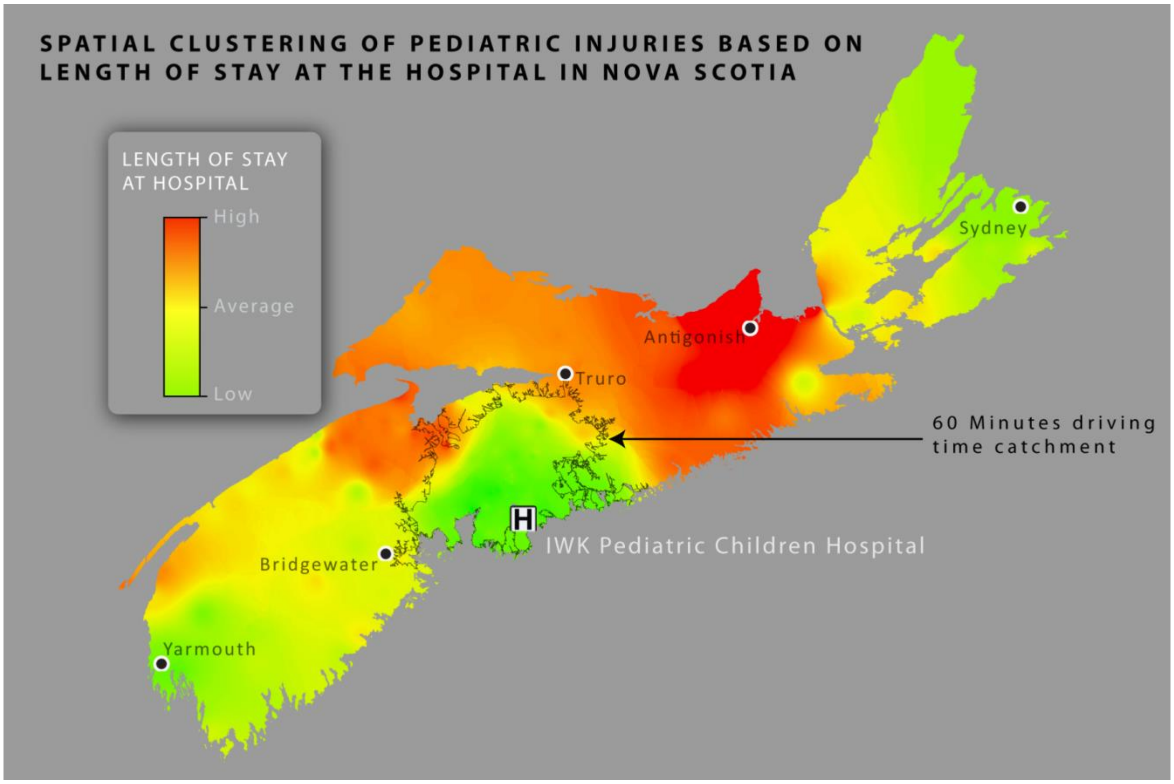

Figure 2-1 Map of length of stay at the hospital in Nova Scotia
Length of hospital stays for pediatric trauma patients at the level I PTC in Nova Scotia. A clustering of injuries resulting in relatively short hospital stays can be seen within the 60 minutes driving time catchment of the IWK Health Centre.

Table 2-1 Length of stay in relation to ISS in Nova Scotia

Average and median lengths of stay in hospital increase as the injury is more severe.

	Average Length of Stay at hospital(days)		Median Length of Stay at hospital(days)	
ISS Group	Inside60Minute	Outside60Minute	Inside60Minute	Outside60Minute
12_15	5.1	6.3	4	6
16_24	5.6	11.7	3	6
25_75	15.5	21.9	8	12.5
12_75	8.8	14.6	4	7

British Columbia

There were 1710 moderate to severe (ISS ≥ 12) pediatric injuries in British Columbia between the years 2001-2010. Almost 40% (683) were treated at BC Children's Hospital, the province's Level I PTC, while the remainder were treated at other non PTCs across the province. For injuries treated at BC Children's Hospital, 47% of patients living within 60 minutes driving time of the hospital were directly admitted to the hospital, while for those outside 60 minutes this dropped to 18%. The median length of stay at the PTC was 3 days for patients within 60 minutes driving time and 5 days for those outside this 60 minute catchment (Figure 2-2). Unlike Nova Scotia, the length of stay did not change as the injuries become more severe (Table 2-2) and the independent-samples t-test was not significant (P=0.083).

Table 2-2 Length of stay in relation to ISS in British Columbia

Average and median lengths of stay at the level I PTC both increase as the injury is more severe. The low number of patients with moderate injuries (ISS 1-15) indicates that most of the injuries arriving at BC Children's Hospital outside 60 minutes are probably those injuries that require specialized care that can only be provided by a level I PTC. Those also represent the injuries that have higher than average stay at the hospital

	Average Length of Stay in hospital(days)		Median Length of Stay in hospital(days)		
ISS Group	Inside60Minute	Outside60Minute	Inside60Minute	Outside60Minute	n
12_15	3	14	3	7	45
16_24	5	6.5	3	4	333
25_75	10	10.5	5	6	304
12_75	7	8.8	3	5	682

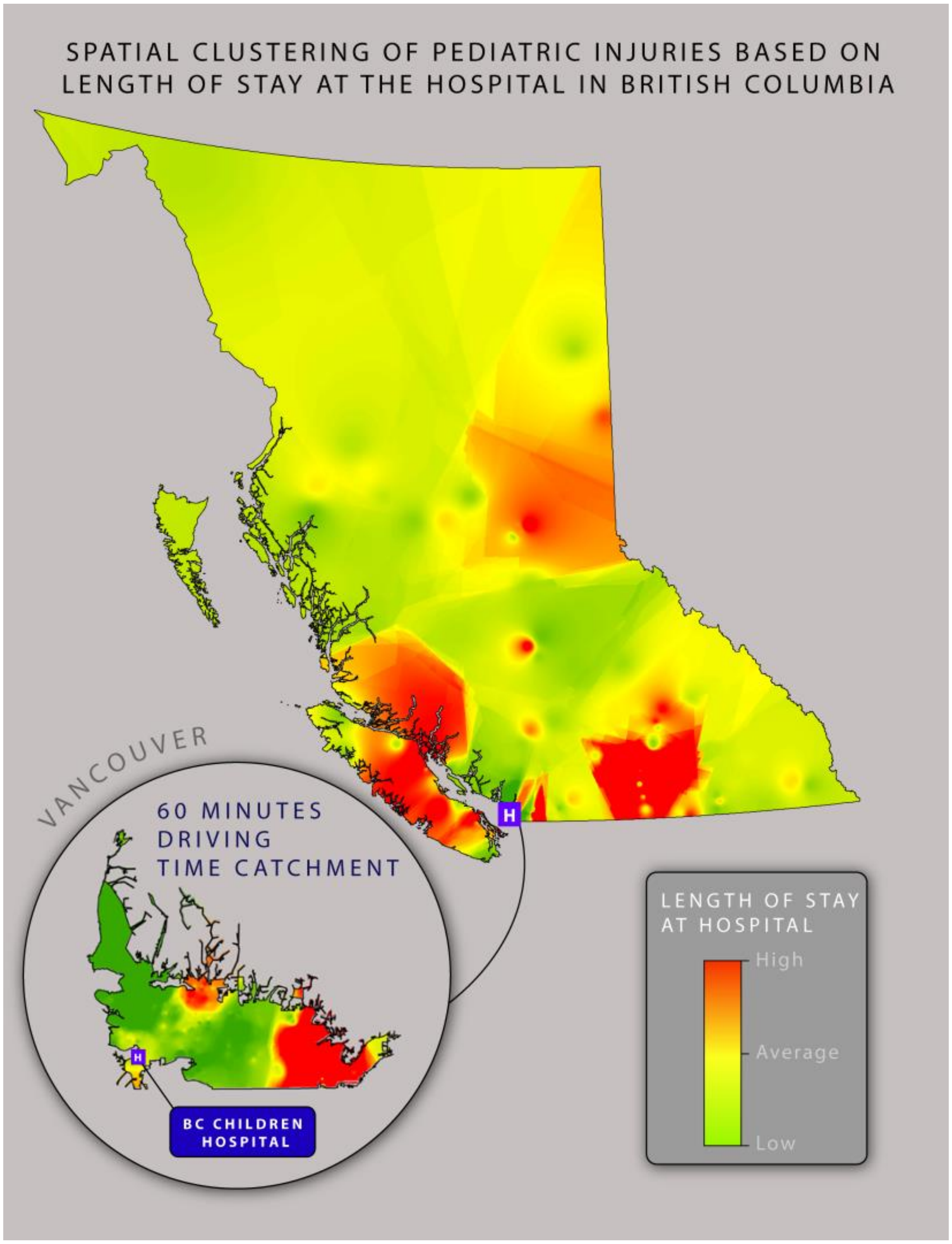

Figure 2-2 Map of length of stay at the hospital in BC

Shows variation in length of hospital stays for pediatric trauma patients in British Columbia. As demonstrated, there is no clear clustering of shorter hospital stays within the 60 minute catchment for BC Children's Hospital. There is also no clear pattern across the province as a whole.

2.4.2. Access to Pediatric Trauma Centers in Canada

There are thirteen level 1 or 2 Pediatric Trauma Centres (PTCs) in Canada. With the exception of Saskatchewan, New Brunswick and PEI, all Canadian provinces have at least one PTC. Although Saskatoon has a trauma hospital with pediatric consultation, this hospital was not counted as a PTC in this analysis. Ontario has four dedicated PTCs while BC, Newfoundland, Manitoba and Nova Scotia each have one.

According to the 2006 census, there are approximately 7,692,835 children between the ages 0-19 in Canada. Approximately 65% of this population resides within one hour of a PTC. The province of Ontario, where just over 75% of the children reside within one hour of a PTC, has the highest PTC accessibility within Canada (Figure2-3). New Brunswick, Saskatchewan, PEI and the territories do not have PTCs and as a result has very low accessibility level, with almost the entire population more than an hour away.

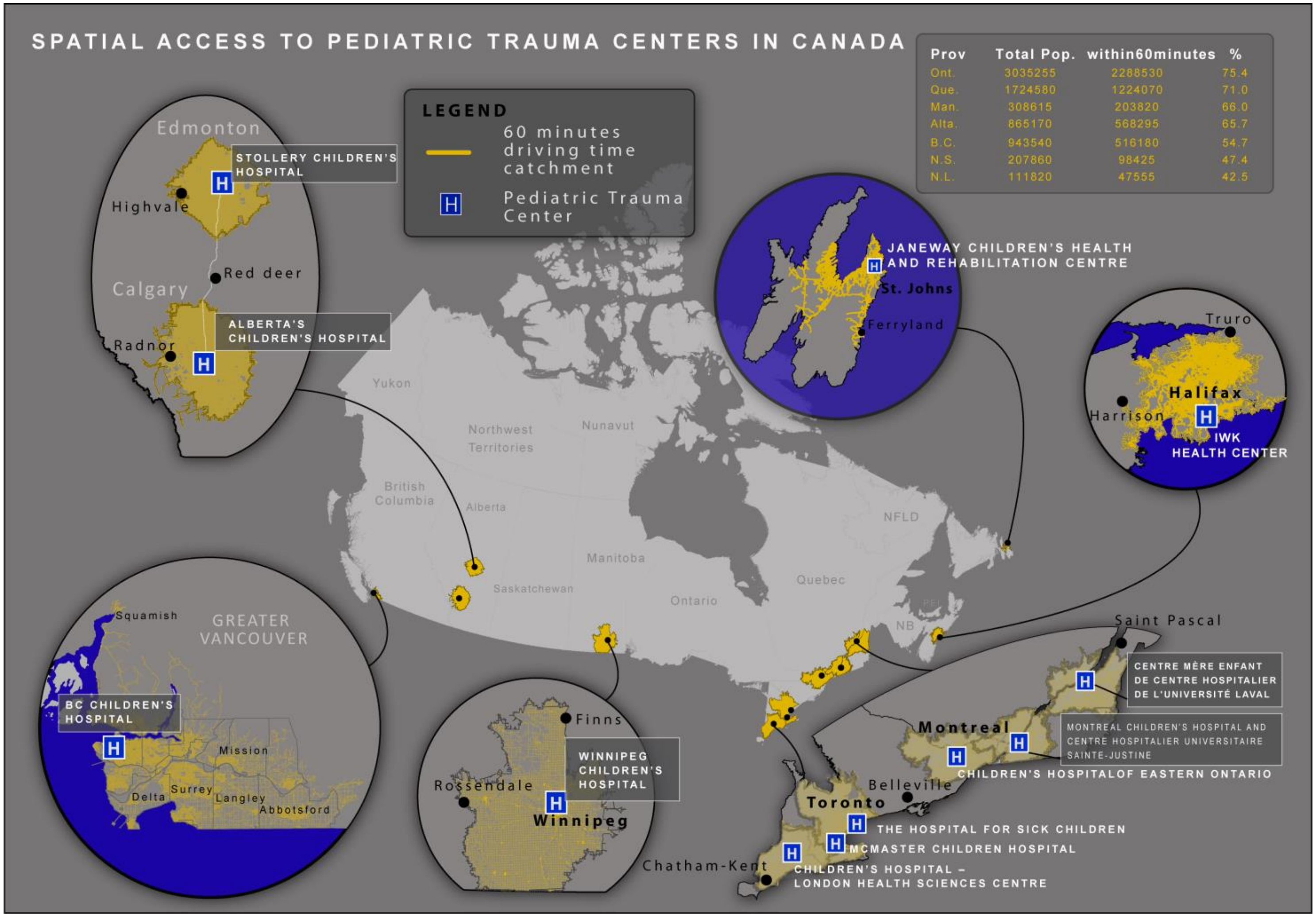

Figure 2-3 Map of access to pediatric Trauma Centers in Canada
Showing 60 minute driving time catchment around PTC's across Canada and the proportion of children aged 0-19 within one hour of a pediatric trauma center.

2.5. Discussion

This paper highlights the importance of timely access to PTCs by demonstrating the relationship between PTC proximity and injury outcomes (defined as length of stay at the hospital). Using the concept of the 'golden hour', the paper also assesses spatial access of Canadian pediatric populations to PTCs. Several studies have highlighted the importance of PTCs in caring for injured children. For example Densmore et al analyzed approximately 80000 cases of pediatric trauma from 27 states in the US and found that children who were treated in PTCs had significantly lower mortality rates than those treated in ATCs or in ATCs with commitment to pediatric care. In addition, they found the length of hospital stay to be much higher in ATCs and ATCs with children's units, concluding that severely injured children were much better off being treated in a PTC (Densmore et al., 2006). Similar results were obtained in the analysis of 13351 patients treated at accredited trauma centers in the state of Pennsylvania. This study found that children who were treated at PTC or an ATC with a demonstrated commitment to care of children had a much better chance of survival than those treated at Trauma centres without any pediatric-specific expertise, especially those with an ISS of greater than 15. The use of more appropriate procedures (operative vs non-operative) may be one of important factors resulting in better outcomes of pediatric trauma patients in PTCs, and has been clearly shown to be related to better survival rates, better outcomes and even cost savings, in terms of length of hospital stay (Nakayama, Copes, & Sacco, 1992; Douglas A Potoka et al., 2001). Similarly, children with a traumatic bbrain Injury (TBI), the most common cause of mortality amongst pediatric trauma patients, , have been found to have significantly lower mortality and higher functional outcome rates when treated at a PTC or an ATC with pediatric-specific expertise than those treated at an ATC .

Timely access to trauma care is a critical component of better health outcomes for children. This has been shown in a number of studies where both morbidity and mortality were higher in rural areas with restricted access to PTCs (Ehrlich, Ortega, & Mucha, 2001; Nakayama et al., 1992; Douglas A Potoka et al., 2001). The results from our study also showed, at least in Nova Scotia, clear distinction in injury outcomes in terms of length of hospital stay for those at greater distances from the PTC at which they were treated (more versus less than one hour). This is not surprising, as trauma centers are better equipped to deal with moderate to severely injured patients. Such centers typically have surgeons on call on a continuous basis as well as trauma teams trained to deal with severe injuries (J. S. P. Sampalis et al., 1997). However, in a country like Canada it is difficult to provide timely trauma centre access to the entire population. This is evident by the country-wide disparities described by Hameed et al, in their study of trauma care access within Canada (Hameed et al., 2010). As PTCs are more specialized than ATCs, very few exist across Canada. As a result, there are even more disparities related to PTC access within this country.

In order to address timely access to care, regional trauma systems are established such that Level 1 and 2 trauma centres rely upon smaller non–trauma hospitals to provide intermediate care (Utter et al., 2006). The use of non-trauma hospitals for the provision of intermediate care prior to transfer to a trauma center is essential to the care of severely injured patients geographically distant from a trauma centre. This is especially the case in large geographical areas where populations are widely dispersed. For example, when comparing BC to Nova Scotia, we see a higher percentage of BC's pediatric population within 60 minutes driving time (54.7% to 47.4% respectively) of a PTC. On the contrary, however, the population outside the 60 minute catchment resides in a vastly larger geographical area, so that even transport by air can be significantly long.. Access to a PTC within these remote areas is also complicated by the presence of island communities. In remote situations like this, smaller hospitals can play a pivotal role in providing access to care. The result of driving time vs. length of stay at the hospital for BC clearly shows that this is the case. In BC, of the injuries occurring outside 60 minutes, 82% were first admitted to a non PTC while in Nova Scotia this figure stands at only 14%. However,

The objective of this paper is to provide an overview of spatial access to PTCs across Canada and to determine a relationship between distance to a PTC and outcome based on length of hospital stay. The literature is almost always clear regarding where best to send seriously injured children if a choice is possible, with the vast majorities of studies indicating that it is often worthwhile to obtain treatment directly from a PTC, even when located further away (Nirula et al., 2010; Wang, Chan, Mahlow, &

Wise, 2007). However, the question of whether outcomes beyond length of stay (eg mortality, functional, psychosocial) vary those with injuries occurring outside the one hour catchment of a PTC is something that needs to be investigated in future studies. .

2.5.1. Study Limitations

This study has a few limitations that need to be acknowledged. First, the location information for each injury recorded in the injury data sets is described by place of residence rather than place of injury. Unfortunately, place of injury data is not consistently captured in the BC and NS trauma registry data. Although this issue is unavoidable, it may introduce some error within the driving time calculation. That said, several studies have shown that most injuries do occur between 5 -10 miles from home (Boyle, 2007; Palmer, Jones, Jones, Polacarz, & Evans, 2005). Additionally, for the BC data set, information regarding the mode of transportation used to travel to the hospital was not provided and it is possible that those patients from very remote distances may have actually reached definitive pediatric trauma care if transported by air faster than those from lesser distances transported by ground. As this may provide some errors, they would be small as only 7% of transports are done using fixed wing or helicopter (Schuurman, Bell, Hameed, & Simons, 2008). Additionally, most of those injuries will not affect this analysis as they can be easily identified as they will be transported directly to BC Children's Hospital from generally remote areas and islands which are not accessible by roads.

Another limitation is the use of length of hospital stay as a proxy for injury outcome as it is not a patient-focused metric. Measuring injury outcomes can be a difficult and complex process in that it often requires risk adjustment as well as patient interviews and/or follow up over a lengthy period of time in order to record elements like visits to health facilities, rehabilitation length and the ability to function in society (Brooks, 1991; Stilwell, Stilwell, Hawley, & Davies, 1998). Given the relatively large data set used in this study, and the lengthy period of time (9 years) over which it was collected, it was not feasible to collect this type of information. That said, we believe that length of hospital stay provided an appropriate proxy measure of outcomes within the scope of this research.

Finally, the driving time calculation utilized does not incorporate traffic information. Therefore, the calculation underestimates driving time within urban areas, especially during times of heavy traffic congestion. However, this error will be consistent across all heavily populated areas, which is where PTCs are typically found.

Chapter 3.

Linking Chapter – Spatial vs Socioeconomic Vulnerability

The previous chapter examined access to pediatric trauma centres within Canada from a geographical perspective. As demonstrated within this chapter, children from rural areas are likely to spend longer in hospital than their urban counterparts, reflecting possible poorer outcome for rural dwellers with similarly severity ofinjuries.

The following chapter will examine the relationship between pediatric injuries and socioeconomic status. More particularly, the chapter will focus on traumatic brain injuries (TBI) within pediatric populations, as these are the most severe type of injuries. The intent of both chapters is to identify populations particularly vulnerable to injury. In the previous chapter, the vulnerability was geographical in nature and resulted from reduced access to pediatric trauma centres. In the following chapter, the vulnerability is shown to be linked to socioeconomic status amongst the pediatric TBI population. In addition to identifying the population experiencing the highest rates of TBI, the following chapter also attempts to identify the characteristics that may increase the risk of this population to be more vulnerable to injury.

The findings from both the previous and the following chapters provide unique and valuable insight into the pediatric populations most vulnerable to injury. These findings will enable prevention and trauma management strategies to be targeted more directly to the affected populations.

Chapter 4.
Socio Economic Status and Pediatric Trauma Brain Injury: a spatial analysis in Greater Vancouver

This paper will be submitted prior to the date of defense: Journal: "BMC Public Health", Authors: Ofer Amram, Nadine Schuurman, Ian Pike, Natalie L Yanchar, Michael Friger and Donald Griesdale

4.1. Abstract

INTRODUCTION:

Within Canada, injuries are the leading cause of death amongst children fourteen years of age and younger and also one of the leading causes of morbidity. Low Socio Economic Status (SES) seems to be a strong indicator of a higher prevalence of injuries. The following study aims to identify hotspots for pediatric TBI and to examine the relationship between SES and pediatric TBI rates in Greater Vancouver, British Columbia (BC), Canada.

METHOD(S):

Pediatric Traumatic Brain Injury (TBI) data from the BC Trauma Registry (BCTR) was used to identify all pediatric TBI patients admitted to BC hospitals between the years 2000 and 2013. Spatial analysis was used to identify hotspots for pediatric TBI. Multivariate analysis was used to distinguish census variables that were correlated with rates of injury.

RESULTS:

Six hundred and fifty three severe pediatric TBI injuries occurred within the BC Lower Mainland between 2000 and 2013. High rates of injury are concentrated in the East, while low rate clusters were most common in the West of the region (more affluent neighborhoods). Low level of education is the main predictor for high rate of injury.

CONCLUSION:

While there is a clear relationship between different SES indicators and pediatric TBI rates in Greater Vancouver, income based indicators do not serve as good predictors within this region.

4.2. Introduction

Within Canada, injuries are the leading cause of death amongst children fourteen years of age and younger and also one of the leading causes of morbidity. Over the last five decades, Canada, like many other western countries, has seen a 50% decline in childhood injuries (Birken et al., 2006); however, low socio economic status (SES) seems to be a strong indicator of a higher prevalence of injuries among children(Catherine S Birken, 2004; Faelker et al., 2000; Simpson et al., 2005). Despite the fact that though the absolute number of injuries has declined across the SES spectrum in recent years, emerging research shows a widening in the gap between rich and poor in terms of injury prevalence (Birken et al., 2006).

Injuries are unique in that they are always externally caused. As a result, they are directly influenced by the physical and social environments (Potter et al., 2005). Physical and social environments can influence the injury rates in a variety of ways. For example, children with low SES typically live in older, less well-maintained homes and may, as a consequence, face a greater risk of exposure to lead poisoning and house fires. Epidemiological studies examining the relationship between SES and injury rates typically use various measures of SES. The most common are income, employment, level of education, housing, and demographics. SES variables can also be combined by creating a deprivation index (Cubbin & Smith, 2002a).

Traumatic Brain Injuries (TBI) are the most common cause of mortality amongst pediatric patients, causing approximately 75% of the injury-related deaths (Keenan & Bratton, 2006). Patients recovering from TBI are also likely to have some type of long term disability. In fact, approximately 50% suffer from cognitive, emotional or behavioural problems (Selassie et al., 2008). The financial cost of recovery from TBI is enormous and is estimated, in Canada, at $93,000 in the first year alone (Griesdale et al., 2015). The high cost of recovery, coupled with the higher incidence of TBI amongst children and families with low socio economic status (SES), causes TBI to have a greater impact on this population (Hawley, Ward, Magnay, & Long, 2003; Yeates et al., 2004).

The study reported here identified hotspots for pediatric TBI and examined the relationship between SES and pediatric TBI rates in greater Vancouver, British Columbia (BC), Canada. More specifically, the study sought to identify those census variables most closely associated with high rates of pediatric TBI.

4.3. Methods

4.3.1. Data

Pediatric Traumatic Brain Injury (TBI) data from the BC Trauma Registry (BCTR) was used to identify all pediatric TBI patients admitted to BC hospitals between the years 2000 and 2013. The primary variables within the data included patient place of residence, age, gender, injury mechanism, intent and injury severity score (ISS). All patients with an ISS of 12 and over were included in the data as such injuries are severe enough to warrant admission to hospital. All locations were geocoded using DMTI geopinpoint (Spatial, 2011a). The study area encompassed the greater Vancouver region between West Vancouver and Hope (Figure 4 - 1)

Population variables (namely, the number of children aged 0 -18), at the dissemination area (DA) level were taken from the 2006 Canadian census gathered by Statistics Canada. The number of injuries within each DA was calculated using a spatial join and a crude injury rate was calculated for each DA using the population of children aged 0-18 as the denominator.

Census data at the DA level was also used to examine the relationship between SES and injury rate. Each DA is generally composed of neighbouring streets that host somewhere between 400 and 700 residents (StatsCanada, 2011). SES census variables that were used as potential predictors for injury rate included: percent of population 15 and over with no high school diploma, median Income and average income (both of which were divided into 10 incremental groups beginning with 0-10,000 and continuing up to 90,000 – 100,000. A separate value was used for those with income over 100,000), percent aboriginal within the population, unemployment rate, and the percent of no detached housing (table2). All potential census variables were chosen based on the systematic review by Bell et al. which examined the most common SES census variables used in injury research (Bell, Arrington, & Adams, 2015). As a separate analysis, a popular composite SES index (the VANDIX) was used to examine the relationship between pediatric TBI rate and SES. The VANDIX is composed of seven variables taken from the 2006 census and used to construct a deprivation index at the DA level. It has been shown to be a good predictor in the assessment of SES and health status (Schuurman, Bell, Dunn, & Oliver, 2007). It provides a deprivation score from 1-5, with 1 being low and 5 being high.

Geographic variables

Two additional variables were created for use as potential predictors in both models. These included a 30 minute driving time catchment around BC Childrens Hospital and a 1000m buffer zone around each population weighted DA centroid. The 30 minute driving time catchment was calculated using the ArcGIS network analyst function and the DMTI Route Logistics dataset. As BC Childrens Hospital is located at the center of the city of Vancouver (ESRI, 2013; Spatial, 2011b), all DA's within 30 minutes of the hospital were considered urban and all DA's more than 30 minutes away were considered suburban. Additionally, a buffer of 1000m was created around each population weighted DA and the sum of the length of roads within each buffer was calculated. This variable was created with the intention of providing an additional potential measure of urban vs. suburban as well as to provide a measure of traffic density around the population centers within each DA.

4.3.2. Hotspot Identification

In order to examine the degree of global spatial autocorrelation within the data, the ArcGIS Global Moran I tool was used. Because the DA's were relatively small in size, we utilized a spatial rate smoother (Kafadar, 1996), as implemented in OpenGeoDa version 1.0.1 (Anselin, Syabri, & Kho, 2006), to adjust the crude injury rates. The spatial rate smoother uses rates from neighboring DA's for smoothing. A Local Moran I tool was used to determine local clusters and was then implemented on the smoothed surface. It is important to note that smoothing was used for visualization purposes only.

4.3.3. Statistical Analysis

Using SPSS statistical software(IBM, 2013), negative binomial (NB) models were created to assess the relationship between SES and injury rate. The first, examined how both individual census variables and geographic variables correlated with injury rate. The second, used the VANDIX composite SES variables together with the geographic variables to assess the same relationship. A NB model was used because the outcome variable had a Poisson distribution (many DA's had a zero count of injuries) with over dispersion (the variance does not equal the mean) and NB models allow for this where Poisson models do not (Gardner, Mulvey, & Shaw, 1995). In the first model, variable selection was implemented by first examining the relationship between each individual census variable and injury rate (count /log(total kids age 0-18)). Only variables with a significant relationship at $p<0.2$ were kept and included as potential variables in the final model. In the final model, only variables with a significant correlation of $p<0.05$ were kept. The second model, simply examined the relationship between injury rate, as the dependent variable, and the VANDIX and geographic variables, as the independent variables. The VANDIX score was also used to explore differences in injury mechanism between the deprived and the less deprived populations. The model residuals were examined in order to assess whether spatial dependency affected the results.

4.4. Results

4.4.1. Descriptive Analysis

Six hundred and fifty three severe pediatric TBI injuries occurred within the BC Lower Mainland between 2000 and 2013. Of these, 27.8% (182) were sustained by girls and the remainder by boys. The largest gender-related difference in injury prevalence is between the ages of 10 and 14 (Figure 4 - 1). In terms of injury severity, almost 52% of all TBI injuries are very severe (ISS 25 and up) with the rest classified as moderately severe. The median ISS were almost identical for boys and girl at the different age groups, except for age group 5-9 where the median ISS is 25 for boys compared with 20 for girls. The majority of injuries occurred within the oldest age group (38%,N=238), with the next highest number within the youngest age group (25%, N=162). In this study, TBIs were most commonly caused by motor vehicle collision (MVC) at 54%, followed by falls at 26% and assault at 10%. As expected, there is a clear downward trend in injuries from falls as children get older, with falls being the primary cause of injury within the youngest age group (62%) and the least significant cause of injury within the oldest age group (7%). MVC are the number one cause of TBIs for children in age groups 5-9, 10-14 and 15 -18 (62%, 71% and 65% respectively) but is responsible for only 17% of the injuries within the youngest age group. Intentional injuries (like assaults) are most prevalent in the oldest age group (23%) followed by the youngest age group (7%). Overall, 12% of the injuries were intentional (Table4-1).

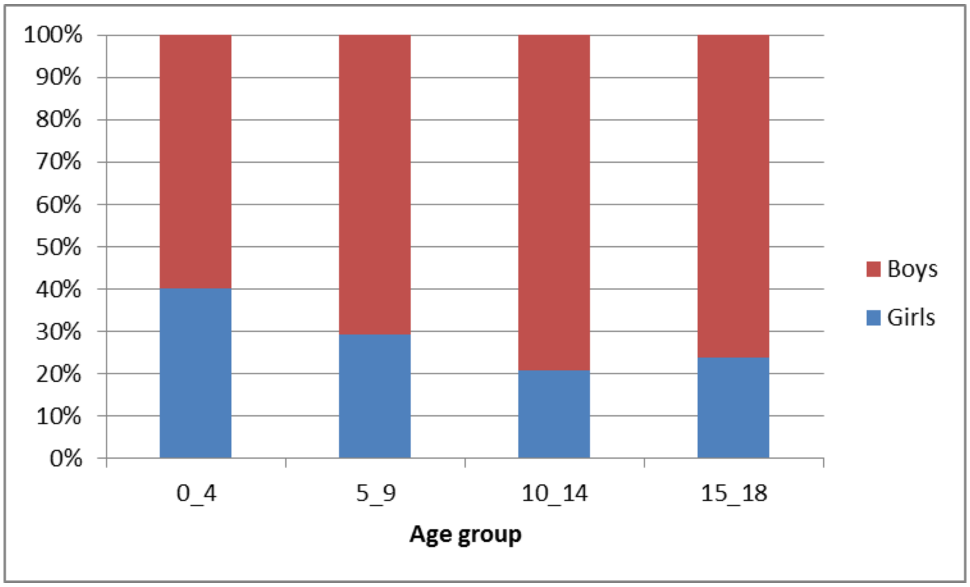

Figure 4-1 TBI by Gender and age group

Shows the distribution of TBI by gender. Boys experience the highest rates of injury at all age ranges, but this difference is most pronounced between the ages of 10 and 14.

Table 4-1 TBI mechanism by age group

Showing pediatric TBI by age group, gender, injury mechanism and intent. Injuries from fall are the major cause of injuries in age 0-4. Intentional injuries and injuries from assault are the number one cause of injuries in age 15-18.

	AGE GROUP				
Median ISS	**0-4**	**5-9**	**10-14**	**15-18**	**ALL**
Female	17	**20**	26	26	25
Male	17	25	25	26	25
Injury Mechanism					
Assault	0.09	0.00	0.03	0.19	0.10
Fall	**0.62**	0.30	0.15	0.07	0.26

MVC	0.17	0.62	**0.71**	0.65	0.54
Other	0.12	0.08	0.11	0.09	0.10
Motivation					
Intentional	0.07	0.01	0.06	0.23	0.12
Unintentional	0.87	0.99	0.92	0.75	0.85
Unknown	0.06	0.00	0.02	0.02	0.02
Total Count	**162**	**92**	**151**	**248**	**653.00**

4.4.2. Hotspot Analysis

The Global Moran I indicates that the data is moderately clustered (P value 0.076) over the study area. After applying spatial smoothing in order to highlight global spatial trends over the study area, clustering of high and low rates of injury are clearly apparent (Figure 4-2). High rate clusters are identified across the eastern part of the Lower Mainland around Mission and the Fraser Valley. Additionally, high clusters can be seen in areas of Coquitlam, Surrey and on the North Shore. Low rate clusters of TBI are visible on the West side of Vancouver, as well as in Richmond and Tsawwassen.

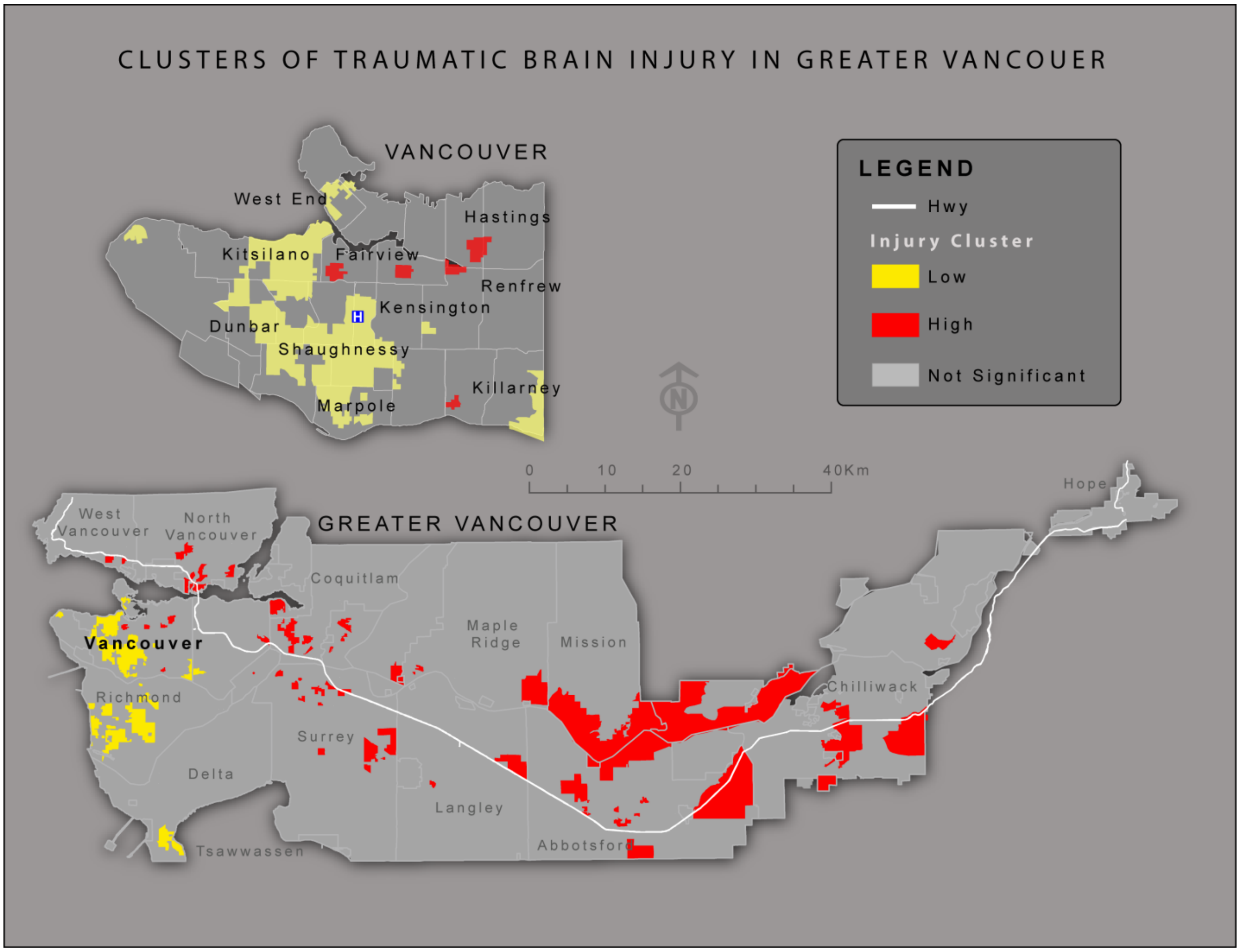

Figure 4-2 TBI clusters

Map showing TBI clusters of high and low significance within greater Vancouver. High rate clusters tend to be concentrated to the east, while low rate clusters are most common in the west of the region. This pattern directly corresponds to SES values for the areas: the west side of Vancouver has consistently higher SES values as illustrated.

4.4.3. Statistical Analysis

Individual census variables

The negative binomial (NB) regression for each individual independent variable showed a value of P<0.2 for the following: average income, proportion aboriginal, proportion with no high school diploma, DA within 30minutes of BC Childrens

Hospital(rural v. suburban) and the sum of roads within each 1KM DA buffer. As a result, only these variables were used as potential variables in the final NB model.

After trying several combinations of variables and comparing their AIC value, the final model for included only two variables: proportion of people with no high school diploma and whether a DA was within 30 minutes of BC Childrens Hospital (Table 4-2). The other three variables were excluded as they were no longer significant (at $P<0.05$) when combined with other variables. The final model results indicated that for each 10% increase in the proportion of people with no high school diploma the rate of injury increased by 13%. Additionally, children who lived in an areas more than 30 minutes (driving time) from BC Childrens Hospital had a 21% greater chance of being injured (Table 4-3).

Composite SES model

The VANDIX composite SES variable was also highly correlated with injury rate when examined both individually and together with the geographic variable (within a 30 minute drive of the hospital). The final model indicated that for every increase in the VANDIX deprivation score (from 1-5) the rate of injury increased by 8% (Table 4-4).

An assessment of both model residuals, in terms of spatial autocorrelation, indicated that a spatial dependency did not exist ($p>0.05$). This indicates that there is no need to modify the model to address this issue.

Table 4-2 Variables considered for the final model

List of variables considered for the final model. Only variables with P-Value of 0.2 and under were used as potential variables in the final model.

Name	Description	P-Value	Group	Pass Criteria for final model
PercAboriginal	Percentage of Aboriginal	0.02	Cultural	Yes
PercLonFamily	Percentage of Lone Families	0.60	Demographic	No
PercNoHSchl	Percentage of age 15 and older with no high school certificate	0.00	Education	Yes
AllRdBfr	Sum of length of roads within 1000m	0.00	Environmental	Yes
PercNoDetHous	Percentage of no Detached Housing	0.35	Housing	No
AvgInc	Average income	0.10	Income	Yes
MedInc	Median Income	0.41	Income	No
UnEmpRate	Unemployment rate	0.88	Occupation	No
Within30min	Within30 minutes of BC Children Hospital	0.01	Rural/Suburban	Yes
VANDIX	Composite SES Index	0.00	Composite Index	Yes

Table 4-3 Multivariate model with census variables

Showing the final negative binomial model for the census variables. The Exp(B) indicate that For each 10% increase in the proportion of people with no high school diploma the rate of injury increased by 13%. Additionally, children who lived in an areas more than 30 minutes (driving time) from BC Childrens Hospital (Children living in suburban areas) had a 21% greater chance of being injured.

Parameter	Sig.	Exp(B)	Lower	Upper
(Intercept)	0	0.001	0.001	0.001
NoHiSchool	0.009	1.013	1.003	1.022
[Within30=0]	0.039	1.224	1.01	1.483
[Within30=1]		1		

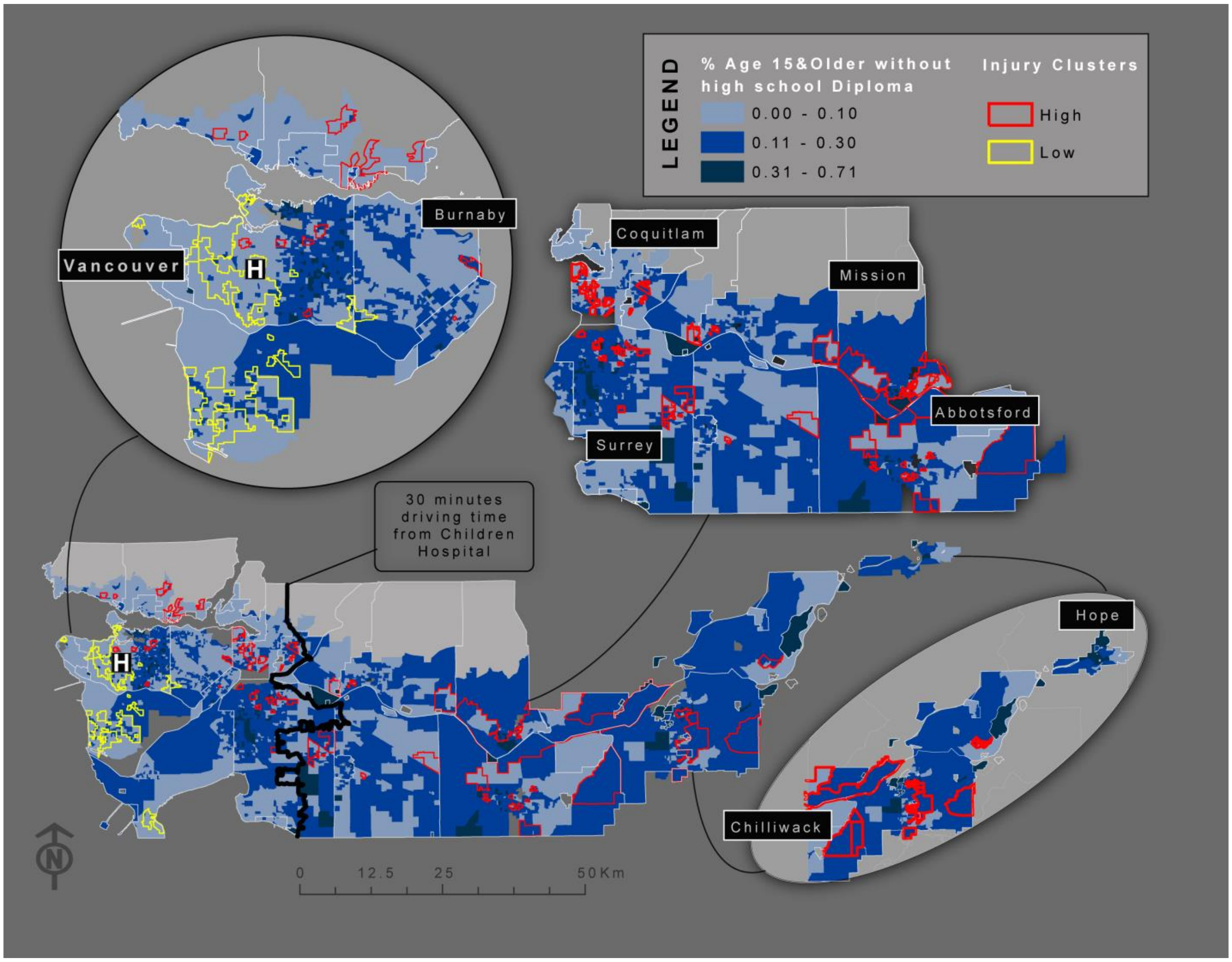

Figure 4-3 Clusters of injury at the DA level

DA level map showing high (red) and low (yellow) clusters of injury rate overlapped with the percent of people age 15 and older with a high school diploma. There is a clear trend between injury rate and possession of a high school diploma, with the highest rates of injury occurring in areas where a very high proportion of the population did not obtain a high school diploma.

Table 4-4 Multivariate model with VANDIX

Showing the final Negative Binomial model for the VANDIX model. The Exp(B) indicate that for each increase in the deprivation score correspond to 8% increase in injury rate.

Parameter	Sig.	Exp(B)	Lower	Upper

(Intercept)	0	0.001	0.001	0.001
VANDIX	0.01	1.083	1.019	1.152
[Within30=0]	0.02	1.252	1.036	1.513
[Within30=1]		1		

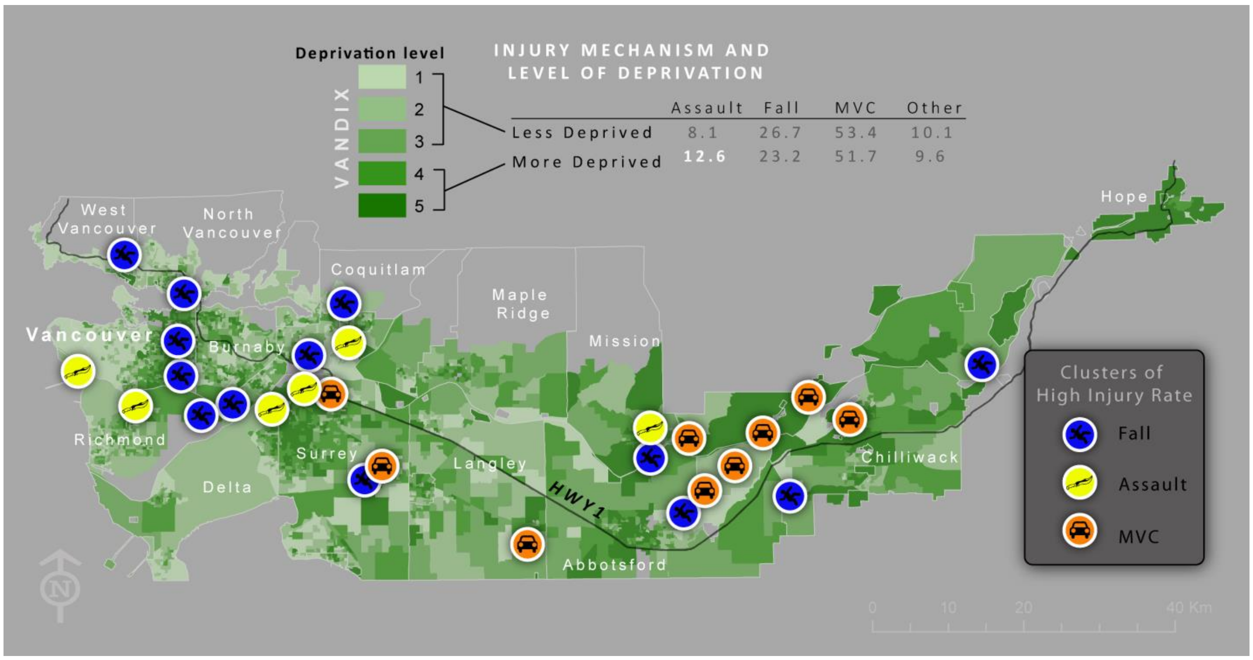

Figure 4-4 Map of clusters by cause of injury

Shows where clusters of high rates of injury by injury mechanism occurs. Injuries as a results of MVC tend to have clusters in the eastern part of the greater Vancouver (suburban) region while assault and falls tend to occur more often in the western part.

Injury mechanism and SES

An examination of injury mechanisms by socio-economic status, using the VANDIX deprivation score, demonstrated that 13% of the injuries in the more deprived DAs (DA with deprivation score 4 and 5) occurred as a result of assault as opposed to 8% in the less deprived DA’s(score 1-3). Injuries from falls have an inverse relationship with SES, with almost 27% of the injuries in the higher SES areas resulting from falls versus 23% in the lower SES areas (Figure 4-4). Injuries from MVC have an almost identical percentage across the SES scores.

4.5. Discussion

This paper highlights the relationship between different SES indicators and pediatric TBI rates in greater Vancouver. A significant relationship is clearly visible when using both the VANDIX (composite SES variable) and education variables (not having a high school diploma) as predictors of injury. Income-based census variables seem to be a poor predictor of rates of TBI. Even though, average income was somewhat significant when used individually, it had very poor predictive value when used in combination with other variables in the final model. Another variable that seems to be a good predictor of injury rates is the percentage of aboriginals within each DA. This is not surprising, as it has been shown that children and youth residing in areas with higher percentages of aboriginal people are twice as likely to be hospitalized when compared with children and youth in other areas. In addition, mortality rates as a result of injury are much higher amongst native children (Harrop, Brant, Ghali, & Macarthur, 2007; Oliver LN, 2012; I Pike, McDonald, Piedt, & Macpherson, 2014). The percentage of people not having high school diploma is likely a better predictor as it encompass within it a large of aboriginal population but also other vulnerable population without education.

Epidemiological research examining the relationship between prevalence of pediatric TBI and SES has shown similar results. Tennant examined the relationship between TBI and SES across all age groups and found that hospital admission rates (including children 0-18) increased by 17.4 percent for each one percent decrease in unemployment rate (age 16-24). Similarly, admission rates increased by 11 per 100000 for every one percent increase in single parent family rate (Tennant, 2005). Yates et al. also found a positive relationship between low SES and higher attendance in emergency departments as a result of head injury for pediatric population. They found that children under 5 years of age in lower SES urban areas were particularly vulnerable to TBI (Yates, Williams, Harris, Round, & Jenkins, 2006). Roberts et al, examining the likelihood of mortality from injuries, found that children in impoverished homes in England were 1.47 times more likely to die from pedestrian injury and 1.46 times more likely to die from fall injury than children with high SES, both of which are major cause of TBI's (Roberts et al., 2000). Injury severity also shows a similar trend. A study from Ontario, Canada found that children from low SES homes were 1.75 times more likely to be admitted to a hospital for injuries occurring within the home and 1.42 times more likely to be admitted for fall injuries. There are several reasons why this relationship exists, most notably the relatively low use of helmets and seatbelts as safety measures amongst low SES and less educated populations (Catherine S Birken, 2004; Karkhaneh, Kalenga, Hagel, & Rowe, 2006; Ian Pike, Desapriya, & Turcotte, 2012). This suggests that prevention strategies should be directed to these populations within the specific geographic areas where higher rates of pediatric TBI exist.

The relationship between SES and pediatric TBI has been shown to persist even in the post-TBI rehabilitation stage. Several studies indicate that rehabilitation outcomes for children with TBI are much more favorable for children of higher SES. Yeats et al. indicated that the social competence scale (ability to get along with friends and siblings) of children recovering from TBIs is much lower for non-white and lower SES children. After studying the impact of TBI on children who were in injured in Ohio, they concluded that TBI rehabilitation results in poorer social outcomes for children of lower SES (Yeates et al., 2004). A similar study of TBI outcomes amongst Australian children found that low SES has an impact on long term social functioning even as children transition to adulthood (Muscara, Catroppa, Eren, & Anderson, 2009).

4.5.1. Study Limitations

This study has some limitations that are important to note. First, the injuries recorded in the injury data sets are recorded by place of residence rather than place of injury. Unfortunately, place of injury is not something that is currently captured by hospitals. As a result, there may be some inherent errors within the driving time calculation. Unfortunately, there is currently no way to overcome this issue. That said, most injuries do occur between 5 -10 miles of home (Boyle, 2007; Palmer et al., 2005). Finally, TBI injuries resulting in death, where the death occurs outside of the hospital, are also missing from this data. While this data is recorded in the vital statistics data for BC, it was, unfortunately, unavailable for this study.

4.5.2. Conclusion

This study utilized advanced spatial analysis techniques to explore where injuries occur in high concentrations and whether distinct social processes may help to explain the existence of these high rates. This information can help policy makers to develop effective and targeted prevention strategies with the aim of reducing injury occurrences in those locations.

Chapter 5.
Linking Chapter - From Canada to Israel: Applying spatial epidemiology methods in different settings

While the previous chapters focused on the identification of spatial and socioeconomic vulnerability within the Canadian pediatric population, the following chapter uses similar methodologies to examine these factors within the state of Israel.

Applying similar methodologies within two different geographical settings allows for an examination and comparison of health outcomes across a broader spectrum. Geographically, Israel is much smaller in size and has a much higher population density than does Canada. In addition, the Negev region, wherein the study was situated, is diverse in terms of both ethnicity and socioeconomic status. The following chapter examines pediatric injury within Israel in order to provide a basis for comparison with the Canadian situation and to determine whether the factors influencing health outcomes within Canada share similarities with those in Israel. This is intended to broaden the applicability of these methodologies in identifying vulnerable populations. This chapter also introduces a temporal analysis in order to examine whether seasonality has an impact on access to care and patient outcomes.

Chapter 6.
Spatial and Temporal Analysis of Pediatric Injuries in Southern Israel

This paper is not yet submitted. Authors: Ofer Amram, Nadine Schuurman, Gadi Shaked, Itay Kloog and Michael Friger

6.1. Abstract

INTRODUCTION:

Timely access to appropriate treatment is central to better outcomes in severely injured children. Pediatric trauma centres (PTC), that are specialized to provide care to injured children, have been shown to obtain superior outcomes in terms of mortality and morbidity, when compared with adult trauma centers.

METHOD(S):

Administrative data from Soroka Pediatric Trauma Hospital in Southern Israel for the period 2006-2013 were used in this research. Variables such as driving time to hospital, ethnicity (Jewish vs Bedouin), injury severity score (ISS), cause of injury, SES and seasonality were included within the analysis and a multivariate analysis was used to examine the impact of these variables on length of stay at the hospital (Depict injury outcome). A descriptive analysis, comparing Bedouin and Jewish population in terms of injury rate, was also conducted.

RESULTS:

A total of 781 patients, aged 0-18 with an ISS of 12 or over, were admitted to Soroka Hospital between 2006 and 2013. The rate of injury amongst the Bedouin population within the region was found to be almost 3.5 times that of the Jewish population. No relationship was found between driving time to hospital and patient outcomes, even when adjusted for seasonality.

CONCLUSION:

Soroka Hospital, servicing the Negev region of Israel, has good spatial accessibility and patient outcomes are not impacted by distance to the hospital.

6.2. Introduction

Timely access to appropriate treatment is central to better outcomes in severely injured children. The relationship between trauma centre access and patient outcomes has been demonstrated in several studies (Ehrlich et al., 2001; Nakayama et al., 1992; Douglas A Potoka et al., 2001). Access to PTCs not only improves patient outcomes by reducing recovery and rehabilitation time and minimizing the burden upon families, it also reduces the cost to the health care system as a whole. Pediatric trauma centres (PTC), that are specialized to provide care to injured children, have been shown to obtain superior outcomes in terms of mortality and morbidity, when compared with adult trauma centers (Densmore et al., 2006; Douglas A. Potoka et al., 2000). Specifically, head and spleen injuries amongst pediatric patients have been shown to have better outcomes at Pediatric trauma centres than at adult trauma centres (McDonald & Yanchar, 2012; Douglas A Potoka et al., 2001). It is not surprising, therefore, that there has been a rapid growth in the availability of PTCs within the last two decades. In the US for example, the number of PTCs has risen from 37 in 1997 to 65 in 2009. However, the availability of pediatric trauma centres is still limited in comparison to that of adult trauma centres, presenting a challenge for health care providers in ensuring timely care for this population.

The aim of this paper is to examine the impact of pediatric trauma centre access on patient outcomes in the southern part of Israel. In addition to spatial access, variables such as time of year (seasonality), ethnicity and socio economic status (SES) will be considered and incorporated into the analysis. To our knowledge, this is the first paper to examine this relationship within the state of Israel.

6.3. Methods

6.3.1. Study Area

This study comprises the area of southern Israel known as the 'Negev', centre around the city of Beer-Sheva, wherein Soroka Hospital, the region's largest trauma hospital, is located. Soroka Hospital is the second largest hospital in Israel with a catchment covering approximately 60% of Israel's geographical area(Hospital, 2015) (Figure 6- 1). The population of the Negev is estimated at approximately 702,600, where 73% are Jewish and the remaining non-Jewish population are Bedouin people of Muslim decent. In terms of pediatric population, approximately 32.3% of the Jewish population within the Negev are between the ages of 0-19 (164665), while 62.8% of the Bedouin population are within this age group (N=121078) (Rudnitzky, Ras, & Fund, 2012). Approximately 67% of the Bedouin population reside in permanent towns while the rest are transient without a permanent location. As a result, the exact Bedouin population count is unknown, causing the total population count for the region to be somewhat inexact (Rudnitzky et al., 2012; Shmueli & Khamaisi, 2011). Within the Bedouin population, those that have no permanent location have been shown to have lower socio economic status than those living in permanent residences. Furthermore, health outcomes, education levels and socio economic status are lower for the Bedouin population as a whole than for the Jewish population within the region (iataskforce.org, 2014; Rudnitzky et al., 2012).

Figure 6-1 Bedouin picture

Showing the living conditions of Bedouin population with no permanent residence.

6.3.2. Data

Administrative data from Soroka Pediatric Trauma Hospital for the period 2006-2013 was used in this research. Soroka serves all pediatric patients from the Negev as well as pediatric patients with multiple and/or head injuries from outside the Negev region (Figure 6 - 2). For the descriptive analysis portion, in order to calculate rate of injury, only data from the Negev population was analyzed and reported. Additionally, in order to focus on the more severe injuries, only patients with an injury severity score (ISS) of 12 or more were used in the analysis. The principle variables included in the data were patient age, location of incident (at the town level), ethnicity (Jewish vs

Bedouin), date of injury, injury severity score (ISS), cause of injury, SES, length of hospital stay and whether patient was released from the hospital alive. Only patients aged 0-18 were included in the analysis. Data regarding SES were gathered from Israel's 2008 census survey (LAMAS) conducted by Israel's central bureau of statistics. This data includes the percentage of people in each town that are considered to have low SES ((Israel), 2015). Spatial access was measured with the aid of Google Maps, by calculating the driving time from each town where an injury occurred to Soroka Hospital (Google, 2015). Seasonal impact on injury outcome was also measured as this region experience an increase of motor vehicle accidents during the winter time. Seasons in Israel were defined using a paper by Alpert that provides an updated definition of seasons for the eastern Mediterranean region (Alpert, Osetinsky, Ziv, & Shafir, 2004). Based on the date of injury each injury was assigned a value from 1 to 4 in relation to the season (Table 6-4).

6.3.3. Modelling Access

Using SPSS v.20(IBM, 2013) a negative binomial analysis was conducted on the entire data set (both for patients within the Negev region and outside) in order to assess the impact of each variable on length of stay in the hospital. In order to assess the impact of driving time on length of hospital stay only patients who were transported by vehicle were included in the analysis (i.e. air transport was excluded). The main predictor variables were seasonality, travel time to hospital, SES, time spent in ER and ethnicity (whether Jewish or not). A univariate model was conducted first and only those variables that were statistically significant at a level >0.2 were kept for possible inclusion in the final model.

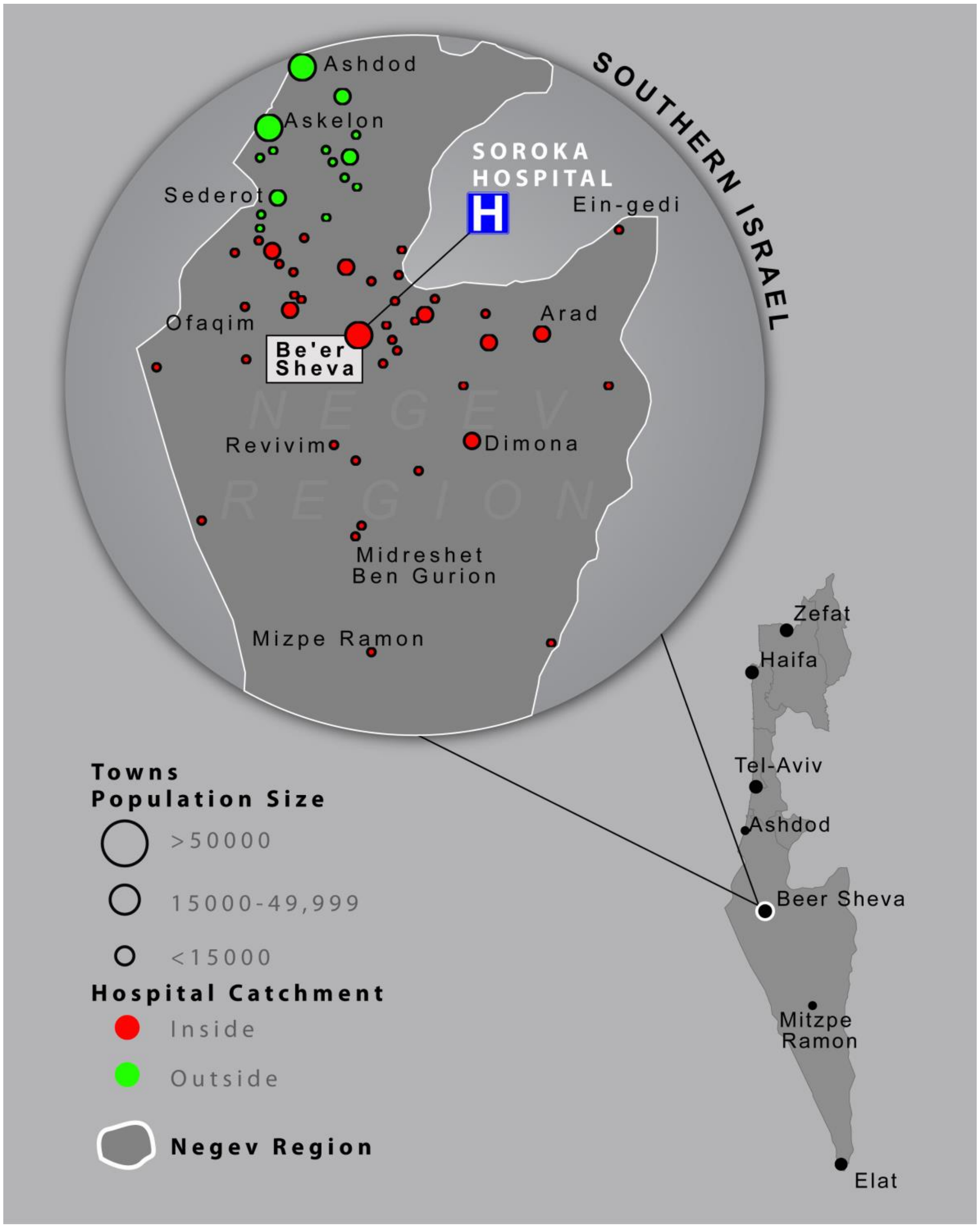

Figure 6-2 Map of the Negev

Showing the Negev region and Soroka Hospital service areas. The red dots represent towns were all pediatric patients are serviced by the hospital. The green dots depict towns were only patients with multiple and/or head injuries are treated at Soroka Hospital.

6.4. Results

6.4.1. Descriptive Analysis

There were 781 patients ages 0-18 with an ISS of 12 or over admitted to Soroka Hospital between 2006 and 2013. Of those, 599 (77%) originated from towns within the Negev region. Of the 599, the crude injury rate is estimated at 30 per 100000 per year. As expected, there is a clear difference in injury rates between the Jewish and Bedouin populations, with the Bedouin injury rate close to 3.5 times that of the Jewish population. Injury rates between both populations varied greatly by age group, with the youngest age group (0-4 yrs) having the highest discrepancy and the oldest age group (15-18 yrs) having the smallest (Table 6-1). There is also a large difference in the causes of injury between the Jewish and the Bedouin populations at the different age groups.

Table 6-1 Crude Pediatric Injury

Crude Pediatric injury for the years 2006-2013 in the Negev region for Bedouin and Jewish population.

Injuries Per 100000

Age Group	All Population	Bedouin	Jewish
0-4	349.8	674.8	110.8
5-9	199.5	323.3	108.5
10-14	129	185.2	87.7
15-18	144.6	180.5	118.3
0-18	208.9	349.4	105.7

Injuries as a result of interactions with animals were much higher within all Bedouin age groups, peaking at more than 10% of all injuries within the oldest age group. Injuries from assault had a relatively low percentage across all age groups, with the exception of oldest age category. In this category, the rate was high for both populations, however the proportion of injuries from assaults within the 15-18 year old Jewish population was almost double that of the Bedouin population (39% compared with 21.7% respectively). Falls are a major cause of injury for children aged 0-14 in both populations; however, the impact of such injuries is proportionally larger within the Jewish population aged 10-14. In this age group, the Jewish population had a 39.5% injury rate whereas the Bedouin population had a rate of only 28.8%. Bedouin children aged 0-4 are injured by falling objects at a proportionally higher rate than Jewish children and fire is also a major cause of injury for Bedouin children within the oldest age group. Motor Vehicle Crashes (MVC) are a major cause of injury for both populations but the rate seems to be higher within the Jewish population (Table 6 -2).

Table 6-2 Cause of injury by age group

Cause of injury within pediatric population by ethnicity and age group.

	Cause of injury by Age Group (%)							
	0-4		5-9		10-14		15-18	
Injury Cause	**Jewish**	**Bedouin**	**Jewish**	**Bedouin**	**Jewish**	**Bedouin**	**Jewish**	**Bedouin**
Animal	2.1	2.8	0.0	7.8	2.6	10.2	2.4	10.9
Assault	0.0	0.5	0.0	1.0	2.6	5.1	39.0	21.7
Fall	41.7	47.0	44.9	44.7	39.5	28.8	9.8	10.9
Falling Object	2.1	8.4	10.2	7.8	2.6	5.1	4.9	4.3
Fire	10.4	12.6	2.0	5.8	5.3	3.4	0.0	10.9
MVC	43.8	27.9	40.8	33.0	47.4	44.1	39.0	39.1
Other	0.0	0.9	2.0	0.0	0.0	3.4	4.9	2.2
Total Count	48	215	49	103	38	59	41	46

Table 6-3 Mortality at the hospital

Showing the percentage of pediatric patients by ethnicity whose injuries resulted in death (within hospital). Average length of stay at the hospital is slightly lower for Jewish as compared to Bedouin populations.

	Count	%dead	Average Length Stay (Days)	Average ISS
Bedouins	423	8	10.7	20.8
Permanent Residence	363 (86%)	6.6	10.6	20.7
No Permanent Residence	66 (14%)	10	11.6	21.3
Jewish	174	8.6	8.9	21.1

While the rate of injuries resulting in death at the hospital is similar (approximately 8%) for the Jewish and Bedouin populations (Table 6-3), the rate is higher, though not statistically significant, for those Bedouins that do not have a permanent residence (6.6% vs 10% respectively). In contrast, those that do have a permanent residence seem to have a lower death rate at the hospital than the Jewish population. Interestingly, only 14% of injured Bedouin children did not have a permanent residence, a much lower percentage than their estimated percentage within in the population (33%).

Table 6-4 Univariate model results

Time in ER and ISS are highly significant while Ethnicity and SES are both not significant with length of stay at the hospital. Table also shows the season variable with their dates.

Name	Description	Type	P	Association
Outside20Minutes	Whether Patient was transported by vehicle 20 minutes from Hospital	Spatial	0.264	Negative
ISS	Injury Severity Score	Individual	0.0001	Positive
SES	% of population living in Poverty	Individual	0.576	Positive
TimeInER	Time Spend in ER	Access	0.0001	Negative
Jewish	Whether Patient is Jewish	Ethnicity	0.79	Negative
Season	Summer: 31 May–22 Sep Fall: 23 Sep–6 Dec Winter: 7 Dec–30 Mar Spring: 31 Mar–30 May	Adjustment Variable		

6.4.2. Modelling Access

After removing any records that could not be geocoded (mainly Bedouins without a permanent residence) as well as any cases that were transported to hospital by air, a total of 464 injuries were incorporated in the access model (including multiple or head injuries that occurred outside the Soroka geographic boundary). All variables except SES (p=0.576) which was insignificant in the univariate analysis were input into the final model. Both the spatial and ethnicity variables were kept, regardless of their significance level in the univariate analysis.

The univariate analysis showed a weak relationship between transport time and length of hospital stay for those more than 20 minutes away from Soroka Hospital (Figure 6-2). In fact, the relationship though weak, appears to be inverse. ISS is positively associated with length of stay and ‘Time spent in ER’ is negatively associated with length of stay at hospital. SES and ethnicity (whether Jewish or not) are clearly not associated with length of stay (Table 6-4).

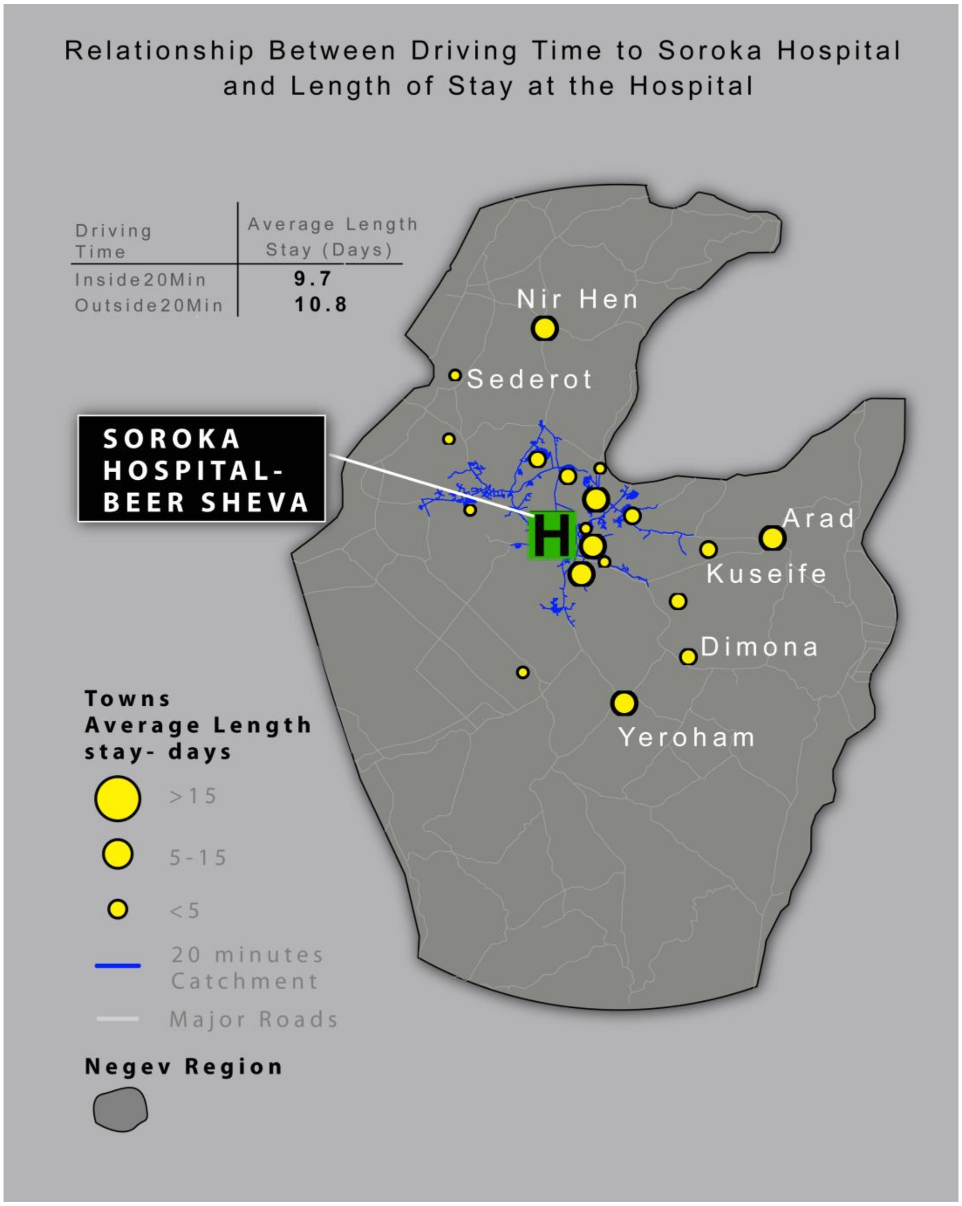

Figure 6-3 Length of stay at the hospital at the Negev

Show Differences in length of stay at the hospital outside and inside 20 minutes travel time of Soroka hospital.

The multivariate model for the entire dataset indicates that ISS and ‘Time spent in ER’ remained very significant when modeling the entire dataset and when adjusting for seasonality. None of the other variables appear to be statistically significant predictors of length of hospital stay when the model is not adjusted for seasonality (Table 6-5).

Table 6-5 Multivariate model

Table showing multivariate models of the data adjusted for seasonality. As with the univariate model, ISS is highly significant across all models while Time spent in ER is only highly significant in the Spring.

	Parameter	Sig.	Exp(B)	Lower	Upper
All	(Intercept)	.000	4.656	3.181	6.815
	Outside20Min	.408	.921	.759	1.119
	ISS	.000	1.049	1.033	1.064
	TimeInER	.000	.876	.818	.937
	Jewish	.962	1.005	.817	1.236
Winter	(Intercept)	.001	4.167	1.863	9.320
	Outside20Min	.799	1.051	.718	1.539
	ISS	.000	1.059	1.027	1.093
	TimeInER	.102	.885	.765	1.024
	Jewish	.672	.916	.609	1.378
Spring	(Intercept)	.000	6.347	2.769	14.548
	Outside20Min	.374	.804	.498	1.300
	ISS	.004	1.038	1.012	1.065
	TimeInER	.005	.797	.680	.935
	Jewish	.896	.966	.575	1.624
Summer	(Intercept)	.000	4.545	2.423	8.524
	Outside20Min	.195	.803	.576	1.119
	ISS	.003	1.040	1.014	1.066
	TimeInER	.154	.917	.814	1.033
	Jewish	.275	1.207	.861	1.692
Fall	(Intercept)	.005	3.541	1.452	8.635

Outside20Min	.978	1.006	.643	1.576
ISS	.000	1.065	1.028	1.103
TimeInER	.111	.888	.768	1.028
Jewish	.733	.915	.549	1.525

6.5. Discussion

Timely access to trauma care services is critical in providing adequate care to severely injured children (Ehrlich et al., 2001; Nakayama et al., 1992; Douglas A Potoka et al., 2001). To the best of our knowledge this is the first paper to examine this relationship within the state of Israel. The results from this paper indicate that Soroka Hospital, servicing the Negev region of Israel, has good spatial accessibility and that patient outcomes (as indicated by length of hospital stay) are not impacted by distance to the hospital. These results may be a reflection of the fact that Israel's population density is higher than other countries where access to pediatric trauma care and length of hospital stay were examined (Bank, 2015). Given the higher population densities within Israel, our analysis used a 20 minute driving time catchment around the hospital rather than the typical golden hour catchment used in similar accessibility studies (Branas et al., 2005; Hameed et al., 2010). This was done because a one hour catchment would not have left enough data for comparison within the analysis. The trend within this analysis actually shows an inverse relationship, wherein the children residing within 20 minutes of the hospital tended to have longer hospital stays.

Like many other injury studies conducted within Israel, this study also shows differences in the rates of injury between the Jewish and non-Jewish population (Gofin, Avitzour, Haklai, & Jellin, 2002; Savitsky, Aharonson-Daniel, Giveon, Group, & Peleg, 2007). Not surprisingly, the Bedouin population, that is the dominant non-Jewish population within the Negev, has been shown to have much higher rates of pediatric injury across all age groups. This is most evident amongst the youngest group of children, aged 0-4 years. A more in depth look at the causes of injury, indicates that MVC are a larger cause of injury within the Jewish population while injuries as a result of interaction with animals and fire are a major cause of injury within the Bedouin population. The dissimilarities in cause of injury not only reflect the cultural and socioeconomic differences between the two populations, but also highlight how poor environmental conditions and lack of education may contribute to higher rates of injury. Differences in rates of injury between Jewish and non-Jewish populations in Israel have also been found in a number of other studies. For example, a study by Savitsky et al. (2007), using data from the Israeli trauma registry, found that both the proportion of severe injuries and the hospital death rate from injuries was twice as high for non-Jewish populations as it was for Jewish populations within Israel. A study by Gofin et al. (2002) also found that non-Jewish children have a mortality rate from injuries 3.2 times higher than that of Jewish children within Israel.

There are also differences within the Bedouin population itself. This population can be divided in to two major groups: those that have a permanent residence and those that do not. The results indicate that Bedouins with a permanent place of residence have lower rates of in-hospital death as a result of injury. Also, injury severity scores and, consequently, length of hospital stay is slightly lower for this portion of the Bedouin population. Despite this, the rate of injured children amongst transient Bedouin populations is much less than what would be expected based on the overall proportion of transient Bedouins within the Bedouin population as a whole. The exact reasons for this are unclear. One explanation may be that emergency services are more accessible to those that have a permanent address, making hospital evacuation easier. Another may be that Bedouins with no permanent place of residence choose not to access trauma services and/or die before reaching a hospital, with the result that these deaths going unrecorded in the hospital registries.

6.5.1. Study Implications

The results of this study highlight the need for interventions aimed at narrowing the difference in rates of injury between Bedouin and Jewish populations. There is a particularly acute need for this within the youngest age group (0-4) where we see Bedouin children hospitalized at 6 times the rate of Jewish children. Educating parents as to the most common causes of injury within this age group as well as common strategies for prevention, may assist in reducing the number of injuries within this group.

As all causes of injury were relatively even across both populations within this age group (0-4 yrs), prevention strategies should be directed towards improving safety within the home (i.e. better standards for building and infrastructure aimed at preventing falls and falling objects) and educating parents as to how to reduce fire hazards around the house and within the community.

6.5.2. Study Limitations

This study has several limitations that require acknowledgment. First, the injury locations within the injury data sets are recorded at the town level. As some of the towns are relatively large in size, the use of the town as opposed to the address coordinate may lead to locational error and, consequently, errors in the travel time calculation. Additionally, the travel time calculation was done without incorporating traffic data. As traffic can impede access to Soroka Hospital at certain times of the day, this can, in turn, affect driving time estimations within the datasets. Lastly, a large proportion of the injury data lacked location information. This data were drawn from the transient Bedouin population and could not be represented within the access model. Unfortunately, most of these limitations are too costly or complicated to overcome and are, therefore, beyond the scope of this paper.

Chapter 7.
Linking Chapter - The importance of data accuracy

The previous chapters aimed to analyze both access to care and socioeconomic status in terms of how they influence pediatric injury. The following and final chapter attempts to address a core issue within spatial epidemiology and injury research; namely, the lack of systematic data collection, particularly as it relates to location information.

Both chapters 2 and 4 state within the section on limitations, that residential location was used as a proxy for injury because injury location data was unavailable. This is not a unique situation, as several other studies have acknowledged this issue. This limitation arises because residential location is often the only locational information recorded within trauma registries. The following chapter examines the relationship between place of injury and place of residence in a variety of ways, while also examining how locational error is distributed across space and its subsequent impact upon results. It also analyzes this error in terms of its relationship to measurements of trauma centre access.

The following chapter is unique in that it is intended to highlight how locational error is propagated within injury-related spatial epidemiology research and to expand discussion on the matter in order to work towards changes that might eliminate or reduce this error in future, thereby advancing injury research as whole.

Chapter 8.
The use of Geographic Information Systems to Assess the Error Associated with the Use of Place of Residence in Injury Research

This paper will be submitted prior to the date of defense: Journal: International Journal of Health Geographics*, Authors: Ofer Amram, Nadine Schuurman, Ian Pike, Natalie L Yanchar and Donald Griesdale*

8.1. Abstract

INTRODUCTION

In any spatial research, the use of accurate location data is critical to the reliability of the results. Unfortunately, however, many of the administrative data sets used in injury research do not include the location at which the injury takes place. The aim of this paper is to examine the error associated with using place of residence as opposed to place of injury when identifying injury hotspots and hospital access.

METHODS

Traumatic Brian Injury (TBI) data from the BC Trauma Registry (BCTR) were used to identify all TBI patients admitted to BC hospitals between January 2000 and March 2013. In order to estimate how locational error impacts the identification of injury hotspots, the data were aggregated to the level of dissemination area (DA) and census tract (CT) and a linear regression was performed using place of residence as a predictor for place of injury.

In order to assess the impact of locational error in studies examining hospital access, an analysis of the driving time between place of injury and place of residence

and the difference in driving time between place of residence and the treatment hospital, and place of injury and the same hospital was conducted.

RESULTS

The driving time analysis indicated that 73.3% of the injuries occurred within 5 minutes of place of residence, 11.2% between five to ten minutes and 15.5% over 20 minutes. Misclassification error occurs at both the DA and CT level. The residual map of the DA clearly shows more detailed misclassification.

As expected, the driving time between place of residence and place of injury and the difference between these same two locations and the treatment hospital share a positive relationship. In fact, the larger the distance was between the two locations, the larger the error was when estimating access to hospital.

DISCUSSION

Our results highlight the need for more systematic recording of place of injury as this will allow researchers to more accurately pinpoint where injuries occur. It will also allow researchers to identify the causes of these injuries and to determine how these injuries might be prevented.

8.2. Introduction

The use of Geographic Information Systems (GIS) and spatial data in injury research has become more common in recent years (Bell & Schuurman, 2010; Edelman, 2007; Geurts, Thomas, & Wets, 2005; Lawson, Schuurman, Oliver, & Nathens, 2013). Over the past two decades, advances have also been made in data acquisition and spatial analysis techniques, allowing researchers to conduct more advanced spatial analysis (Graham et al., 2004). As a result, GIS is now more commonly used within injury and trauma systems research to determine the relationship between trauma centre access and injury outcome or to identify injury hotspots (geographic area of significant number of injuries) and their causes (Branas et al., 2005; Hameed et al., 2010; Härtl et al., 2006; Nirula et al., 2010; J. S. Sampalis et al., 1997). GIS also plays an important role in mapping the role of external environmental factors (e.g. playgrounds with faulty equipment) in order to establish prevention methods or remove hazards that may cause injuries (Catherine S Birken, 2004; Cubbin et al., 2000; Faelker et al., 2000; Williams et al., 1997).

In any spatial epidemiology research, the use of accurate location data is critical to the reliability of the results. In injury research this is particularly important because the analysis is often dependent upon knowing exactly where an injury occurred. Unfortunately, however, many of the administrative data sets used in injury research do not include the location at which the injury takes place. Instead such data sets are typically restricted to locational data based on place of residence (normally at the postal code or zip code level) (Information, 2014). As a result, researchers have no choice but to use place of residence in their analysis although this clearly introduces error within the data. Furthermore, in many cases, place of residence at the census level is also used to establish the socio economic status of the person injured and to draw links between socio economic status and injury mechanism (e.g. older houses, less well maintained playground equipment, etc.), however as injuries may take place in areas that do not reflect the same socio economic status as place of residence, this can also lead to error (it is important to note that SES also varies considerably within geographic areas, and even knowing place of residence at the census level is not guarantee that SES is the same as other individuals in the DA or CT). While there are many valid reasons to include place of residence in injury research, it is important that researchers be aware of the error that may result in using it as a proxy for place of injury.

The aim of this paper is to examine the error associated with using place of residence as opposed to place of injury in injury research. Specifically, the paper will examine how this error affects specific age groups (i.e. children and school-age youth, working adults and adults over 65) and classification of injury mechanisms. In so doing, the paper is also meant to assist those researchers who must use place of residence to understand the impact that this error may have upon their results, and to suggest the means of minimizing its effect.

8.3. Methods

8.3.1. Data Preparation

Traumatic Brian Injury (TBI) data from the BC Trauma Registry (BCTR) were used to identify all TBI patients admitted to BC hospitals between January 2000 and March 2013. Geographic information within the TBI dataset includes the hospital where the patient was treated, the patient's place of residence and, when available, the place where the injury occurred, all at six-digit postal codes. All postal code variables were geocoded using the Statistics Canada Postal Code Conversion File (PCCF). Other variables collected included patient age and injury mechanism.

To assess the locational error between place of residence and place of injury, a calculation of driving time was made between these two locations. This calculation was done for three different age groups (0-18, 19 -64 and 65 and older) as they show significant differences in daily trip time likely because children and school-age youth spend much of their days at home or at a day care or school relatively close to their home, working adults tend to travel somewhat further from home during the day and retired persons (65 or older) also tend to be at or closer to home during the day (Santos, McGuckin, Nakamoto, Gray, & Liss, 2011). The driving time calculation was made using the ArcGIS Network Analyst. This tool allows for relatively accurate estimations of travel time in that it provides turn-by-turn calculations while taking into account road speed limits. A more detailed explanation of this methodology can be found in previous publications (Cinnamon et al., 2008; Schuurman et al., 2010). The DMTI road data set was used to supply the road network data as it is suitable for use with the Network Analyst extension.

While the assessment of the locational error affecting injury hotspots is relatively straightforward, the identification of locational error as it relates to hospital access is complex. This is because it requires examination of three separate driving time calculations: the first calculation describes driving time between place of residence and the hospital (T_{rh}); the second between place of injury and the hospital (T_{ih}); and the third calculation identifies the locational error (driving time) between place of injury and place of residence. In this situation, the third calculation (T_{ir}) is not necessarily equivalent to the difference between the first and second calculations, because the place of injury may be much closer to the hospital than the place of residence or vice versa. Similarly, the place of injury could be in an entirely different location but have approximately the same driving time to the hospital (Figure 8-1). In order to assess the locational error within the data, a calculation was made of the difference in driving times between both place of residence and the hospital where the patient was treated and place of injury and the same hospital ($T_{rh} - T_{ih}$). For this analysis, only patients transported directly to hospital by automobile were selected.

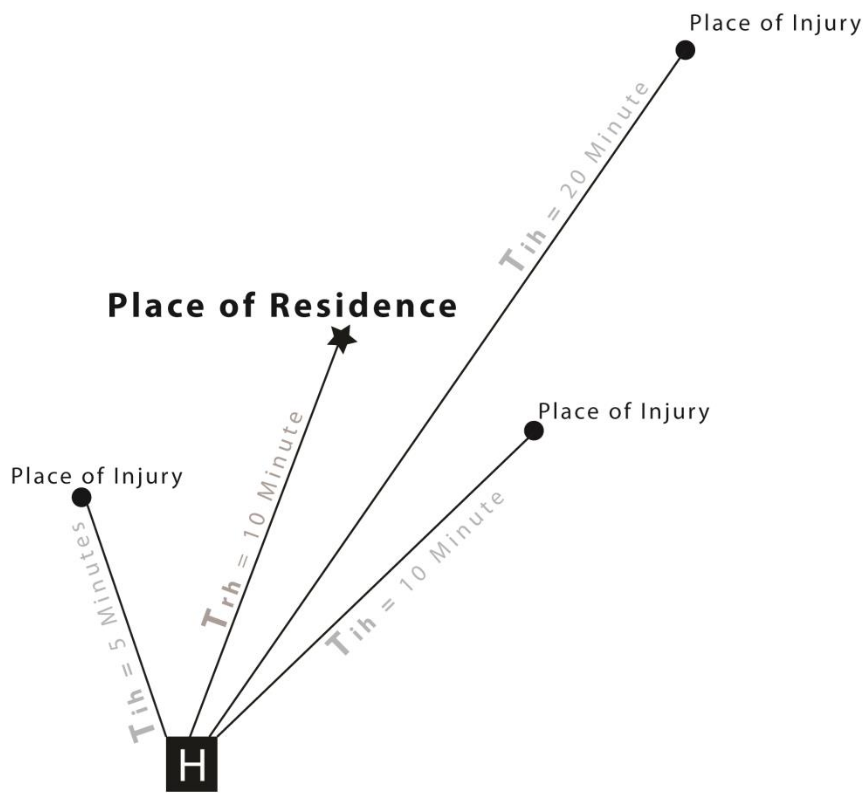

Figure 8-1 Illustration of locational error

Shows how using place of residence as a proxy for place of injury can cause various errors in calculating driving time to hospital.

8.3.2. Estimating error for hotspot identification

In order to estimate how locational error impacts the identification of injury hotspots, the data was aggregated to the level of dissemination area (DA) and census tract (CT) and a linear regression was performed using place of residence as a predictor for place of injury. A residual map (mapping of the model residuals) was then created to highlight areas of under and over prediction at both the DA and CT level. As the DA is the smallest census unit at which census variables can be joined, they are often used to calculate disease rates. CTs, on the other hand are much larger in size and are often used as proxy for neighborhood in epidemiological studies(Coulton, Korbin, Chan, & Su, 2001; Kohen, Brooks–Gunn, Leventhal, & Hertzman, 2002). For this analysis, the City of Vancouver boundaries were used for the assessment of the error.

8.3.3. Estimating error in access to trauma center studies

In order to assess the impact of locational error in studies examining hospital access, driving times were calculated between both place of residence and the hospital (T_{rh}), and place of injury and the same hospital (T_{ih}). An analysis of the driving time between place of injury and place of residence (T_{ir}) and the difference in driving time between place of residence and the hospital and place of injury and the hospital was then conducted (T_{rh} - T_{ih}).

8.4. Results

8.4.1. Injury Hotspots

Within the dataset, 7368 case of TBI met inclusion criteria for the study, with complete postal code data on place of residence and place of injury. Of the entire dataset 73.3% of the injuries occurred within 5 minutes driving time of place of residence (T_{ir}), 11.2% between five to ten minutes and 15.5% over 20 minutes. When the data was stratified by age group, those over the age of 64 had the highest percentage (86.8%) of injuries occur within five minutes driving time of place of residence (T_{ir}), while those 19-64 years of age had the lowest percentage of injuries within this same driving time (Figure 8-2). The data also showed trends in terms of injury mechanism. For example, 61.6% of motor vehicle injuries occurred within 5 minutes of place of residence in contrast to 82.3% of falls (Figure 8-3).

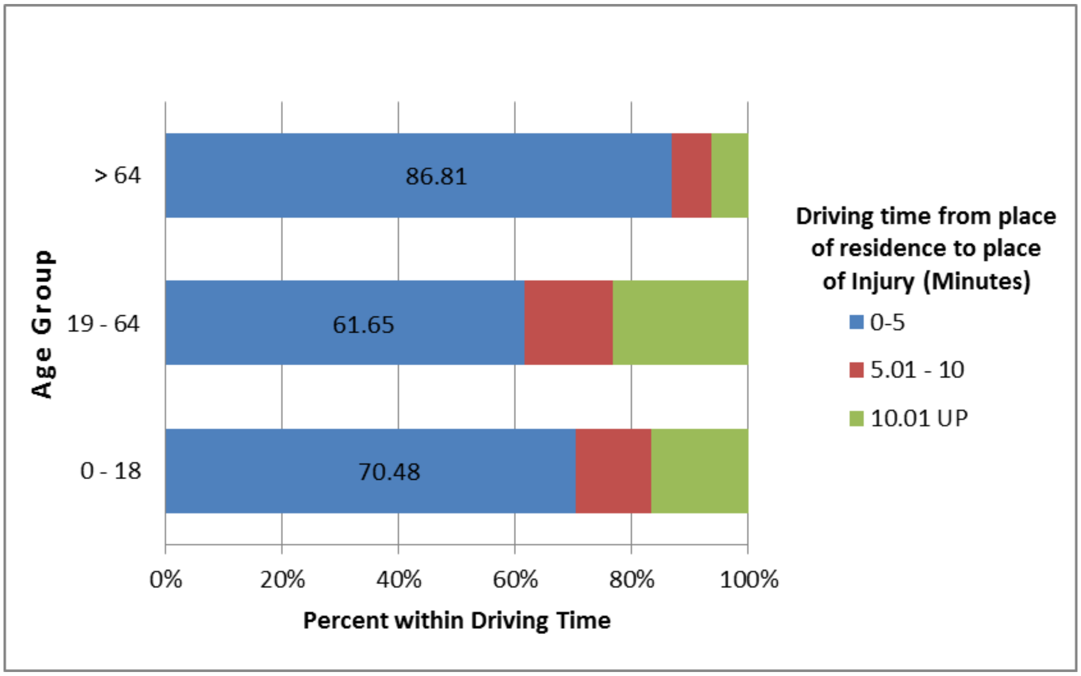

Figure 8-2 Driving between place of residence and place of Injury by age group

Shows injuries (%) occurring at place of injury stratified by driving time to place of residence. The graph indicates that 85% of the injuries for those 65 and older occur within 5 minutes driving time of their place of residence.

Mapping injuries based on place of residence also results in error in the identification of injury hotspots. Figure 8 - 4 demonstrates the error over space at both the DA and CT level of TBIs within the city of Vancouver. The residual map of the DA clearly shows more detailed misclassification. This is because the DA's smaller size makes it less common for both place of injury and place of residence to fall within the same area (Figure 8-4).

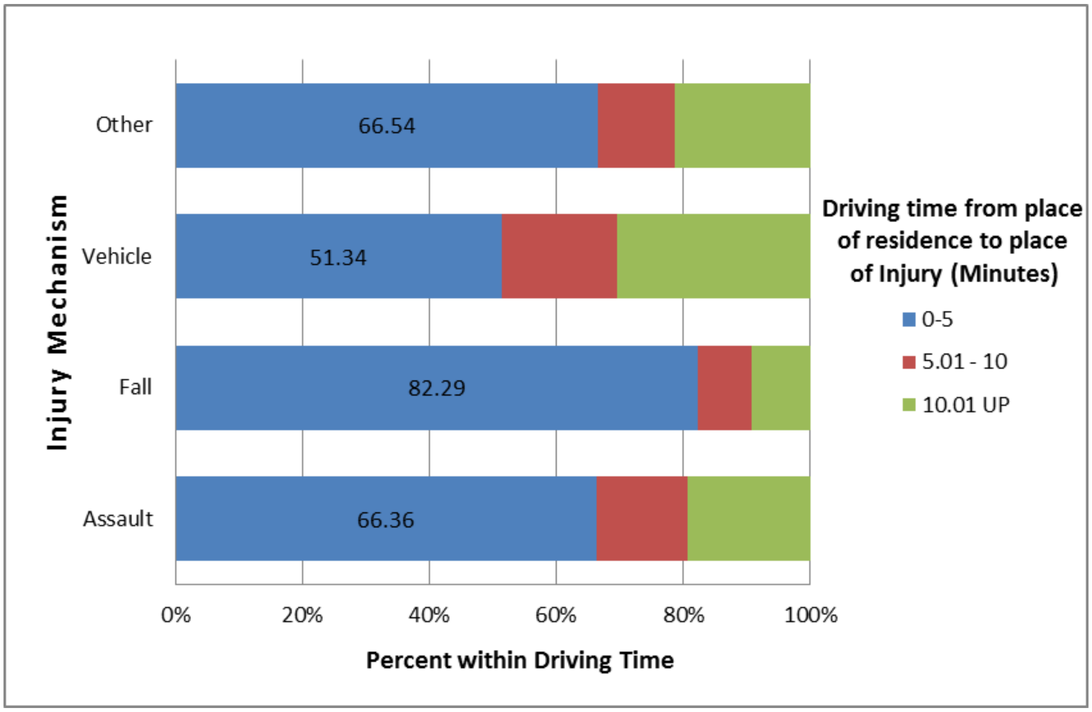

Figure 8-3 Driving between place of residence and place of Injury by cause of injury

Shows injuries (%) occurring at place of injury stratified by driving time to place of residence. The graph indicates that injuries resulting from a fall tend to be closer to home while injuries resulting from a MVC tend to occur further away.

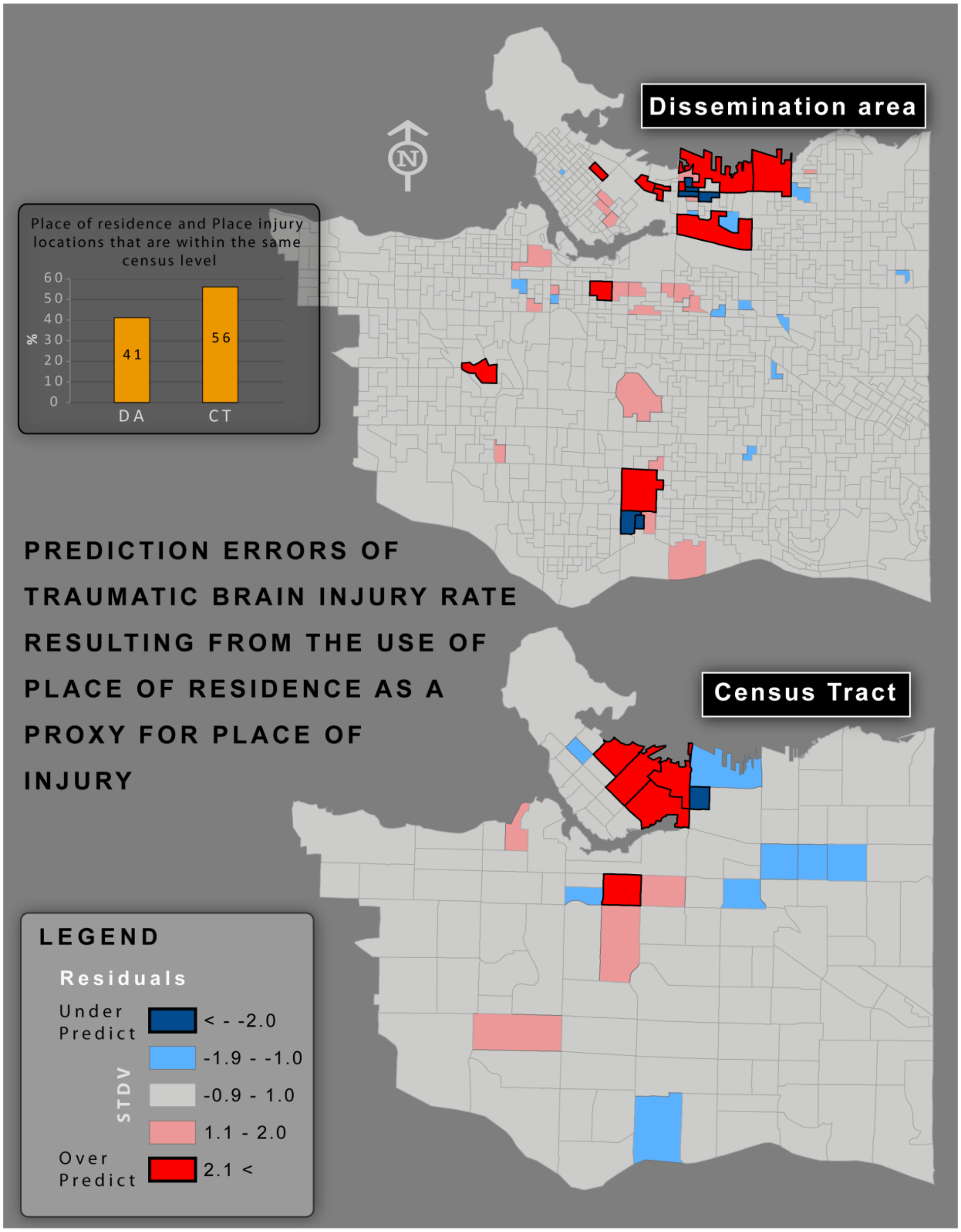

Figure 8-4 Locational error at the DA level

shows the locational error at both the DA and CT level. With the DA map clearly shows more detailed misclassification. This is because the DA's smaller size makes it less common for both place of injury and place of residence to fall within the same area.

8.4.2. Access to Hospital

This analysis includes data from 636 cases that were transported to hospital via motor vehicle. In this particular dataset, the mean, median and interquartile measures of hospital driving time were almost identical from both place of residence and place of injury (Table 8-1). As expected, the driving time between place of residence to place of injury (T_{ir}) and the difference between these same two locations and the hospital (T_{rh} - T_{ih}) share a positive relationship (Table 8-2). The greater the distance between the two locations, the greater the error when estimating driving time to the hospital.

Table 8-1 Comparison of travel time to hospital

Descriptive statistics of driving time to the hospital from both place of residence and place of injury.

	Driving time To Hospital (Minutes)				
	Q1	Q3	Interquartile Range	Mean	Median
Place of Residence	12.2	103.2	91.0	96.4	40.8
Place of Injury	11.5	100.6	89.1	96.7	42.3

Table 8-2 Driving time between place of injury and place of residence

Shows that as the driving time between place of injury and place of residence increases, the error in driving time to the hospital also increases. The sharp difference in error indicates that the use of place of residence as a proxy for place of injury is reliable only with case populations where the distance between place of residence and place of injury is minimal (eg elderly, falls).

Tir: Driving time between Place of Injury and Place of Residence(minutes)	Trh – Tih: Difference in Driving time between Place of Residence and hospital and Place of Injury and hospital (minutes)	
	Mean	Median
0 – 10	0.9	0.1
10.1 - 20	8.7	9.4
20up	70.8	42.0

8.5. Discussion

This study examines how using place of residence as a proxy for place of injury may result in errors in the description of injury hotspots and the measurement of trauma center access. Using GIS, this study highlights not only the numeric value of the error but also the spatial distribution of the error over space. The results of the study also correspond with those of other studies that indicate that injuries tend to take place in areas close to the patient's place of residence. For example, a study that examined violent injury found that injuries taking place during daytime hours had similar hotspots for both place of residence and place of injury, indicating that these violent injuries were occurring closer to home. At night however, the hotspots tended to shift to areas farther from home(Cusimano, Marshall, Rinner, Jiang, & Chipman, 2010). This study however, analyzed the data at the CT rather than the DA level. A different study, using a much smaller sample (321 participants), and done in a rural area of Wales, found that 80% of the participants' injuries occurred within 10 miles of home (Palmer et al., 2005). In recent years, the increased use of highly accurate locational data has enhanced researchers' ability both to identify injury hotspots and to understand the causes of injury at these locations. In addition, the use of more accurate location data has allowed for a better understanding of how access to trauma care impacts injury outcomes and how trauma systems can be optimized to provide better care. However, the use of place of residence rather than place of injury when conducting such research can hinder the ability to accurately assess the impact of injury. The results of this paper clearly show that using place of residence rather than place of injury increases the uncertainty in the identification of injury hotspots (showing hotspots where no hotspots actually existed and vice versa). This paper also indicated that place of residence can provide a good proxy for place of injury, but only when the place of injury and the place of residence are within 10 minutes driving time of one another. This may only apply to certain sub-populations (eg elderly) or with certain mechanisms of injury (e.g. falls). For the dataset in this study, almost 80% of TBIs occurred within 10 minutes of place of residence.

The results from both analyses indicate that reliability is affected by geographic scale (census tract vs dissemination area) when using place of residence as a proxy for place of injury. In the hotpots analysis, the use of more aggregated census boundaries, like census tract (CT), improved the reliability of the results. Using CT levels resulted in better classification of hotspots and higher numbers of injuries where both place of injury and place of residence were within the same level (56% for CT compared to 41% for DA). However, while the use of CT (or even more aggregated census levels) for hotspot identification may increase confidence in the results, it will also reduce the precision with which each specific place of injury can be identified. The choice of scale should also take into consideration the characteristics of the study area. Based on our results, the use of place of residence as a proxy for place of injury may be better suited for urban areas where major activities, like going to school and work, tend to be closer to home.

Another area of consideration is the type of injury being studied. As mentioned, motor vehicle injuries tend to take place further from home than do other types of injuries. This is supported by a U.S. transportation report that found that only 47% of the motor vehicle injuries take place within 5 miles from home (Boyle, 2007). Our study also supports this, in that our comparison of injury mechanisms, found motor vehicle injuries took place furthest from home, with a median driving time of 5 minutes between place of residence and place of injury. Because there is such a large degree of error for motor vehicle injuries, it is more challenging to compensate for this through the aggregation of census boundaries.

8.5.1. Study Limitation

This study has limitations that may skew the results. First, the measurement of hospital driving time included within the study is based on the hospital at which the patient was treated. This measurement was then compared to the driving time distance between the patient's place of residence and the same hospital. In reality, however, in cases where the patient was injured at or close to his/her home, the patient may have been transported to a different hospital, assuming it was closer or had different specializations. While the hospital closest to the patient's place of residence could have been used in this study, this would have been based purely on assumption. Instead, the recorded hospital was used within the study. Second, the driving time calculations utilized do not take into account traffic information. As a result, the driving times are likely underestimated in urban areas where traffic is congested.

8.5.2. Study Implications

To the best of our knowledge, this is the first study to provide an in-depth look at how using place of residence rather than place of injury may lead to error. Our results highlight the need for more systematic recording of place of injury as this will allow researchers to more accurately pinpoint where injuries occur, to identify the causes of these injuries and to determine how these injuries might be prevented.

Chapter 9.
Conclusion

Pediatric injuries are one of the leading causes of morbidity and mortality within Canada and the Western world. This dissertation is intended to assist public health professionals in identifying pediatric populations at high risk of injury and in pinpointing the areas in which populations have restricted access to pediatric trauma care. This is done with the aim of allowing more effective provision of services or resources to these populations. Within pediatric populations, low socioeconomic status appears to be a high predictor of increased injury risk. In addition, rural populations with limited access to pediatric trauma centres experience outcomes inferior to those of their urban counterparts. Using spatial methodology as a basis for the analysis, this project provides insight into areas of high risk for pediatric injury identifies the socioeconomic factors influencing injury risk and examines the impact of limited access to pediatric trauma care. Conducting this research within several different geographical settings not only provides a more comprehensive and well-rounded understanding of these relationships but also solidifies the reliability of the methodology. In addition, this research outlines the issues that arise when using incorrect location data in injury research and presents methods of mitigating these. The following chapter summarizes all research chapters within the dissertation in terms of their contributions to research. It also discusses the influence of the dissertation as a whole. This is followed by a reflection on the project and a description of limitations.

9.1. Project Overview and Contributions, and Directions for Future Research

Chapter 2 used two different analyses to examine spatial access to pediatric trauma care within Canada. In the first analysis, a spatial accessibility model was used to create a one hour driving time catchment around each pediatric trauma centre within Canada and to summarize the accessibility of Pediatric Trauma Centres across the country. In the second, the impact of spatial access on length of hospital stay was explored within the provinces of British Columbia and Nova Scotia. The results from this second analysis were used to demonstrate the ways in which geography impacts the provision of specialized and timely care to children living in rural areas. The study described in Chapter 2, is the first of its kind to examine spatial accessibility to Pediatric Trauma Centres in Canada. It is also the first to assess the relationship between Pediatric Trauma Centre access and patient outcome. Using visualization, the study highlights those provinces and geographical areas with poor access and provides an estimate of the population with adequate access to care. The primary contribution of this chapter lies in the application of established methods to a sub population (the specialized trauma centre) that has not previously been explored within injury research. Although still in the development stage, a further study, not included within this dissertation, uses more detailed traumatic brain injury data to explore access to care in terms of impact on patient outcomes. This data includes information such as the amount of time spent with emergency personnel and the procedures performed on the patient prior to arrival at the trauma centre, as well as detailed physiological indicators. The level of detail within this data will allow for a more rigorous analysis of accessibility and outcome.

Chapter 4 focuses on identifying pediatric populations at high risk of traumatic brain injury. In this analysis, spatial statistical methods were used to identify areas of high or low injury risk within Greater Vancouver. After having identified these areas, a statistical analysis was conducted to determine the causes of elevated risk. This analysis found low levels of education to be the main factor influencing high rates of traumatic brain injury. It also found high injury rates in areas with a high proportion of aboriginal people (statistically significant but not to the same extent as a low level of education), thereby confirming that aboriginal children within Canada are at high risk of injury. In that it clearly demarcates the areas in which pediatric injuries are occurring and the causes of injury in each location, this paper makes an important contribution to the limited body of epidemiological injury research within British Columbia. The findings contained within this paper also play an important role in advancing public health through the provision of targeted resources and preventative education to populations within these areas.

A future study, planned for completion within the next year, will link high resolution location data to administrative data on aboriginal status in order to undertake a more detailed analysis of injury rates and causes amongst aboriginal children. As this type of study has yet to be conducted within BC, it should provide valuable information to public health professionals working in the area of injury prevention.

Chapter 6 explores the spatial accessibility of Soroka Hospital in Southern Israel and provides a descriptive analysis of the state of pediatric injury within this region. Using methods similar to those utilized within the previous research chapters, this project also incorporates a temporal dimension within the analysis (seasonality). Findings from this study indicate that patient outcomes in this region are not affected by distance to hospital, likely because of the relatively uniform access throughout the catchment. This study also explores differences in injury rates and mechanisms between the Jewish and Bedouin populations within the area. This is the first study to examine pediatric trauma centre (or any trauma centre) access within Israel. It is also the first to focus specifically on pediatric injury. Although several studies have examined the disparities in health outcomes between Jewish and Bedouin populations, none have focused on pediatric injury.

Chapter 8 draws attention to the use of place of residence as a proxy for place of injury, an important limitation in spatial epidemiology research. In this chapter, a TBI dataset containing both place of residence and place of injury was used to determine how trauma center accessibility analysis and cluster detection are impacted by the use of place of residence as a proxy for injury. The results from this study indicate that the error is dependent upon both the geographic scale of the analysis and the level of data aggregation. Where the study area is relatively small in size, the error propagated by this practice is magnified to the point that it causes the results to be unreliable. While a small number of studies have tried to assess this issue, this research took a slightly different approach, using GIS mapping technology to visualize and quantify the ways in which the error is propagated over space. This paper is also unique in examining this error in relation to trauma center accessibility. As such, it makes an important contribution to injury research and sheds light on a serious limitation within the discipline. It is hoped that the issues brought forward within this paper will prompt further discussion on this topic and ultimately lead to changes in current methods of injury data collection.

9.1.1. Overall Contribution

Unlike most other illnesses, injuries are caused by external factors. As such, injuries are directly related to the physical location (home, playground, neighborhood, etc.) in which they occur and are inextricably influenced by the social, cultural and environmental processes at play within that location. This work attempts to describe the physical locations in which injuries occur in terms of both their spatial (distance to nearest trauma centre) and socioeconomic characteristics, using theoretical concepts and methodological constructs from health geography and spatial epidemiology to further examine these characteristics. This is done in an attempt to better understand how these characteristics influence health outcomes and to determine how those adversely affected by their location (in terms of socioeconomic characteristics or distance to nearest health facility) can be better served and treated.

While each of the papers within this dissertation plays a unique role, the dissertation, as a whole, has three overarching contributions: First, it takes methods developed in spatial accessibility research and applies these to pediatric populations and pediatric trauma centres, underscoring the importance of pediatric injury research and substantially adding to the existing body of knowledge in this field. Second, it contributes significantly to research into social determinants of pediatric injury, showing that this relationship can be generalized (relationship between low SES and pediatric injury) or place specific (e.g Bedouin in the Negev) . Third, and most importantly, this dissertation emphasizes the critical role of locational data in injury research.

A number of studies have used advanced methods of spatial accessibility to measure and examine access to trauma centres(Lawson et al., 2013). Work by Schuurman et. al, for example, examined spatial access to adult trauma centres in Canada while a similar American study used spatial methods to examine access to pediatric trauma centres (Carr & Nance, 2010; Hameed et al., 2010). A few studies have also examined the relationship between spatial access to adult trauma centres and patient outcomes. However, none have focused specifically on pediatric trauma centres in same way that this study does. In this respect, this dissertation fills a gap within the existing research and contributes to our understanding of outcomes for this very important subpopulation.

This dissertation also furthers research into the social determinants of pediatric injury, and more specially, into Traumatic Brain Injury, where research is particularly scarce. This is a significant contribution not only because there is limited information available in this area but also because previous research indicates that children of low SES face much less favourable outcomes in the post-TBI recovery phase(Muscara et al., 2009; Yeates et al., 2004). In this sense, this work assists in providing a more comprehensive picture of the difficulties experienced by low SES children with traumatic brain injuries. In addition, this dissertation is the first to examine and describe the differences in pediatric injury rates between the Bedouin and Jewish populations of Southern Israel. Although the disparities between these two populations are fairly well known within Israel, the extremely high rates of injury found amongst the Bedouin population sets the stage for further investigation into the potential influence of social and cultural factors(Rudnitzky et al., 2012). It is hoped that the results presented in this chapter will provoke additional studies on this topic within the Israeli research community.

The most significant contribution made within this dissertation is the emphasis placed upon the use of accurate location data in injury research. Although a limited number of studies have attempted to assess the error between place of injury and place location in injury research, the unique contribution of this research is its attempt to assess how this error impacts the analysis of spatial access to trauma centres. In so doing, this research emphasizes the critical role of locational data in conducting effective injury research and argues that there is a need to prioritize the collection and use of accurate location data.

9.2. Personal Reflections

With my PhD nearing the end, I want to express how excited I am to have been involved in a project that has the potential to positively impact the lives of children. That said, if I had the opportunity to start over again, there are a few things I would have done differently. First, I would have used a micro scale analysis to address the variation within the range of socioeconomic indicators within this study. This would have allowed for a more detailed examination of the causes of injuries within specific areas and would have been useful in defining the factors of greatest importance when attempting to reduce injury rates within these areas. Secondly, I would have begun my collaboration with Ben-Gurion University much earlier. In addition to the further professional collaborations this would have allowed, there are certain parallels between the Israeli Bedouin population and the indigenous populations of British Columbia that could have added tremendously to the impact of this project. For example a longer collaboration might have allowed for a comparative study between the two countries in which the spatial and socioeconomic factors influencing health outcomes amongst these populations were examined in more detail. It may also have allowed for more extensive collaboration with health care professionals and researchers around social and cultural barriers affecting access to health care services for these populations. Finally, it would have been interesting to explore methods of providing more uniform access to trauma care within BC and Nova Scotia by using location allocation models to determine where best to situate additional trauma resources (pediatric trauma specialists, for example). As the results of Chapter 2 showed, it is very challenging to provide adequate access to trauma care across such a large geographical area. A study that explored how better to address this issue would not only add to the existing body of research but also assist decision makers in mitigating this problem.

In addition to contributing to injury research, this dissertation also adds to existing knowledge in the fields of health geography and spatial epidemiology. In terms of social determinants of health, Chapters 4 and 6, are a direct addition to the body of health geography research. In Chapter 4, the relationship found between low levels of education and poor health outcomes reaffirms theories already established in health geography, while the relationship between low socioeconomic status and poor health outcomes is further confirmed by the drastically higher rates of injury found amongst lower SES Bedouin populations in Southern Israel and described in Chapter 6. In terms of spatial epidemiology, both Chapters 2 and 6 used previously developed methods of spatial access in their analyses. However, in the study conducted in Southern Israel, the access model incorporated ethnicity and SES, in addition to spatial variables, in order to create a more complete model. Furthermore, the work described in Chapter 8 uses a unique combination of spatial methods to assess error within the data. By combining the spatial methods in an unusual way, this study provides a guide for researchers from different fields with similar data issues.

9.3. Challenges and Limitations

Before concluding, I would like to provide a brief overview of the challenges and limitations involved in conducting injury research. While there are a variety of barriers, the two primary issues centre around data inaccessibility and data inaccuracy. Within Canada, as a whole, and BC in particular, gaining access to injury data is a time consuming and discouraging process. In addition, once available, the data is often provided at such coarse resolution (health authority level) that it cannot be effectively used for spatial analysis. This means that data often has to be pieced together from a variety of sources, causing inconsistency in the data variables and affecting the timeliness of research completion. As mentioned previously, the fact that injury locations are not systematically recorded also makes it more likely that error will propagate within the results. A more integrated approach, whereby emergency services personnel record the exact location at which an injury took place and link this to the hospital administrative data in a standardized fashion, could drastically improve the reliability of epidemiological injury research. Finally, in order to better understand the implications of injury research, there is a need to include researchers from both the social and medical sciences. This would allow for a multidisciplinary approach to both data collection and interpretation, and would improve the likelihood of the research findings being used to influence professional practice.

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