A SPATIAL EPIDEMIOLOGY OF TRAUMA: SOCIAL AND SPATIAL PERSPECTIVES TOWARD INJURY

by

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THESIS SUBMITTED IN PARTIAL FULFILLMENT OF
THE REQUIREMENTS FOR THE DEGREE OF

DOCTOR OF PHILOSOPHY

In the
Department of Geography

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SIMON FRASER UNIVERSITY

Fall 2009

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Degree: **Doctor of Philosophy**

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ABSTRACT

Intentional and unintentional injury is the leading cause of death and potential years of life lost in the first four decades of life in North America and around the world. Despite surgical innovations and improved access to emergency care, research has shown that certain populations remain particularly vulnerable to the risks and consequences of injury. In particular, recent integration of geographic information systems (GIS) is beginning to demonstrate the power of mapping and spatial analysis for better understanding these determinants.

This dissertation demonstrates the utility of GIS for better understanding incidence patterns of injury using five different case studies. Each case study is an independent investigation, however all five studies converge on three research questions. First, is there a relationship between geographic scale, socio-economic status, and incidence patterns of intentional injury? Second, would information from this analysis possibly go unnoticed if spatial analysis and mapping are not used to analyze the data? Third, can GIS be used to better explain relationships between incidence patterns of injury and social and demographic data over and above non-spatial surveillance practices? To answer question one, multilevel modeling and scale and zoning restructuring analysis of

Census boundaries were employed. Data were analyzed for the following injuries: assault, suicide, motor vehicle collisions, falls, and pedestrian. To answer question two, a spatial autocorrelation test was used and analyzed against intentional injuries. Finally, to answer question three Poisson probability mapping was applied using a dichotomized classification of intentional and unintentional injury. All data are inclusive to populations living in the province of British Columbia between 2001 and 2006. Secondary data sources included 2001 Census spatial and socio-economic records, British Columbia Trauma Registry data, and provincial Coroner records.

Results indicate that severe injury morbidity and mortality in British Columbia follows a social gradient. However, this relationship is not universal and can vary according to the Census indicator, the injury, as well as the size and scope of the administrative boundaries used to assess the relationship. Further commitment by injury preventionists and Geographic Information Scientists is necessary to yield new knowledge about social and spatial determinants of injury.

ACKNOWLEDGEMENTS

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1: INTRODUCTION

1.1 Overview

Intentional and unintentional injury is the leading cause of death and potential years of life lost in the first four decades of life in North America and in industrialized countries around the world (CIHI 2001). In Canada, injuries are the leading cause of death for all persons under the age of 34 and the fourth leading cause of all hospitalizations (CHIRPP 2006). For every injury mortality there are 45 hospitalizations and an estimated 1,300 visits to the emergency room – of which most are the result of a predictable and preventable circumstance (CHIRPP 2006).

The costs from injury are similarly as staggering. Recent estimates of the cost of hospital care and permanent disability alone totalled $8.7 billion ($CA) annually (Angus, Cloutier et al. 1998). When expanded to include the indirect costs associated with lost wages the magnitude of this burden increases to over $12.7 billion per year, or just under $400 per capita, ranking 4th after cardiovascular disease, musculo-skeletal conditions and cancer in total expenditures (CHIRPP 2006). In British Columbia, it has been estimated that nearly 1,200 people are unintentionally injured per day (Cloutier and Albert 2001). Roughly , 4 people die

each day in British Columbia from severe injury and an additional 10,000 persons are permanently or temporarily disabled (Cloutier and Albert 2001).

Across Canada, mortality from severe injury has steadily improved due to improved coordination and delivery of emergency medical care (Sampalis, Denis et al. 1999; Simons, Eliopoulos et al. 1999; Kortbeek and Buckley 2003). However, Birken et al (2006) have shown that despite improved mortality the percentage of sub-classes of injuries as a proportion of all injury have actually persisted and have disproportionately grown alongside a social gradient (Birken, Parkin et al. 2006).

At its core, this dissertation tacitly acknowledges the importance of adapting a population health perspective for identifying why some populations are injured or at risk of injury more than others. Central to the population health thesis is a recognition of how and why social gradients in health – the stepwise rise in health where outcomes improve as one moves upward from the lowest social stratum to the next higher social stratum – are manifest throughout society and how individual health outcomes are affected in the process (Marmot 1986). This approach addresses the entire range and interaction between individual and societal factors that determine the health and well-being of Canadians. From this framework, it is possible to use an evidence-based approach to identify individual and collective factors that affect health and from these findings propose new

strategies for assessing why some populations are at an increased risk of injury more than others.

Population health encompasses a broader understanding of mechanisms that influence health beyond disparities in the social environment alone. However, this thesis primarily explores the use of geographic information system (GIS) technology for addressing the artefact of scale and the influence of areal partitioning when using administrative data to measure the relative distribution of social and economic conditions associated with injury. To date, no clear attempt has been made by geographers to address the nuances and modifiable effects of discretizing social processes into areal boundaries when analyzing the social determinants of injury. Moreover, research is still emerging on the social determinants of injury, and our understanding (or the lack thereof) of its social and spatial determinants remain largely underdeveloped.

In this vein, this dissertation attempts to fill two timely and important gaps pertaining to our understanding of injuries and their social and spatial expression. Firstly, this dissertation proposes a number of novel methodologies using GIS to link incidence data with spatial identifiers for revealing new trends that would have not been flagged without considering the location of the incident. Converging evidence from international studies on social and spatial indicators associated with injury patterns is now forging new perceptions in our

understanding of how neighbourhood environments impact incidence patterns of severe injury (Geurts, Thomas et al. 2005; Gruenewald and Remer 2006; Rezaeian, Dunn et al. 2006). To date, these analyses analyzes have not been widely used in Canadian research.

Of parallel importance is linking the information-intensive spectrum associated with GIS with the growing evidence in support of exploring health outcomes at the local, community scale, and in conjunction with multiple and interrelated social, economic, and environmental indicators. To date, few Canadian studies have systematically addressed population differences in injuries according to individual or neighbourhood variations in SES. Of these, nearly all focus on incidence patterns among children and youth (Pickett, Garner et al. 2002; Soubhi, Raina et al. 2004; Simpson, Janssen et al. 2005). While infancy and early childhood are critical stages in our physical, mental, and behavioural development, injuries operate at every stage in our life course and evidence is needed from all ages in order to highlight the full spectrum of its magnitude. This dissertation explores adult (ages 18+) injury patterns throughout British Columbia and offers evidence for considering both the nature of its occurrence and its social and economic determinants. The integration of GIS and a population health perspective toward injury will help reinforce the need to manipulate and think past the spatial constraints imposed by the Census when incorporating information on social and economic determinants into risk assessments of injury.

This thesis uses Injury Severity Scores (ISS) to broadly identify severe trauma and uses this score as a basis for all comparisons against individual and contextual comparisons against social and economic factors that may increase the susceptibility of greater risk of injury. The ISS is one of the most widely used measures of physical injury severity (Kuhls, Malone et al. 2002; Gittelman, Pomerantz et al. 2006). The ISS is an anatomical scoring system that assigns an overall score for patients hospitalized from severe injury. Injuries sustained in the head, face, chest, abdomen, extremities, and internal organs are included in its construction. In addition, this thesis further classifies injuries according to intentional and unintentional classes throughout rural and urban areas in British Columbia between the years 2001 and 2006.

Within British Columbia, many health conditions disproportionately affect populations living in rural areas (Lin, Allan et al. 2002; Gilbert, Dawar et al. 2006). In fact, health outcomes are known to follow well-defined social and geographic patterns throughout the province's urban, rural, and remote areas and it may be that injuries follow the same patterns (Dunn 2002; MacNab 2004; Andresen 2006; Alamgir, Cvitkovich et al. 2007; Schuurman, Cinnamon et al. 2009). The intent of this research, however, is not to explain or to understand social structure in any great extent, but to demonstrate how its relationship with injuries may vary at different geographic scales, according to different proxy indicators of social processes, as well as when taking into account the modifiable affect of spatial

boundaries used to derive evidence of this relationship. Through this initial

effort, it is hoped that we will be able to better understand how and why social

gradients in injury exist in British Columbia and what we might do to minimize

their impact.

Research findings are primarily highlighted using two methodological

approaches. Firstly, the use of census-based socio-economic indicators as proxy

measures for individual and neighbourhood socio-economic indicators is used

throughout this thesis. There has been considerable research into the strength of

direct versus indirect measures of socio-economic deprivation taken from the

Census and several studies have reported significant associations using proxy

measures (Carstairs 1989; Krieger, Williams et al. 1997; Martikainen, Maki et al.

2004; Bell, Schuurman et al. 2007). Of parallel importance is linking census-

based indicators of SES with the analysis tools associated with GIS. This

coupling serves two purposes. First, it allows researchers to quantify and

visualize complex spatial relationships between numerous indicators of injury

risk. Second, it also provides an ideal medium through which to explore health

outcomes at the local, community scale and in conjunction with multiple and

interrelated social, economic, and environmental indicators.

Including this introduction, there are eight chapters in this thesis. Chapter two is a

structured review of research advancements in injury prevention as well as

challenges at the intersection of injury prevention and GIS. Chapters three through seven are independent case studies designed for peer-review publication. Each case study is unique and should be interpreted as a stand-alone investigation addressing an important gap in our understanding of the socio-spatial pattern of injuries within a Canadian context. However, all five case studies converge on three similar goals, including: (i) improving our understanding of injury risk, (ii) identifying differences in incidence rates among different population groups, and (iii) the emphasis of novel methodologies for better understanding the environments in which injuries occur. Each case study is similarly based on data taken from the British Columbia Trauma Registry (BCTR) and further analyzed using small-area census and postal code administrative boundaries and secondary datasets. Finally, chapter eight summarizes key findings and limitations in this thesis and highlights expectations for future research.

1.1.1 Case study summaries

There is compelling evidence that neighbourhood socio-economic environments matter profoundly to individual health outcomes. Chapter three (case study one) is a multilevel investigation into individual and neighbourhood-level socio-economic determinants of intentional injury within the Vancouver Metropolitan Area. The purposes of this study are to: (i) determine the extent to which individual and neighbourhood-level socio-economic variables taken from the

Census can be used to broadly assess social processes associated with assault injuries within a Canadian city, (ii) examine the significance of this relationship, and (iii) determine if this relationship is best explained at the individual or neighbourhood scale.

The primary intent of chapter four (case study two) is to develop a better understanding of the specific socio-economic and spatial dimensions associated with intentional injuries in the Vancouver Metropolitan Area. The study also serves a dual purpose in that it proposes a more refined analytical approach toward assessing injury 'clusters' than what has currently been proposed in the literature and highlights a novel use of GIS in providing additional insight into their occurrence.

Case study three is a retrospective socio-demographic analysis of severe fire/burn-related morbidity and mortality instances throughout the whole province over a five year period. Rural and urban fatal and non-fatal injuries are assessed in light of socio-economic and occupational data for each patient and stratified according to Statistics Canada definitions of rural/urban environments. This case study is one of the only accounts of socio-economic variations in burn injury in Canada.

Case study four discusses the important challenges in ecological analysis of injuries, particularly the effects of the Modifiable Areal Unit Problem (MAUP). The

MAUP is a well researched problem in geography but one that has received little attention in injury prevention. The analysis highlighted in this case study points to the inherent dangers associated with compositional and contextual analysis of injuries, but also the underemphasized importance of digging deeper into the intricate relationship between social and economic processes and how they characterize incidence patterns of injury.

Finally, case study five weaves together many of the underlying concepts within the previous four case studies. The patient cohort in this study is specific to persons who were injured on an Aboriginal Reserve throughout BC. The objective of this case study is to examine the spatial distribution of fatal and non-fatal injuries on Aboriginal Reserves in BC in reference to local and regional health outcome patterns. The specific aim of this research is to determine if, and to what extent, incidence rates on reserves are most representative of the burden of injury when assessed against geographically similar communities.

2: LITERATURE REVIEW

2.1 Introduction

Throughout North America, improved injury mortality has primarily been equated with improvements in the coordination and delivery of emergency medical care; including pre-hospital care, shock resuscitation, and critical care and operative techniques (Liberman, Mulder et al. 2005; Sampalis 2006; Tinkoff, O'Connor et al. 2007). However, injury rates remain high, and some populations remain particularly vulnerable to the risks and consequences of injury. For example, a recent review by Birken et al (2006) illustrated that despite a rate reduction of childhood injury in Canada of upwards to 50% since 1952, the percentage of sub-classes of injuries as a proportion of all injury have actually persisted and have disproportionately grown alongside a social gradient (Birken, Parkin et al. 2006). While innovations in critical care medicine highlights improved mortality, it also suggests that there is room for improvement.

However, as with other health conditions, alternative models of injury prevention have been underplayed in favour of the more predominant approach that equates better outcomes with more realized access to healthcare services (Mustard and Frank 1994). Only recently have injury preventionists conceptualized the burden of injury in relation to factors from the social and physical environment, including population and traffic density or social and economic conditions (Shafi, Nathens

et al. 2006). Researchers are keenly interested in the role of geographic information systems (GIS) in this area (Lerner, Billittier et al. 1999; Peleg and Pliskin 2004; Geurts, Thomas et al. 2005; Sciortino, Vassar et al. 2005; Treno, Johnson et al. 2007).

GIS are computer information platforms designed to collect, manage, and store spatial and non-spatial data, as well as combine data sources to help describe the world around us (Schuurman 2004). GIS offer injury preventionists numerous sets of tools for understanding how the spatial organization of social processes converge to either shelter or expose individuals to potentially harmful events (Cromley and McLafferty 2002). These might include the effect of neighbourhood socio-economic environments, accessibility to resources, municipal or regional zoning policies, and other artifacts from the public space (Gruenewald and Remer 2006; Tanser, Gijsbertsen et al. 2006; Aronson, Wallis et al. 2007; Bell, Schuurman et al. 2008). The spatial medium also enables researchers to observe how the amalgamation of spatial and non-spatial data sources yields important knowledge about social and structural processes that might not have been otherwise possible.

One of the most general data sources used in GIS to conceptualize social and spatial indicators associated with population health outcomes is the Census (Mitchell, Dorling et al. 2002; Wang and Luo 2005; Bell, Schuurman et al. 2007).

In particular, Census data and their associated spatial boundaries are emerging as key data sources for a wide range of purposes to illustrate how context from the social environment broadly characterizes incidence patterns of injuries (LaScala, Gerber et al. 2000; Hasselberg, Laflamme et al. 2001; Gruenewald and Remer 2006). Spatial tools, such as adjacency functions or spatial lag models, can also be used to clarify how different spatial arrangements of census boundaries alter our perspectives on the relationship between the social environment and health outcomes (Diggle and Elliott 1995; Nakaya 2000; Krieger, Chen et al. 2002; Schuurman, Bell et al. 2007). To date, there has been little attention given to both the nuance and modifiable effects of discretizing social processes into areal boundaries has when analyzing injury patterns using GIS.

This chapter reviews key perspectives for how geographic space has been used to characterize variations in incidence patterns of injury and highlights important challenges at the intersection between GIS and injury prevention. The chapter also reviews, albeit only in part, core cross-disciplinary theoretical and methodological contributions from both geographic and epidemiologic disciplines that have helped shape a socio-spatial epidemiology of injury. Lastly, this chapter summarizes the principal determinants of injury that have been illuminated through the use of GIS and highlights research methods that have the capacity to increase our understanding of its social determinants.

2.2 The burden of injury

2.2.1 Severe injury in Canada

Severe Injury resulted in the death of approximately 5 million persons worldwide in 2000 (WHO 2002). In Canada, the vast majority of inpatient hospital records for trauma patients are classified as resulting from an unintentional injury. For 2001-2002, the *Canadian Institute for Health Information* (CIHI) National Trauma Registry reported motor vehicle collisions as the leading mechanism of major injury in Canada, accounting for 47% of all major trauma hospitalizations (n=4,386) (CIHI 2002). Of these, 17% (n = 736) were pedestrian-related. Unintentional falls accounted for 29% of all hospitalizations (n = 2,656), with an additional 8% (n = 784) purposively inflicted by another person (CIHI 2002).

In Canada, the vast majority of all injuries among persons between the age of 5 and 14 were to passengers or pedestrians in a motor vehicle collision (CIHI 2002). 36% of all injuries to children under the age of 5 are from unintentional falls, with an estimated 42% of all major trauma hospitalizations for children under 1 due to injury that was purposively inflicted (CIHI 2002). Motor vehicle collisions are the leading mechanism for all major trauma hospitalizations for adults aged 15 – 54, representing nearly 35% of all trauma hospitalizations. The same population group was also the most susceptible to intentional injury from interpersonal violence, representing nearly 90% of all intentional injury

hospitalizations (CIHI 2002). Hospitalizations from unintentional falls were the leading injury mechanism for all adults over the age of 65, representing nearly 62% of all hospitalizations. Gender also plays a significant role in injury, with males representing nearly 72% of all major trauma cases nationwide and no less than 68% of injuries in any category. An estimated 7% of all major trauma injuries in Canada occur at the workplace (CIHI 2002).

2.2.2 Unintentional and intentional injuries

Four sub-classifications of injury were investigated in this thesis, including burns, pedestrian-related injuries, assaults, suicides.

Burns

Burns constitute a significant cause of injury morbidity and mortality for children and adults. In the home, patterns of burn-related injuries usually result from scalding in near-kitchen locations (Delgado, Ramirez-Cardich et al. 2002; Van Niekerk, Reimers et al. 2006). However, nearly one third of all burn-related injuries in Canada occur on the job and are predominantly from electrical, chemical, or thermal heat sources (Gang and Bajec 1992; Khoo, Wee et al. 1994; McCullough, Henderson et al. 1998; Munnoch, Darcy et al. 2000; Mandelcorn, Gomez et al. 2003). However, there is a sharp divide between incidence patterns of burns between countries in the developed and developing world. In Jamaica, for example, burns from chemical-related sources are more

prevalent in assault-related incidents than from job-related injury (Branday, Arscott et al. 1996). In India, burns are second only to motor vehicle collisions as a major cause of death, with one hospital study reporting nearly 20% of all burn-related deaths a result of attempted suicide (Subrahmanyam 1996).

Pedestrian Injuries

Appriximately 30,000 children are struck by cars each year in the US (Hameed, Popkin et al. 2004). In Canada, pedestrian injuries result in nearly 4,000 hospitalizations a year (NTR Analytic Bulletin 2004). Pedestrian-related injuries vary according to both pedestrian and traffic volume, but are also linked to population density and transportation routes that coincide with increased urban development (Braddock, Lapidus et al. 1994; Ewing, Schieber et al. 2003). Most pedestrian injuries occur during clear sunny conditions with excellent visibility and when traffic is moving in both directions (Joly, Foggin et al. 1991). Where children bike and street type have also had significant impact on injury rates as the majority of collisions happen on straight sections of streets and far from traffic signals (Joly, Foggin et al. 1991). Education programs designed to reduce the rates of pedestrian injury previously have met with mixed success relative to environmental modifications, such as creating barriers between foot and vehicle traffic (Klassen, MacKay et al. 2000).

Suicides

Unintentional injury and violence account for about 30% of all lost years of productive life before the age of 65, exceeding losses from heart disease, cancer, and stroke combined (Waller 1994). Public health concern of intentional injuries is still emerging and we still know relatively little of its aetiology and its environmental determinants (Mair and Mair 2003; Middleton, Sterne et al. 2006). Recent studies suggest that greater risk of subsequent suicidal behavior for adolescents and young adults stems from growing up in a family environment characterized by socio-economic adversity and exposure to adverse, dysfunctional, or abusive childhood environments (Fergusson, Woodward et al. 2000). Much of this work has been based on Durkeim's theory of social fragmentation and it has been shown that populations having strong social bonds and a high degree of social cohesion experience lower suicide rates (Whitley, Gunnell et al. 1999).

Violence

In Canada, trauma from violent assault was the seventh leading cause of hospitalization between 1990 – 2003, accounting for six percent of all severe and non-severe cases (Cloutier and Albert 2007). Socio-economic status is one of the most citied risk factors for violence-related injuries by both criminologists and injury preventionists alike (Wright and Kariya 1997; Andresen 2006). Among

indigenous populations across Canada, interpersonal violence is a leading

cause of lowered life expectancy (Richmond 2007).

2.3 Injury prevention and public health

Many of the explanatory concepts and processes of enquiry into injury

prevalence stem from research conducted in the United States. One of the first

national accounts of the burden of injury was published by the American College

of Surgeons Committee on Trauma, which found that in 1965, injuries in the USA

accounted for over 52 million hospitalizations, and resulted in 107,000 deaths

and over 400,000 disabilities (Committee on Trauma and Committee on Shock;

National Research Council 1966). At the time, the state of critical care was so

poor that military personnel returning from overseas publicly asserted that if

critically injured the odds of survival were better in the combat zone than on any

city street in America (Committee on Trauma and Committee on Shock; National

Research Council). These findings prompted an outpouring of attention and

research into the status of injury in America.

One of the most difficult initial tasks for injury prevention epidemiologists was to

change the opinion of the public and many prfessionals/physicians who believed

that injuries occurred as the result of 'luck', 'chance', or by 'accident' (Haddon

1968). In *Accident Research, Methods, and Approaches*, Haddon et al (1964)

summarized current national and international perspectives toward injury

prevention, outlining future needs and the necessary perspectives to create an independent scientific field dedicated to its study (Haddon, Suchman et al. 1964). Three distinct interrelated public health advancements evolved from this publication.

Firstly, there was a tremendous push to transition injury prevention into a more scientific and research-based discipline. Haddon et al (1964) emphasized that injuries results from a series of predictable – and therefore largely preventable – occurrences that arouse out of the relationship between human ecology and potentially or actually hazardous physical and chemical environments (Haddon, Suchman et al. 1964). This description developed alongside the biomedical model paradigm of Western medicine. During the 1960's, injury preventionists borrowed heavily from epidemiology and biomedical engineering in addition to US military experience treating injuries during wartime, hoping that advancements in these fields could be used to recondition professional and public opinion toward notions of injury (Gordon 1949; Waller 1994). For example, Haddon's specification that injuries could be classified into pre-event, event, and post-event phases was structured around the framework previously used to model infectious diseases (Haddon 1968). Haddon's model simplified the determinants of injury into a series of interrelated events, including the host – the individual involved or susceptible to the 'accident', the agent – its specific causal factor, and the environment in which these two factors interacted (Moll,

Donoghue et al. 2002; Cortes, Hargarten et al. 2006; Eddleston, Buckley et al. 2006).

Secondly, reduced exposure to hazardous work-related toxins as well as safety improvements over the past 40 years improved many of the conditions surrounding our daily lives. Many of these improvements are from legislation, such as the requirement for fencing around swimming pools as well as strengthening residential building codes (Skog 2003; Phelan, Khoury et al. 2005). These improvements are also the result of a changing workforce structure within developed countries. Hazardous occupations such as smelting or underground mining are far less significant sources of employment than they were 50 or 100 years ago (Rivara 2000). More broadly, these initiatives stem from improved effectiveness of economic, social, and health care networks, such as transportation networks as well as markedly improved living conditions (Rivara 2000).

Thirdly, injury mortality has dramatically improved as a result of refining the coordination and delivery of emergency healthcare resources (Liberman, Mulder et al. 2004; Utter, Maier et al. 2006). Since the 1970's, the majority of North American trauma centres have been transformed into hierarchical healthcare units. Resource criteria streamline the transport and surgical care of patients in need of facilities across a spectrum of sites from those having only a basic

provision of acute care services to core trauma centers that contain all the necessary resources for definitive life-saving care (Sampalis, Denis et al. 1999; MacKenzie, Rivara et al. 2006). This practice has been based on US military models for organizing and expediting the transport of the injured and has formed the backbone of North American standards in the coordination and delivery of emergency services (Branas, MacKenzie et al. 2005).

One of the earliest civilian analyses demonstrating the life-saving efforts of a coordinated approach toward emergency medical care and the resulting impact that this protocol offered for reducing injury mortality was a retrospective study conducted by West et al (West, Trunkey et al. 1979). The authors analyzed cases of motor vehicle trauma victims who died after arrival at a hospital in Orange County (90 cases) and in San Francisco County (92 cases), California. The purpose of this study was to determine whether patients in Orange country – who were transferred to the nearest hospital after the ensuing incident had different outcomes from those directly transferred to a fully staffed trauma care facility (as were patients who were injured in San Francisco County). An independent panel concluded that two-thirds of the patient deaths in Orange County would have been clearly or potentially preventable had the victims been taken directly to a fully staffed trauma hospital (West, Trunkey et al. 1979). Subsequent investigations have echoed the findings of the two county study,

finding that the systems approach toward patient triage lowered mortality rates by as much as 30 percent (Utter, Maier et al. 2006).

These key developments also demonstrate an underlining focus on measures that required only minimal effort on the part of the individual to improve their health (Gielen and Sleet 2003). Initial advancements in injury prevention largely reflect an underlining belief that any measure that does not require the continued and active cooperation of the public is likely to be more effective than those that do (Haddon and Goddard 1962). Legislation has similarly been viewed as the most efficient and effective model for injury prevention under the rationale that it is far easier to create social expectations through models of social authority than attempt to alter public behaviour (Christoffel and Gallagher 2006).

Improvements in mortality gained through either reduced exposure or increased access to emergency care have also been used to help design tangible models of injury risk. Risk, however, is a multifaceted construct and problemtized by the use of very narrow, ostensibly objective terms that public health agencies use to manage uncertainty (Cohen 1999). Take for example a narrow perspective of 'injury risk' as the number of deaths or hospitalizations each year per 100,000 persons. There is strong evidence that suggests passive prevention strategies aimed at reducing environmental exposures, coordinating healthcare delivery or designing safer transportation networks have not adequately addressed this

growing societal health problem. For example, as we moved forward from 1965 to 1990 – nearly thirty years after development of trauma systems geared toward accessible definitive care within one hour – annual injury statistics in America were shown to account for one out of every 14 deaths and over 150,000 fatalities (Baker, O'Neill et al. 1992). Defining crude death rates as the number of deaths per 100,000 persons, based on 1965 and 1990 population statistics for the USA this actually translates into an *increase* in injury mortality. Clearly, despite significant advancements in injury prevention important and diverse questions remain as to why incidence rates of injury have remained so robust.

The disparity between what is known about the determinants of injury and what is done in terms of actually preventing it is greater than any other major health problem, including both HIV and AIDS (Christoffel and Gallagher 2006). The relative lack of emphasis on alternative models of injury likely stems from a number of complex and interrelated factors. This research gap could be partially explained by an overwhelming policy focus in the delivery of emergency medical services. It may also be attributed to barriers to data, resource limitations, a lack of generalizability of indicators of social or economic position, as well as the presumption that aspects of a person's socio-economic position are not amenable to public health intervention (Cubbin, LeClere et al. 2000; Edelman 2007). Equally likely is the relatively recent notion that injuries are not 'accidents', but are the result of a series of predictable and therefore preventable

circumstances, thereby able to be studied using the same scientific principles that have been applied to most of the other major diseases (Macarthur and Pless 1990).

For example, active prevention efforts to reduce burn/fire-related injury in Canada have primarily addressed risks that occur in the kitchen (Ryan, Shankowsky et al. 1992; Backstein, Peters et al. 1993; Wijayasinghe and Makey 1997; Spinks, Wasiak et al. 2008), from the misuse of cigarettes or alcohol (O'Connor, Bauer et al. 2007), or resulting from improperly positioned/faulty electrical heaters and electrical wiring (Gilbert, Dawar et al. 2006), while leaving largely underdeveloped any theoretical perspectives of why these risks may systematically vary among certain population groups.

To date, the dissemination of occupational or residential safety information remains a core educational and prevention component for burn-related injury reduction. However, the effectiveness of this approach has had mixed success (Mandelcorn, Gomez et al. 2003). In response, injury preventionists have used research from behavioural science to identify particular aspects about human behaviour that either increase or decrease the effectiveness of traditionally more passive injury prevention programs. Mechanisms that may dictate the success of a smoke alarm delivery program may, for example, be influenced by the extent the home owner forms a strong positive intention to maintain the smoke alarm

(i.e. tests the smoke alarm battery every month), encounters no environmental barriers to accessing the smoke alarm (i.e. the alarm is reachable by a household step ladder), and has the skills necessary to successfully test the alarm (Gielen and Sleet 2003). Indirectly, the potential impact of the program would be even more likely to succeed if the home owner also believes that regularly testing the alarm is useful, understands that it is the right thing to do and feels that other residents in the neighbourhood would do the same, feels that it is part of being a responsible home owner, and sees this effort as outweighing other competing household or family demands (Warda and Ballestreros 2007). The behavioural model bridges the historic false dichotomy between active and passive prevention strategies in effort to deliver more effective prevention (Sleet and Gielen 2007).

However, evidence derived from other health outcome studies has shown that key components thought to contribute to the effectiveness of a personal prevention program may be missed when efforts focus exclusively on 'lifestyle' choices measured through such risk modifiers as behavioural patterns (Marmot and Theorell 1988). Syme (1990), for example, found that nearly half of all persons selected for a risk factor intervention trial were unable to follow the recommendations for dietary change and smoking cessation (Syme 1990, cited in Mustard and Frank, 1994). One of the limitations posited from these findings was that in focusing exclusively on the individual, preventionists failed to

acknowledge broader social and cultural forces that may have affected these outcomes, such as stress and empowerment disparities associated with employment hierarchies (Mustard and Frank 1994). To place injuries within the context of broader social or economic conditions throughout society is necessary in order to identify whether factors external to the individual are useful and relevant contexts for explaining why certain populations are continually at a greater risk of injury than others.

2.3.1 Social determinants of health

Some of the most compelling research on the relationship between health and social inequalities refers to findings first published in the *Report of the Working Group on Inequalities in Health*, more widely referred to today as *The Black Report* (Black, Townsend et al. 1982). In the report, crude differences in mortality rates throughout the UK between various social classes were consistently found to be twice as high among unskilled workers than professional labourers, but with rates five to ten times higher among the lowest social classes when itemized by specific disease such as tuberculosis and many cancers (Black, Townsend et al. 1982). These rates persisted across all age groups, with neo-natal and post-neo-natal mortality reportedly two to five times higher among children born into families in the lowest social class. Parallel research from the influential *Whiltehall* studies, a longitudinal study of cardiovascular disease among 17,000 British civil servants, offered additional early evidence that health outcomes were not

isolated, individual events, but shared an overwhelming linkage to an individual's position as he or she moves along the social ladder (Marmot, Davey Smith et al. 1991).

Additional evidence in support of this perspective was highlighted in the early 1990's in a discussion paper written by Goran Dahlgren and Margaret Whitehead for the World Health Organization (Dahlgren and Whitehead 1991). In their report, the authors highlighted the implications in continuing to address health conditions through relatively narrow medical perspectives. They argued instead in favour of adapting a more holistic, encompassing perspective in which individual, communal, and societal factors are viewed as interrelated and intrinsically associated with health and well-being (Dahlgren and Whitehead 1991). The emphasis of this work was to provide a lens for better understanding why addressing single causal elements associated with negative health conditions may fail to decrease inequalities.

There is ample research to justify this alternative perspective toward health inequalities. One of the foremost is from McKeown's (1979) research on life expectancy and the role of modern medicine during the 20th century, which was found to be largely insignificant relative to other factors, particularly nutritional improvements (McKeown 1979). Similarly, and in the face of collectively funded health care systems such as in Canada and the UK, medical or resource-based

models have failed to address why privileged populations continually live longer,

healthier lives than those who experience greater disadvantage (Black,

Townsend et al. 1982; Ross, Wolfson et al. 2001; Dunn 2002).

Figure 2.1 Differences in mortality and life expectancy in England and Wales, 1911-1981. Figure adapted from (Bartley 2004).

Mortality by Social Class (1911 - 1981)

Men, 15-64 years, England and Wales
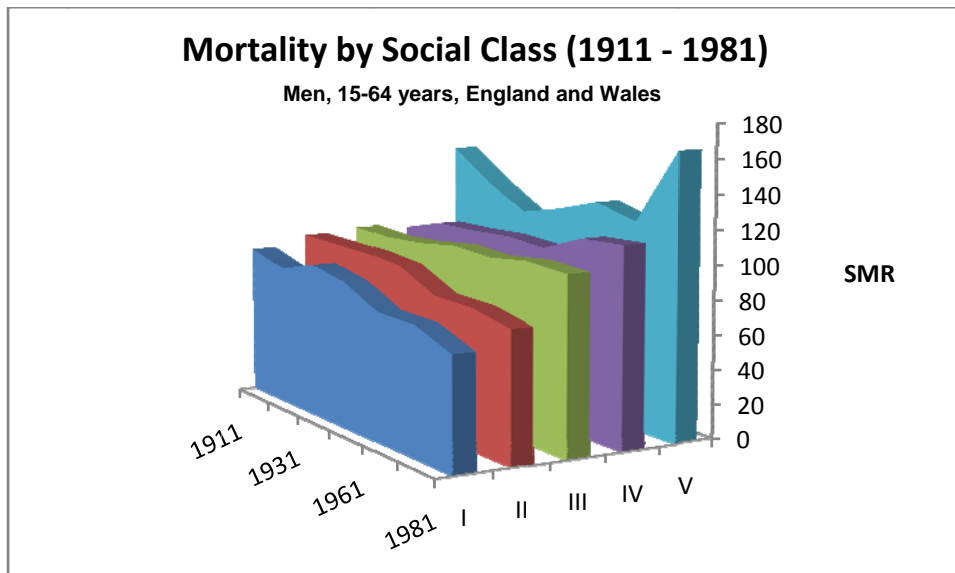
An example of the significance of this perspective is provided in figure 2.1, which

highlights two important concepts. First, across each social stratum, mortality

rates in the UK are clearly decreasing as one moves across the axis of time and

the social spectrum from the lowest social classes (V) to the highest (I).

Secondly, and more importantly, is the apparent lack of a threshold between

improved material living standards of the 20th century and health outcomes. In

fact, the graph is actually showing a reverse effect. Throughout 20th century

Britain, gradients in health were actually *increasing*, suggesting that the

widening gap in relative material wealth led the vast majority of the populations –

not just the poor – to disproportionately experience poorer health outcomes with

each stepwise decrease in social position (Marmot and Wilkinson 2006). It is

important to recognize that these findings emphasize *relative* mortality risk, not

absolute risk. Death rates are decreasing for everyone in industrialized countries,

but not at the same relative rate.

Canadian studies have similarly shown that this pattern is not solely descriptive

of populations in the UK. A previous study of employment earnings of more than

500,000 Canadian males during the 10 to 20 years prior to their retirement

produced a direct relationship between variations in earned income and

increased longevity (Wolfson, Rowe et al. 1993). The magnitude of this

relationship was consistent with evidence earlier reported in *The Black Report* as

Canadian men in the bottom 5 percent of the earning bracket were found to be

twice as likely to die within the first five years of retirement than men in the top 5

percent in the income bracket (Wolfson, Rowe et al. 1993). However, while

variations in morbidity and mortality between the richest and poorest individuals

in society are important to identify, evidence suggests that this relationship is not

solely found among populations in the extremes of wealth and poverty but

stretches across the population stratum as one moves upward to the next highest

social or economic stratum (Mustard and Frank 1994).

2.3.2 Social determinants of injury

Pertaining to injury, Kim et al (2007) raised a significant socio-economic and geographic question, "Why do places matter for injury risk?" (Kim, Subramanian et al. 2007). Among children, for example, a recent study conducted by Edwards et al (2006) found that children with unemployed parents were 13 times more likely to die from an injury as were children who lived in substantially more socially and economically privileged households (Edwards, Green et al. 2006). At the individual scale, it was posited that the increased risk of injury potentially stemmed from psychosocial challenges associated with unemployment and its effects on parental supervision (Edwards, Green et al. 2006). However, viewing 'place' as a location, one can also point to influences of SES, as unemployment holds a direct link to community wealth and the ability to determine, in part, local access to healthcare services, procuring the means to pay for goods such as pedestrian traffic lights and safe playgrounds, as well as in increasing the ability to maintain strong patterns of residential stability that may indirectly lower crime (Cubbin, LeClere et al. 2000). Among youths, these factors become increasingly important as their ability to control their surroundings is quite limited (Kim, Subramanian et al. 2007). If costs preclude areas from having playgrounds more children are likely to play in the street, abandoned buildings, or other hazardous areas, which all increase the likelihood for injury (Durkin, Davidson et al. 1994).

Among adults, the relationship is not as clear-cut. The effects of poverty, education, family context, ethnicity, and lower socio-economic position have all shown to be associated with increased incidence of injury (Cubbin, LeClere et al. 2000). However, evidence has also shown that the strength in association between socio-economic indicators and injury are differentially related to age (Wright and Kariya 1997), gender (Hijar, Kraus et al. 2001), ethnicity (Loomis 1991), occupation (McCullough, Henderson et al. 1998), population density (Fife, Faich et al. 1986), and behavior (Soubhi, Raina et al. 2004) and each of these characteristics interact differently according to the specific cause of trauma (Lyons, Jones et al. 2003; Potter, Speechley et al. 2005). Other injuries, such as those stemming from child abuse, cut across all socio-economic boundaries, but remain systematically linked to substance abuse, economic stress, as well as having parents who were previously abused as children (Christoffel and Gallagher 2006).

Injuries have also been posited to vary according to the context of the social and physical environment where one lives. Neighbourhood conditions have been found to influence one's risk of injury regardless of the strength of their own or that of their families social and economic position (Borrell, Rodriguez et al. 2002; Ferrando, Rodriguez-Sanz et al. 2005; Middleton, Sterne et al. 2006). Here too, however, the relationship is not universal (Agerbo, Sterne et al. 2007).

The importance of SES as a condition that affects either observed or expected incidence patterns of injury among adults is equally diverse. Lower socio-economic position has been posited to effect a persons ability to gain knowledge or purchase resources on safety and protective devices (Ferrando, Rodriguez-Sanz et al. 2005). When coupled with the neighbourhood of residence the importance of SES has been equated with infrastructure problems, poor state of repair of buildings, or buildings with insufficient safety measures (Ferrando, Rodriguez-Sanz et al. 2005).

To date, the predominant response to increased prevalence of adult injury across socio-economic lines focuses on behaviour versus social structure/circumstance when targeting 'high risk' individuals or communities. For example, singular elements associated with high risk behaviours, such as 'drunk driving' and 'speeding' are recurring in the social determinants literature, though now highlighted in reference to persons who live in 'poorer neighbourhoods' who would benefit from direct education and outreach (Mosenthal, Livingston et al. 1995; Braver 2003; Whitlock, Norton et al. 2003; Gill, Taylor et al. 2005).

There are two important exceptions to these trends and both are particular to intentional injury. At least five contemporary research investigations have used proxy markers of social fragmentation or social cohesion to better understand recent and historic population trends in adult suicide morbidity and mortality

(Congdon 1996; Crawford and Prince 1999; Whitley, Gunnell et al. 1999; Congdon 2004; Hempstead 2006). Similarly, social disorganization theory has been incorporated into a small, but emergent research literature within injury prevention in an attempt to highlight an alternative research framework for explaining increased patterns in adult injury injuries stemming from interpersonal violence (Cubbin, LeClere et al. 2000; Fox and Benson 2006; Boyle and Hassett-Walker 2008). The broad intention has been to identify aspects of concentrated poverty that relate to increased violence and injuries (Boyle and Hassett-Walker 2008). Aspects of community cohesion, frequently measured by proxy through rates of mobility and proportions of lone parent families, are viewed in both of these literatures as indicators of decreased community function that impede the collective sense of empowerment as well as limit residents' control over aspects of the neighbourhood or the residents therein (Cubbin, LeClere et al. 2000). All of these variables are viewed as integral components for nurturing community life and stronger equity, effectively reducing the circumstances that lead to violent behaviour and intentional injury.

Interest in social fragmentation and its relationship to individual health outcomes can be traced back to the pioneering work on suicide compiled by French sociologist Émile Durkheim (1858-1917), who found that suicide rates amongst population groups exhibited relatively stable patterns over time even though the populations themselves were dynamic (Durkheim 1952). Durkheim regarded the

social environment as a phenomena that was created by individuals and was also independent of them, constructed from shared ideas, beliefs, customs; the combination of which formed a 'reality' that was more than the sum of any one individual factor (Yen and Syme 1999). This reality was conceptualized as a form of social integration, measured using such constructs as strong social bonds and a high degree of social cohesion, in which highly integrated societies were routinely found to exhibit the lowest suicide rates (Evans, Middleton et al. 2004). The results from this analysis also provided core evidence as to the strength of the social environment in influencing health, particularly in what is by far the most individualized of all health conditions.

The maturation of Durkheim's research into the influence of the social environment and links to individual health outcomes, particularly violence and suicide, was influenced by urban ecologists in the Chicago School of Sociology during the 1920's – 1940's who described how many negative health outcomes were linked to consequences of the growth and development of American cities (Yen and Syme 1999). The challenges of an increasingly urban and technological society were viewed as a result of the influx of rural population transitions to urban life and the unfamiliar social transformations that were needed to survive, socially, in highly dense urban environments, including: anonymity, transitory relationships, as well as role segmentation (Yen and Syme 1999). Consequences of this social transformation, including increased incidence

rates of homicide and suicide, were seen to be more relevant among certain subpopulations – such as highly mobile populations or those who were isolated or cut off from the mainstream (e.g. transients, unemployed, and the elderly). These groups were seen as potentially devolving to states of disorganization and were at risk of succumbing to crime, injury, or death (Yen and Syme 1999).

However, little discussion has taken place within Injury prevention regarding the influence of turning to critical theory for structuring more equitable models of health outcomes (Labonte 2004). These studies have also avoided tackling questions as to the feasibility of including individuals and groups into a set of structured social relationships that were responsible for excluding them in the first place (Labonte 2004). However, it is important to recognize that research into broader, structural indicators associated with intentional injuries is still evolving and has not yet sufficiently consolidated new theoretical frameworks or transformed many existing frameworks into stronger 'upstream' prevention models.

2.4 Geographies of health

2.4.1 Medical Geography

Transitions in geographic thought have progressed along similar lines as in Injury prevention. Beginning in the 1950's, substantive focus on health-related topics had been the foremost interest of medical geographers. Medical geographers

apply geographic concepts and techniques to investigate health, disease, and the organization of health care resources (Meade, Florin et al. 1988). At the heart of this sub-discipline was the pioneering work of French surgeon Jacques May, who is credited as the founder of medical geography and the first to initiate the idea that disease could be studied as a geographical concept (Meade and Earickson 2000). May, like many geographers during the post war era, characterized the spatial identity of populations by compartmentalizing human behaviour and spatial processes into idiographic and homogenous zones (Peet 1998). For example, of particular interest in May's research was comparing patho-physiological variations in surgical outcomes among European and Asian patients who were subjected to the same surgical procedures (Meade and Earickson 2000). May later compartmentalized these variations into cultural and environmental spheres in an attempt to identify unique characteristics about culture and geography that could explain why individual patients responded differently to similar events (Meade and Earickson 2000). May's research was also aligned with a biomedical perspective toward health. Patients' infections and the conditions of their lives were classified for purposes of identifying cultural and environmental conditions that produced and limited their disease (Meade and Earickson 2000).

Also underlying the foundations of medical geography, particularly the use of mapping and spatial analytical methods, are assumptions toward health and

disease that are grounded in a 'positivist theory of space' (Johnston 1991).

Positivism emphasizes that observable facts are the only possible form of

knowledge (Raper 2001). One of the defining features of the transition toward a

positivist epistemology was that it became necessary to reduce the complexity of

idiographic theories in order to formulate laws that could govern the organization

of spatial processes. This transition was necessary to ensure that singular

observations could be used to predict spatial relationships (Peet 1998). Positivist

thought, and the adaptation of its theories into geography, developed along

Comte's (1842) view that the methods of the physical sciences could be applied

to human behaviour and organization (Raper 2001).

Throughout the 1950's and 1960's geographers borrowed from advances in

scientific fields in neurological science, biology, or plant and animal ecology,

hoping that advancements in these fields could redefine human notions of a

'sense of place'(Mitrašinović 2006). For example, Christaller's central place

theory was designed to measure how an optimal, centralized settlement pattern

emerged out of competition for resources, much as how species maintain a

hierarchy of domination. Christaller's theory simplified 'space' into a series of

isotropic planes, where movement across each plane, or cell, could be predicted

using a pre-defined hierarchy assigned to settlement interactions. 'Space'

became the focus of analysis, envisioned as an abstract plane or grid, where

processes from the real world, such as distance, proximity, or clustering could

be quantified and defended through unifying theories of mathematics (Peet

1998).

Many classic models of this era, such as von Thünen's spatial zonation theory,

Christaller's central place theory, and Hägerstrand's diffusion model were

reworked into medical geography as a major component of geographical inquiry

into disease diffusion (Meade, Florin et al. 1988; Shannon, Pile et al. 1989). In

particular, advancements in computer systems and the spatial processing of

geographic information made it increasingly possible to not only model complex

interactions between pathogens and health care services, but also forecast

where pathogens might spread beyond the boundaries of the observed cases

(Bailey and Gatrell 1995). By the 1970's, the increasing sophistication of

computer systems also resulted in more 'realistic' analysis of extraneous

variables' influence on disease processes, such as analyzing 'economies of

scale' or incorporating methods for handling uncertainty and probability (Raper

2001).

During the 1980's and into the 1990's, numerous attempts were made in human

geography to formally define limitations of the positivist epistemology, particularly

the view toward space as merely a container of things (Holt-Jensen 1999). Of

particular importance with respect to medical geography were its low regard

toward disease causation as social construct and how 'place' was identified

primarily as a spatial representation associated with a 'location' with little regard

for a broader conceptualization of a socially constructed experience (Kearns

1993; Gesler, Bird et al. 1997). Dear and Wolch's classic observation of

community mental health care facilities, for example, brought to life awareness of

the interdependency between facility location, demand for services, and policy

toward social and spatial stratification (Dear and Wolch 1987).

At the same time, progressive frameworks for addressing patterns of health and

disease were beginning to emerge in the UK (Krieger 2001). Among them were

new conceptualizations toward the etiology of disease based largely on social

and economic perspectives (Syme 1994). In particular, this research challenged

the biomedical and resource model of health under the premise that the physical

and social environments do not exist independently of each other (Yen and Syme

1999).

Within human geography, the definition of 'place' was similarly transforming away

from a singular reference to a physical location and toward a bounding parameter

where social and spatial identities could be defined and constrained (Duncan

2000). This transformation fuelled burgeoning interest in understanding a wide

number of social, political and economic features of places or communities that

could influence the day-to-day events that helped shape individual health

outcomes. These ranged in scope from factors associated with one's

engagement with community (Dyck 1992), to social processes associated with

structural inequalities (Veenstra 2005), to understanding the relationship between

health and the inequitable distribution of resources (Rosero-Bixby 2004); all of

which have enabled the discipline to be defined by a more holistic and

encompassing perception of a 'health geography' (Bennett 2005).

2.4.2 Representations of social space in GIS

Geographers have attempted to convey, spatially, that injury patterns can be

investigated – and mapped – to better understand the circumstances against

which they occur. The earliest examples of this line of reasoning date back to at

least the 1980's. Whitelegg (1987) reflected on the significance of spatial

patterns to help tease out the interrelationships between human behaviour,

perception, scale and spatially varying susceptibility to hazards (Whitelegg 1987).

Similarly, Joly et al. (1991) used mapping to indicate concentrations of injuries

and the utility of small-area census boundaries to illustrate how demographic

structure and population density factors affected injury (Joly, Foggin et al. 1991).

In fact, the continued collaboration between geographers and injury

preventionists has fueled a burgeoning interest in quantifying the influence of

neighbourhood socioeconomic context on incidence patterns of injury (Lapidus,

McGee et al. 1998; Schneider, Khattak et al. 2001; Graham and Glaister 2003;

Noland and Quddus 2004). Importantly, the increasing analytical power of GIS has enabled trauma investigators to evolve from simple aspatial rate mapping techniques into more complex analysis of spatial interactions. For example, Lightstone's (Lightstone, Dhillon et al. 2001) distance-based analysis of childhood pedestrian injuries in relation to street networks highlighted the physical relationship between proximity, transportation structures, and residential dwellings, highlighted by an incremental decrease in injury prevalence with increased distance between collision sites and residential dwellings (Lightstone, Dhillon et al. 2001). This evidence has been used to fuel new perspectives toward traffic density, intersection design, or modifications to the built environment (Lightstone, Dhillon et al. 2001). Parallel research has similarly been used to quantify the impact of roadway conditions, street geometries, and traffic control devices and incidence patterns of injury, particularly in and around alcohol outlet locations (LaScala, Gerber et al. 2000; Gruenewald and Remer 2006; Treno, Johnson et al. 2007).

Quantifying risk

Detailed assessments of the magnitude of social and spatial burden of injury on the population are commonly constructed using the census. The census is the most widely used data source for identifying the numbers of people at risk according to the same socioeconomic characteristics. Most often, the exposure variable is the individual's, household's, or neighbourhood socio-economic

position relative to the surrounding population. This follows a well-known interest in quantifying how relative variations in both physical and social aspects of places parallel both individual or neighbourhood variations in health. Neighbourhoods have long been conceptualized as dynamic spaces which both enforce and reflect personal identities and values but which are also synthetically tied to broader socio-economic conditions that help to reinforce these perspectives (Diez-Roux, Nieto et al. 1997; Subramanian, Belli et al. 2002).

Mapping risk

Individualized feelings of safety, cohesion, or economic utility associated with one's neighbourhood are similarly associated with an aspect of geographic scale. Quantifying this relationship requires the use of a basic assumption that some defining 'condition' can be held constant over geographic space and over some span of time (Raper 2001). This assumption has most often been played out using administrative boundaries of the census (Laing and Logan 1999; Hasselberg, Laflamme et al. 2001; Howe and Crilly 2001; Pomerantz, Dowd et al. 2001; Lyons, Jones et al. 2003; Marcin, Schembri et al. 2003; Hasselberg, Vaez et al. 2005; Van Niekerk, Reimers et al. 2006).

Small-area census units have been shown to roughly follow similar boundaries of personal reflections of community (Aronson, Wallis et al. 2007). Census boundaries are also relatively stable from year to year (conflation strategies of

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GIS are a large reason for this (Schuurman, Grund et al. 2006)). These two

spatial qualities position researchers to use aggregate-level data to broadly

characterize how proximal or more distal socio-economic, environment, or

physical attributes might also correlate with population health outcomes.

Geographic references highlighting the relationship between social and economic

conditions and incidence patterns of injuries are mapped using either

compositional or contextual references to SES. In both approaches, contextual

aspects of places that are associated with individual health outcomes are largely

based on a 'materialist' framework. The 'material' perspective toward health

inequalities is based on the premise that the a person's opportunities in life are

constrained through features of the physical or social environment, whereby the

accumulation of these forces through one's life course can either positively or

negatively influence their health (Labonte 2004; Veenstra 2005).

Compositional models of this effect, for example, can be used to assess if

relative variations in SES within one geographic area correspond with variations

in the same area's injury morbidity and mortality levels (Pampalon and Raymond

2000). Material variations in health outcomes are measured directly, though

indicators such as average income, or indirectly, using educational attainment,

unemployment ratios, and percentages of home ownership.

Incidence patterns of injuries have been posited to vary according to the context of the social and physical environment where one lives. Neighbourhood conditions have been found to influence one's risk of injury regardless of the strength of their own or that of their families social and economic position (Cubbin, LeClere et al. 2000; Haynes, Reading et al. 2003; Soubhi, Raina et al. 2004). These findings are the primary emphasis of interest in collective social functioning on individual health outcomes; referring to factors from the scale of the social, including shared norms, feelings of empowerment, criminal activity, political and religious histories, traditions, and feelings of trust or safety, that may influence individual health outcomes independent of compositional reasons (Veenstra 2005).

Strategies to quantify the various effects of conditions such as feelings of safety, resource sharing, or the amalgamation of other features that are thought to be a part of more equitable societies, such as social cohesion, levels of trust, and group membership are analyzed using multi-level modelling (MLM). MLM separately analyzes the variance both between and within areal units so as to obtain a nested hierarchy of contextual as well as compositional influences on individual health outcomes (Kennedy, Kawachi et al. 1998; Singer 1998; Diez-Roux 2000; Ross, Tremblay et al. 2004). Research has found that the absence or unequal distribution of many aspects of 'place' measured at the scale of the community may combine with one's individual circumstance (e.g. income,

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employment status) to influence their health status (Kawachi, Kennedy et al. 1999; Ross, Tremblay et al. 2004).

It is important to recognize, however, that both composition and context affect how poverty and poorer living conditions may influence patterns or risk of injury, but data constraints often limit researchers to studying incidence patterns of injury using aggregated data. This is troublesome because of the ecological fallacy, which occurs whenever a researcher makes assumptions about an individual based on aggregated data from a group of individuals (Openshaw 1984). Although multilevel models can circumvent the ecological fallacy they can be similarly criticized for overselling the meaningfulness of contextual effects on health that necessarily must be derived from proxy indicators (Yen and Syme 1999). These problems can be further compounded due to the level of representativeness in the data (Crampton 2004). In Canada, for instance, the census is particularly poor in capturing meaningful socio-economic information among First Nations peoples living on reserves (Statistics Canada 2003).

2.5 Challenges at the intersection of GIS and injury prevention and control

Geographers play a key role in furthering our understanding of the linkages between the social environment and injury and identifying populations at a high risk of suffering an injury. Nearly any data from a health registry can be encoded

with geographic identifiers and explored, spatially, to uncover patterns in morbidity and mortality in ways that were previously either not possible or only feasible at a national scale. GIS is potentially a powerful tool for elucidating and communicating injury trends and the technology can offer both confirmatory and exploratory data solutions to a variety of questions related to its occurrence. The research intersection between GIS and injury prevention and control is still being developed and there is much potential for the technology to serve as a means of analysis and communication of health trends and their graded nature.

2.5.1 Monitoring health outcomes using administrative data

One important starting point in the use of GIS in Injury prevention is in understanding how space is implicated in the production of injury. Many assumptions regarding the social determinants of injury link causes and effects at a specific geographic resolution. In British Columbia, for example, resource allocation formulas for monitoring injuries on aboriginal reserves are primarily derived from provincial and health region statistics, which are the largest of the health authority catchment units (BC Ministry of Health 2006). However, many other scales operate within these boundaries that may be better suited for identifying local variations in utilization or need of healthcare services by population sub-groups. For example, Mao et al (1992) demonstrated that mortality concentrations on reserves are potentially more reflective of actual risk levels if the reference populations exclude major urban centres, which tend to

downgrade small area rates in favour of the larger populations (Mao, Moloughney et al. 1992).

Mao et al's (1992) technique was a derivative of a probability map. Probability mapping techniques combine the strengths of classic rate mapping, but control for population variability by adjusting the significance of the population at risk using information taken from adjacent areas (Choynowski 1959). They are similar to a standard mortality ratio, but reveal the likelihood that the incidence rate would be significant if it were the same for the spatially adjacent reference population. This can help reduce bias from the small numbers problem, which arises due to the common reliance on census administrative geographies to map population aggregates at the finest scale possible while still having access to the descriptive attribute tables about the population (Black 1993).

When mapped, probability techniques also offer a number of criteria for deriving more meaningful reference populations than are currently employed by provincial health authorities. For example, in contrast to referencing regional populations when addressing high or low risk incidence rates of injuries on aboriginal reserves, GIS could potentially be used to define each reserves' "neighbourhood" according to the immediately adjacent communities. This provides a window to investigate health outcomes on reserves relative to populations that are likely to be more socially, economically and geographically relative communities than the

broader regional populations. Currently both the province and aboriginal

communities are moving toward a more local perspective of monitoring health

outcomes on reserves (Government of British Columbia 2005; Government of

British Columbia 2005). Research has shown the important nuances in health

outcomes among First Nation's Peoples that is exposed when focusing more

closely on communities (Chandler and Lalonde 2008). This is an important

research area and developing GIS-based approaches that are extensions of

these perspectives can help redefine and facilitate a more spatialized

understanding of local environments and the burden of injury.

2.5.2 Implications on non-independence

However, in many instances when an event's significance is assessed as a

product of its location additional care must also be given to the relevant spatial

controls. Areas that are close together tend to have similar characteristics, or are

said to be autocorrelated, which may confound the etiological models of injury as

the assumption of variable independence cannot be sustained. A common

approach to control for the distribution of events is to identify spatial

autocorrelation (Goodchild 1987; Odland 1988).

The spatial autocorrelation statistic is similar to a traditional descriptive statistic

such as the mean or the standard deviation, but it also reveals information about

how events are arranged in space (Cliff and Ord 1973; Goodchild 1987; Odland

1988). The utility of the statistic for injury surveillance is two-fold. First, quantifying the spatial variation of injuries allows researchers to infer the extent to which injury risk may be characterized by its location. Second, the measure allows researchers to determine the likelihood that explanatory socio-economic factors are spatially independent, which is beneficial for identifying type I errors.

Thus far, injury preventionists have employed Moran's I autocorrelation technique to uncover spatial patterning of injuries in relation to SES mechanisms (LaScala, Gerber et al. 2000; Geurts, Thomas et al. 2005; Gruenewald and Remer 2006; Rezaeian, Dunn et al. 2006). However, Moran's I is based on the assumption that the measured phenomenon (either SES or the health outcome) follows a Gaussian (e.g normal curve) spatial process (Moran 1950; Geary 1968). Injuries, however, are decidedly non-normal events.

2.5.3 The modifiable effect of boundary design

Problems associated with geographic scale and adjacency arise as a result of the dependence on aggregate data and its associated spatial boundaries. To date, injury prevention literature has focused on identifying ecological processes rather than evaluating, spatially, how different methodologies might redefine how we conceptualize this relationship. Statistical conclusions from aggregated data are susceptible to the magnitude of data aggregation and the ways in which the units are subdivided whenever researchers work with data that are partitioned by

administrative fiat. This problem, more formally referred to as the *modifiable*

areal unit problem (MAUP), has long been the focus of attempts to disentangle

the statistical effects that arise out of various partitioning of areal datasets –

especially those derived from the census (Soobader and LeClere 1999;

Soobader, LeClere et al. 2001; Martin, Dorling et al. 2002).

Attempts to address the MAUP are primarily condensed into two distinct, but

closely related problems. The first is the well known scale effect. As the name

implies, different statistical results are obtained from the same set of geographic

units when they are organized into an increasingly higher (or lower) spatial extent

(Openshaw 1984). Not unrelated, the zoning effect refers to the effect of basing a

hypothesis from areal geographic units, which, if subdivided differently *at the*

same spatial extent, may or may not lead the investigator to conclude differently

(Haynes, Daras et al. 2007).

Recognition of the MAUP is of particular importance in ecological assessments of

injuries as social and economic determinants of health may operate at different

spatial extents (Nakaya 2000; Krieger, Chen et al. 2002; Haynes, Daras et al.

2007; Schuurman, Bell et al. 2007). However, explicit attention to its effects has

yet to be addressed within the injury prevention literature. This is problematic as

the influence of SES may have direct or indirect influences at both proximal and

more distal geographic scales.

For example, targeting 'high risk' neighbourhoods where intentional injuries

occur more frequently might be a suitable scale for the analysis of morbidity and

mortality data, but we might also equally infer that this epidemic is a reflection of

society, thus suggesting that comparisons are more accurate if individual risk

patterns are contextualized against larger municipal or regional environments.

The versatility of GIS enables the analysis of variation across multiple spatial

extents. However, this is not an entirely satisfactory solution as this does not

allow us to determine if incidence patterns are an artefact of how the areal units

are partitioned. Researchers have rarely moved beyond the manipulation of

geographic units defined by the census to model neighbourhood influences on

health – thus contributing an underexplored areal artifice. The task ahead is to

demonstrate if social gradients in health might be made more visible if the

modifiable nature of the areal units is taken into consideration.

2.5.4 Summary

Thus far, the use of GIS for identifying populations who are at a high risk of

suffering an injury has fit the traditionally more passive lens of injury prevention.

This has included mapping aspects of environmental exposures (Braddock,

Lapidus et al. 1994; Zavoski, Lapidus et al. 1999), structuring legislative

improvements (Lapidus, McGee et al. 1998), or measuring the effects of location

and distances on the delivery of emergency medical care services (Peleg and

Pliskin 2004; Morency and Cloutier 2006). In addition, descriptions of singular

variables associated with increased risk of injury, such as 'drunk driving' and 'speeding' have been replaced by 'location to alcohol facility' and 'distance to road network' (Lightstone, Dhillon et al. 2001; LaScala, Gruenewald et al. 2004; Gruenewald and Remer 2006; Treno, Johnson et al. 2007). Where SES has been included, it has primarily been confined into dichotomous classifications ('deprived or privileged', 'unemployed or employed', low income or high income), which limits the creation of new evidence as to the graded relationship between status and health.

In other health outcomes literature, GIS are emerging as key tools for corroborating evidence linking social and economic processes to population health outcomes (Szwarcwald, Bastos et al. 2000; Martin, Dorling et al. 2002; Mitchell, Dorling et al. 2002; Bell, Schuurman et al. 2007). Whilst the inclusion and variations of these perspectives are testaments to growing interest in mapping the burden of injury, increasing spatial inequalities require that researchers take a stronger role in building evidence of the parallel relationship between health and social inequalities.

These challenges lend themselves to further discussion if we are to draw from the census to infer meaningful descriptions of compositional and contextual influences on injury. Within injury prevention, there is a need for greater inclusion of GIS-based methods for amalgamating scaleable datasets that can illuminate

the interaction between social inequalities and injury patterns. Consequently, methodologies discussed above, while capable of fulfilling this objective, may or may not be as capable of disentangling the hierarchical nature of social processes on individual health outcomes as multilevel modeling (Diez-Roux 2000). So long as GIS researchers have access to data from multiple scales, however, these methods should be considered as viable and valuable approaches for increasing our understanding of injury and its social and spatial determinants.

2.6 Conclusion

Injury remains a hidden epidemic and its social determinants should remain a concern among researchers engaged in healthcare policy and health promotion. Geographers today find themselves in a unique position for refining our understanding of contemporary research into health and well-being, particularly injuries, as space and place might be considered intrinsic characteristics of injury – a health condition whose cause originates from outside the body. However, to date there have been few attempts within the discipline to contribute to emerging research on injury and its social determinants (Leslie and Butz 1998; Dorling and Gunnell 2003; Pearce, Barnett et al. 2007). This is not so surprising given how little advocacy within the discipline as a whole has been explicitly directed at the pathways by health inequalities are embedded in the context of our routine encounters with others and the graded nature that these encounters produce

over the life-course (Taylor 1993; Hayes 1994; Dunn and Hayes 2000; Hayes 2004). Importantly, this perspective is not necessarily unique to the discipline as broader interest in addressing the social determinants of health have continually stood in contrast to more medical- and service-based prevention efforts (Mustard and Frank 1994).

Research on the social determinants of injuries is still emerging, and could be much enriched if also explored using geographic information technology. One of integral benefits of GIS is that it often builds on top of traditional analytic methods whilst recognizing that events are also likely to be spatially linked. Geographical concepts can be used to ferret out the complexities of our social environment and help preventionists better understand why some populations consistently and persistently experience greater risks of injury more than others. However, at the intersection of this interdisciplinary merger, there is a need to continue to identify how the information-intensive analysis associated with GIS can be used to corroborate the growing evidence in favour of investigating health outcomes at the local, community scale, and in conjunction with multiple and interrelated social, economic, and environmental indicators. This collaboration constitutes an important component of modern public health research into injury surveillance and prevention.

3: A MULTILEVEL ANALYSIS OF THE SOCIO-SPATIAL PATTERN OF ASSAULT INJURIES IN GREATER VANCOUVER, BRITISH COLUMBIA

3.1 Abstract

Objectives: The purpose of this study is to i) determine the extent to which individual and neighbourhood-level socio-economic indicators broadly reflect the social conditions associated with assault injuries within a Canadian city, ii) examine the significance of this relationship and iii) determine if this relationship is best explained at the individual or neighbourhood scale. Methods: Assault-related hospitalization data (2001 – 2006) were obtained from the British Columbia Trauma Registry (BCTR). Data from the 2001 Census were used as proxy measures of individual and neighbourhood socio-economic status (SES). A generalized hierarchical nonlinear model was used to differentiate between individual and neighbourhood effects. Results: A social gradient according to individual and neighbourhood SES and frequency of assault injuries was observed for adults of all ages. After controlling for age and individual SES,

probability of greater risk of assault injury amongst individuals living in progressively less privileged neighbourhoods remained 1.5 – 3 times higher than individuals living in the least deprived neighbourhoods. For adults under the age of 35 neighbourhood SES was a more statistically significant indicator of increased odds of assault injury than individual income. Discussion: Assessing compositional and contextual variations in health outcomes provides health researchers engaged in injury surveillance a way of showing how, and for which type of people, neighbourhood environments influence the likelihood that an individual will be hospitalized from an intentional injury. This analysis suggests that prevention efforts exclusively focused on the individual may have a limited effect in reducing the occurrence of assault-related injuries, especially among young adults.

3.2 Introduction

In Canada, injuries are the leading cause of death among people under the age of 45 and the leading cause of potential years of life lost, with indirect and direct costs estimated at over $12.7 billion (CIHI 2001). Studies have routinely shown that unintentional and intentional injuries are preventable and – as in many health outcomes – have also been found to vary according to both individual and the neighbourhood socio-economic determinants (Baker, O'Neill et al. 1992; Howe and Crilly 2001; Cubbin and Smith 2002). Evidence from international cohort investigations on multilevel modeling of hospitalization patterns from injury found

that individuals living in disadvantaged neighbourhoods experience a disproportionately higher risk of trauma (Reading, Langford et al. 1999; Cubbin, Williams Pickle et al. 2000). One such study in Canada found that self perceived measures of neighbourhood quality were negatively associated with higher risk for fighting injury among adolescents (Simpson, Janssen et al. 2005).

While we are aware of no study in Canada that has investigated the multilevel association between individual and residential socioeconomic influences on adult hospitalizations from severe assault injury, evidence suggests that individuals living in disadvantaged neighbourhoods are more susceptible to committing violent crime (Sampson, Raudenbush et al. 1997; Wright and Kariya 1997). Multilevel analysis of health outcomes has gained currency over the past decade due to its ability to examine the duel complexity of compositional and contextual influences on health (Diez-Roux, Nieto et al. 1997; Diez-Roux 2000; Macintyre, Ellaway et al. 2002). This research area is underdeveloped within Canadian injury prevention, but may potentially provide health researchers engaged in injury surveillance with a more comprehensive understanding of intentional injury patterns and whether public health initiatives toward injury reduction are best directed at individuals, neighbourhoods, or both.

Using population data from greater Vancouver, British Columbia as a case study, the purpose of this study is to i) determine the extent to which individual and

neighbourhood-level socio-economic variables taken from the Census can be used to broadly reflect the social conditions associated with assault injuries within a Canadian city, ii) examine the significance of this relationship and iii) determine if this relationship is best explained at the individual or neighbourhood scale.

3.3 Methods

Assault-related hospitalization data (2001 – 2006) from the BCTR, the most detailed source of information on severe injuries throughout BC, were used for this analysis. The BCTR contains data for patients injured from multisystem trauma requiring 2 or more days of hospitalization and with an Injury Severity Score (ISS) greater than 12. The database also contains information on the injury mechanism, treatment paths, and in most cases sufficient data on the location of the injury (intersection or postal code) to spatially map the incident and link the patient record with additional attribute information. ICD-10 classification codes within the BCTR were used to determine if the injury mechanism could be attributed to an assault. Injuries sustained from an assault by sexual force or stemming from legal intervention were excluded.

Patient data was spatially linked to population data from the Vancouver Census Metropolitan Area (CMA) using the CanMap Postal Geography dataset. Each patient's residential postal code was assigned to the Census Dissemination Area (DA) and Census Tract (CT) administrative boundary that encapsulated its

location. Due to data suppression in the National Census and to minimize the effect of ecological fallacy, micro-level socio-economic data on average individual income using Census DA's were used as proxy indicators for individual socio-economic position. Neighborhood SES was assessed using the Vancouver Area Neighborhood Deprivation Index (VANDIX).

The VANDIX was previously developed by the authors using feedback from provincial Medical Health Officer's (MHO's) as to the Census indicators that best characterized health and socio-economic deprivation outcomes in the province (Bell, Schuurman et al. 2007). The final index was constructed from the aggregation of the seven variables (shown in table 3.1) that were most frequently selected by the MHO's. Each variable was given a weight proportional to frequency of expert responses. The outcome score is the product of the seven SES indicators z-score, which were standardized to span a negative (least deprived) to positive (most deprived) scale. To control for sampling error and representation, DA and CT boundaries with populations of at least 250 residents, on aboriginal reserves or contained in regional district electoral areas (RDAs) were suppressed from this analysis. In a small number of cases (n = 29), CTs with less than 3 DAs were aggregated into the neighbouring tract to increase the sampling parameters of the multi-level model.

A two-level fixed effects Bernoulli generalized hierarchical linear model (GHLM) was constructed for this analysis using Hierarchical Linear and Nonlinear Modeling (HLM[©]) software published by Scientific Software International. GHLM models are appropriate when it is unrealistic to assume the data follows a Gaussian (e.g. normal curve) distribution and it is not realistic – as is often the case with injury records – to perform a transformation to make them do so. Level-1 variables (n = 3,181) represented individual SES records and were constructed from the DA data. Level-2 variables (n = 345) represented neighbourhood SES and were constructed from the CT data. Dummy variables were constructed for both factors and recoded into high, medium-high, medium-low, and low SES categories. High SES was used as the reference category. Patient records were stratified into 10-year age groupings and weighted based on the 2001 Census population data. In order to decrease the risk of ecological fallacy our analysis was not adjusted by gender as there is no unique identifier linking the BCTR to the National Census.

3.4 Results

Descriptive statistics of individual and area assault injury distributions within the Vancouver CMA between 2001-2006 are listed in table 3.2. Figure 3.1 shows the prevalence scores for assault injury by individual SES. A social gradient follows assault injury patterns for all ages. For all ages, there is over a three-fold increase when classified according to individual income. Injury occurrences rose

stepwise from 12% for individuals within the highest income quartile to 41% for those in the lowest income quartile. This gradient is most evident for adults between 18 – 54, with an average step-wise increase from 11% to 43%. Prevalence of assault injury according to individual SES was less pronounced for adults between the ages of 55 – 64 and highly variable for adults over 65. Figure 3.2 shows the frequency distribution of assault injuries by neighbourhood SES. For all ages, there is a 6-fold increase in assault injury rates by neighbourhood SES. The gradient was evident for all adults under the age of 65, with approximately a 11-fold increase in injury rates across neighbourhood SES for adults between the ages of 35 – 54. Figure 3.3 provides an illustration of assault injury locations within the Vancouver CMA mapped by postal code of the patient's residence and individual-income data from the Census.

In the unconditional HLM model (no SES indicator variables), the results suggest that partial explanation of the variation in assault injuries can be attributed to the between-neighbourhood variation in injury rates (X^2=821.8, p = 0.000, 344_{df}). Results from the conditional HLM model between individual SES and neighbourhood SES are shown in Table 3.3. After weighting for age variation and controlling for individual SES, adults between the ages of 18 and 65 and residing in the most deprived neighbourhoods throughout the Vancouver CMA were 3 to 5 times more likely to be be hospitalized from an intentional injury than adults living in the least deprived neighbourhoods. While a stepwise social gradient in injury

hospitalizations according to neighbourhood SES was similarly found for all ages, itemized age variations across neighbourhoods for adults over the age of 35 collapsed or mirrored the probabilities generated from the individual level model. For adults of all ages, after controlling for neighbourhood SES, using average individual income as a proxy measure for individual SES was not a significant predictor of assault-related injury.

3.5 Discussion

This research provides evidence of a social gradient in hospitalizations from intentional injury throughout greater Vancouver according to both individual and neighbourhood SES patterns. Similar to other health outcomes research from the Vancouver CMA, (Oliver, Dunn et al. 2007) the results from the HLM show that substantial neighbourhood gradients in assault injuries across all social groups remain or are intensified even after controlling for age and individual income characteristics. As in other health outcomes research,(Yen and Kaplan 1999; Merlo 2003; Winkleby and Cubbin 2003; Cubbin and Winkleby 2005) disentangling individual and area SES characteristics associated with increased risk of trauma injury enables researchers to assess the extent to which neighbourhoods influence health. The findings in this research are consistent with other studies that have isolated individual and neighbourhood influences of assault injuries and points to the efficacy of targeting injury prevention at neighbourhoods – as it is more likely that the determinants of intentional injury

have to do directly with the contextual environment of the neighbourhood rather than with the individual (Durkin, Davidson et al. 1994).

The results also show that, when itemized by age, after controlling for neighbourhood SES, greater probability of increased risk of injuries among adults under the age of 35 was statistically unrelated to individual income statistics. This relationship changed among older adults where the influence of neighbourhood SES collapsed or remained equally constant against individual socio-economic position. This variation may point to the likelihood that, among young adults, disadvantaged neighbourhoods increase feelings of social isolation and, in turn, violence. The results also suggest that neighbourhoods are powerful markers of residential stability and community cohesion that can help reduce or buffer the social and psychological factors that influence violent behaviour. Though neighbourhood SES was not a statistically significant indicator of increased injury risk among older adults its relationship mirrored the stepwise gradient between individual income and increased probability of assault injury. This suggests that older adults injured from assault tend to cluster in areas that are more homogenous in terms of individual and neighbourhood characteristics. However, as the main focus of this study was to identify the 'general' association between individual and neighbourhood characteristics and prevalence of intentional trauma injury throughout greater Vancouver we did not identify particular

neighbourhoods more or less prone to varying injury rates or if the location of

neighbourhoods with similar injury patterns were spatially clustered.

Although multilevel modeling techniques are increasingly the standard for

disentangling the impact and relevance of individual and neighbourhood

influences on health, their complexity makes these models highly conditional

(Subramanian 2004). In particular, HLM models are extremely data hungry and

there has been little discussion as to a minimum number of records to produce

reliable estimates. Research from education-related studies suggests a minimum

range of 25 cases nested in each of 25 groups to 60 cases nested within 160

groups,(Paterson and Goldstein 1992; Bryk and Raudenbush 2002) though

others have suggested that these thresholds generally pertain to maintaining the

reliability in estimates generated from small level-two sample sizes (Duncan,

Jones et al. 1998). The use of multilevel modeling has also renewed discussion

over the use of administrative data to quantify area influences on health over

more meaningful neighbourhood or community geographies (Mason 1995;

Macintyre, Ellaway et al. 2002). However, this caveat is often unavoidable in

health research as is the reliance on proxy measures of individual SES using

small-area Census variables such as income. While this remains a limitation,

administrative geographies and their data nevertheless capture broad notions of

context as factors such as income are one of the strongest indicators of health

inequality and widely understood as one of the most important indicators of class status (Kawachi and Kennedy 1997).

In conclusion, one of the benefits of simultaneously assessing compositional and contextual variations in health outcomes is that they provide a way of showing how, and for which type of people, neighbourhood environments matter (Duncan, Jones et al. 1998). Within Vancouver, it is estimated that over 50% of all assaults take place in either the assailants' or victims residence – with nearly two out of every three victims knowing their assailants (Government of British Columbia 2006). This analysis suggests that an exclusive focus on individual determinants of intentional injuries will have limited effect on reducing their occurrence, especially among young adults. While the differences between individual and neighbourhood socio-economic characteristics are complex and difficult to completely reduce to individual indicators of material deprivation, such as average income or the VANDIX, these variables nevertheless capture many of the broader social conditions that characterize health outcomes. Thus, and as was emphasized in this study, multilevel models can provide health researchers with a stronger understanding of the pathways and mechanisms through which the social environment influences injury patterns.

3.6 Figures

Figure 3.1 Distribution of hospitalization cases from assault-related injuries by age and individual SES quartiles derived from average income statistics*, BCTR (2001-2006). BCTR = British Columbia Trauma Registry. *Average income was derived from the 2001 Canadian Census Dissemination Area (DA) geographies.
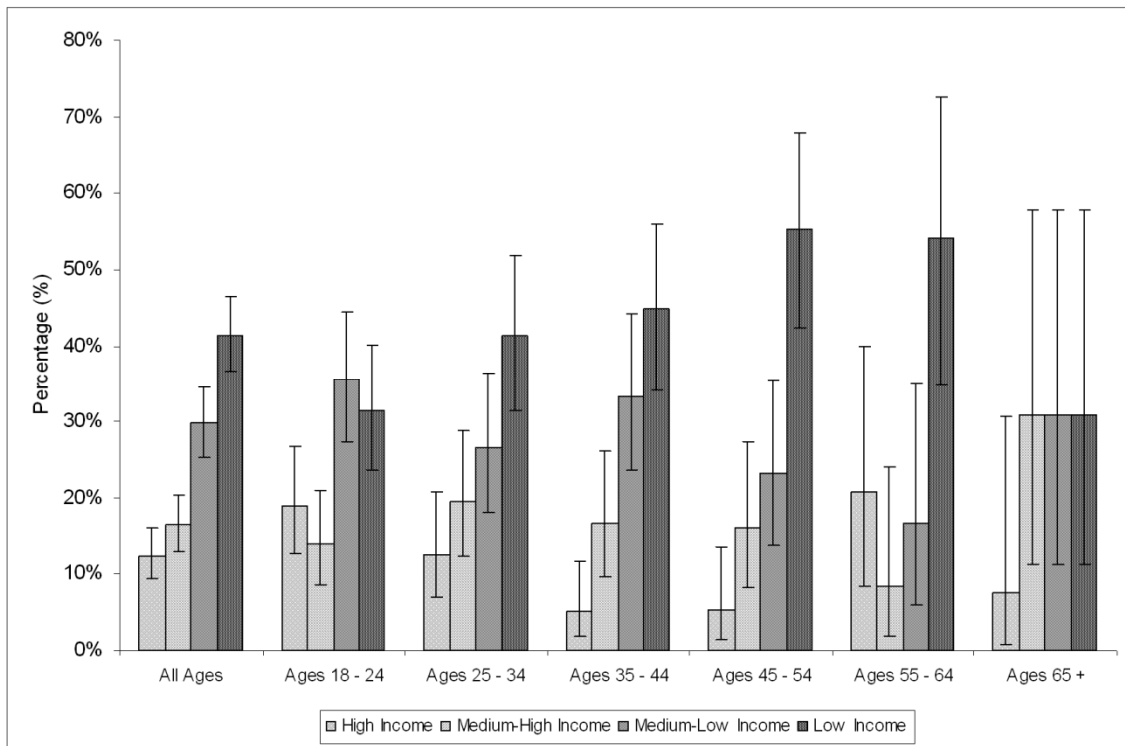
Figure 3.2 Distribution of hospitalization cases from assault-related injuries by age and neighbourhood SES quartiles*, BCTR (2001-2006). BCTR = British Columbia Trauma Registry. *Neighbourhood SES was derived from the VANDIX and 2001 Census Tract (CT) geographies.
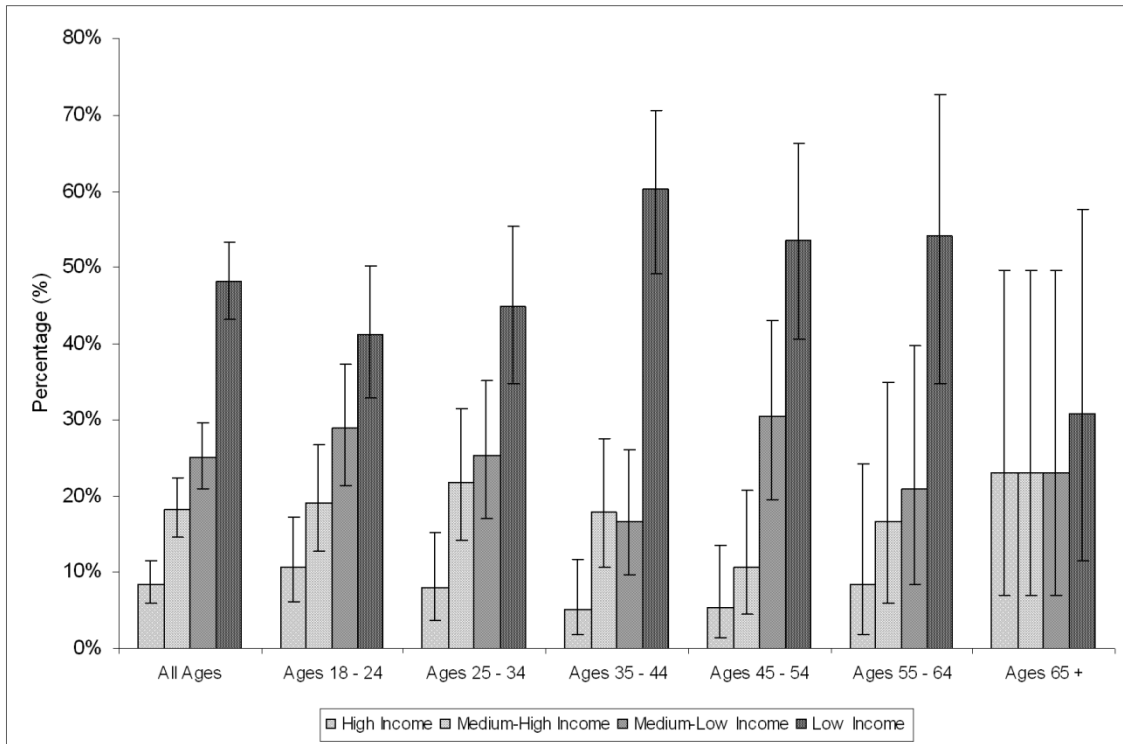
Figure 3.3 Map of severe assault trauma injury and residential income patterns, Vancouver CMA.

2001-2006 Severe Assault Injuries
Vancouver Census Metropolitan Area

Bowen Island

West Vancouver

North Vancouver

Stanley Park

DTES

Port Moody

Burnaby

Coquitlam

Pitt Meadows

Vancouver

Maple Ridge

YVR

Richmond

Surrey

Delta

Langley

British Columbia

Vancouver CMA

Key

▲ Assault Injury

Low Income

Medium-Low Income

Medium-High Income

High Income

SES data suppression

10 Km

Source: British Columbia Trauma Registry; Statistics Canada

3.7 Tables

Descriptive Statistics				
	Count	Mean Age	Mean LOS	Mean ISS
Individual Statistics				
Males	374	35	17	23
Females	29	42	19	21
	Low SES	Mid/Low SES	Mid/High SES	High SES
Area Statistics				
Age 18 - 24	50	35	23	13
Age 25 - 34	39	22	19	7
Age 35 - 44	47	13	14	4
Age 45 - 54	30	17	6	3
Age 55 - 64	13	5	4	2
Age 65 +	4	3	3	3
Total	**183**	**95**	**69**	**32**

Table 3.1 Variables selected for the VANDIX by British Columbia's Medical Health Officers.
The complete survey can be found at:
http://www.gis.sfu.ca/survey/survey_intro.html

SES Constructs	Response Rank	Weight (%)
Average Income	5.5	0.089
Home Ownership	5.5	0.089
Single Parent Family	4	0.143
No High school Completion	1	0.250
With a University Degree	3	0.179
Employment Ratio	7	0.036
Unemployment Rate	2	0.214

Table 3.2 Descriptive statistics of assault injuries taken from the British Columbia Trauma Registry (2001 – 2006) and their socio-economic classification assigned using the VANDIX. ISS = (Injury Severity Score); LOS = (hospital length of stay).

Conditional HLM Model	Ages 18 - 24			Ages 25 - 34			Ages 35 - 44			Ages 45 - 54			Ages 55 - 64			Ages 65 +		
	OR	95% CI		OR	95% CI		OR	95% CI		OR	95% CI		OR	95% CI		OR	95% CI	
		Lower	Upper		Lower	Upper		Lower	Upper		Lower	Upper		Lower	Upper		Lower	Upper
Individual Level																		
Low Income	0.34*	0.19	0.62	0.86	0.46	1.61	3.37*	1.53	7.44	3.36*	1.43	7.91	0.84	0.34	2.09	21.21*	11.36	39.61
Med. - Low Income	0.59	0.34	1.02	0.63	0.35	1.13	5.12*	2.55	10.29	2.38*	1.04	5.42	0.23*	0.12	0.44	22.40*	10.85	46.29
Med. - High Income	0.36*	0.21	0.63	0.67	0.37	1.19	2.83*	1.54	5.20	2.14	0.93	4.90	0.31*	0.18	0.53	9.16*	5.91	14.18
High Income	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Area Level																		
Low SES	5.29*	2.57	10.92	4.33*	2.18	8.62	3.27*	1.53	6.98	4.00*	1.91	8.38	4.27*	1.77	10.32	0.40	0.14	1.15
Med. - Low SES	2.70*	1.35	5.40	2.58*	1.39	4.82	1.15	0.58	2.31	2.81*	1.43	5.56	2.89*	1.31	6.36	0.30*	0.13	0.66
Med. - High SES	1.51	0.70	3.28	3.38*	1.67	6.86	1.64	0.86	3.15	1.42	0.73	2.76	1.60	0.79	3.25	0.59	0.26	1.33
High SES	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--

Table 3.3 Odds ratios (OR) from the hierarchical nonlinear model assessing individual and neighbourhood-level SES against instances of hospitalization from severe assault injury in the Vancouver CMA (2001 – 2006).

4: ARE INJURIES SPATIALLY RELATED? JOIN-COUNT SPATIAL AUTOCORRELATION FOR SMALL-AREA INJURY ANALYSIS

4.1 Abstract

Objective: To present a geographic information systems (GIS) method for exploring the spatial pattern of injuries and to demonstrate the utility of using this method in conjunction with classic ecological models of injury patterns. Design: Profiles of patients' socio-economic status (SES) were constructed by linking patients' postal code of residence to the Census Dissemination Area (DA) that encompassed its location. Data was then integrated into a GIS, enabling the analysis of neighbourhood contiguity and SES on incidence of injury. Setting: Data for this analysis (2001 – 2006) were obtained from the British Columbia Trauma Registry (BCTR). Neighbourhood SES was calculated using the Vancouver Area Neighbourhood Deprivation Index (VANDIX). Spatial analysis was conducted using a join-count spatial autocorrelation algorithm.

Patients: Male and female patients over the age of 18 and hospitalized from severe injury (ISS > 12) resulting from an assault or intentional self-harm and included in the BCTR were analyzed. Results: Male patients injured by assault and who resided in adjoining Census areas were observed 1.3 to 5 times more frequently than what would be expected under a random spatial pattern. Adjoining neighbourhood clustering was less visible for residential patterns of patients hospitalized with injuries sustained from self-harm. A social gradient in assault injuries rates existed separately for males and neighbourhood SES, but less than what would be expected when stratified by age, gender, and neighbourhood. No social gradient between intentional injury from self-harm and neighbourhood SES was observed. Conclusions: This study demonstrates the added utility of integrating GIS technology into injury prevention research. Crucial information on the associated social and environmental influences of intentional injury patterns may go under-recognized without also conducting a spatial analysis. The join-count spatial autocorrelation is an ideal approach for investigating the interconnectedness of injury patterns that are rare and occur only among a small percentage of the population.

4.2 Introduction

Studies have routinely shown that intentional injuries are more prevalent amongst the young and individuals from adverse SES backgrounds (Kellermann, Rivara et al. 1992; Burnley 1995; Singh and Yu 1996; Hussey 1997; Cubbin,

LeClere et al. 2000; Cubbin, Williams Pickle et al. 2000). There is also growing concern that individuals living in disadvantaged neighbourhoods experience a heightened risk of exposure to violence and are more susceptible to experiencing depression and hopelessness (Howe and Crilly 2001; Perez-Smith, Spirito et al. 2002; Mair and Mair 2003). This evidence corroborates the interconnected social and material gradients in health first presented in *The Black Report* (Black, Townsend et al. 1982). In Canada and many nations, injury is the leading cause of death among people under the age of 45 and the leading cause of potential years of life lost, with indirect and direct costs estimated at over $12.7 billion (CIHI 2001). Clearly efforts to better understand and reduce injury inequity are needed.

Using spatial autocorrelation it is possible to identify the contiguity or spatial connection between areas with similar or dissimilar injury patterns (LaScala, Gerber et al. 2000; Geurts, Thomas et al. 2005; Gruenewald and Remer 2006; Rezaeian, Dunn et al. 2006). Spatial analysis can provide valuable supporting evidence as to the influence of the social environment in increasing individual injury rates and offers a means to explore injury patterns beyond classical ecological models alone. A spatial autocorrelation technique that systematically looks at injury patterns that do not exhibit Gaussian (e.g. normal curve) spatial process has not been reported to date. Injuries, moreover, typically do not fit a normal distribution. The join-count autocorrelation test can be used to measure

small-area variations in injury patterns and is particularly useful for exploring the patterns of health outcomes that are rare and occur only within a small percentage of the total population. Using this approach, intentional injury records from a large metropolitan population in Canada are explored for significant socio-economic and spatial clustering.

4.3 Aims & Objectives

Using patient data from greater Vancouver, British Columbia (BC), the aim of this study is to demonstrate the utility of GIS techniques for exploring small-area spatial patterns of intentional injuries within a large urban metropolitan area. The specific objective of this research is to present a method for measuring spatial 'clustering' and use this technique alongside classical ecological statistic models to determine to what extent GIS offers injury preventionists a more nuanced understanding of the influences of place and health.

4.4 Methods

4.4.1 Setting

Data for this analysis were based on aggregated five-year patient records (2001 – 2006) from the British Columbia Trauma Registry (BCTR) stemming from intentional third party and self-harm injury. The BCTR is the most detailed source of small-area information for severely injured patients in the province, compiling

patient data from nine accredited trauma hospitals in BC. The BCTR houses

data on patient characteristics, injury location and mechanism, aspects of acute

care, and outcome on all individuals who have been injured from multisystem

injury requiring 3 or more days of hospitalization and with an Injury Severity

Score (ISS) greater than 12. Intentional injury records were extracted from the

injury mechanism field using ICD-10 classification codes. Records were

assessed using age and sex stratified groupings (18 – 34; 35 – 54; 55 and over).

Patient records were not sub-classified further according to the specific injury

mechanism (e.g. blunt/penetrating).

This analysis was based on the SES characteristics of the patient's area of

residence. Accumulating evidence suggests that unmasking the social,

economic, and physical conditions of everyday life is central to understanding

individual health outcomes (Yen and Syme 1999; Roux 2001). Thus, modeling

material and meaningful dimensions of individual health outcomes has become

an important component of injury prevention efforts (Durkin, Davidson et al.

1994; Borrell, Rodríguez et al. 2002; Marcin, Schembri et al. 2003; Hasselberg,

Vaez et al. 2005). Such investigations capture, in broad terms, the embedded

context of our routine encounters with others and the particularly influential

impact these encounters have over the entire life-course – ultimately pointing to

the processes that create health inequalities and the graded nature of their

production (Hayes 2004).

In this analysis, neighbourhood SES was assessed from the Vancouver Area Neighborhood Deprivation Index (VANDIX). The VANDIX was previously developed by the authors based on a survey of provincial Medical Health Officers (MHO's) of the census indicators that best characterize health and socio-economic outcomes in BC (Bell, Schuurman et al. 2007). The VANDIX is based on the aggregation of seven most frequently cited variables as selected by the MHO's, including: the proportion of the population without a high school education, the unemployment rate, the proportion of the population with a university degree, families headed by a lone parent, home ownership, average income, and the unemployment ratio. Proportional weights were assigned to each indicator based on the frequency of survey responses. Patient hospitalization records were aggregated into the corresponding DA collection boundary that encapsulated their home postal code. In Canada, DA's are the smallest collection boundary for which population socio-economic information can be extracted. DA's are roughly the size of a small number of neighbourhood blocks within high density urban areas and increase in size when encompassing lower density suburban and rural populations. On average, a single DA encapsulates a population of 600 residents within greater Vancouver.

4.4.2 Analysis

This analysis has two parts. First, using GIS, we analyzed the degree of spatial clustering of intentional injuries, which was assessed by the patient's

neighbourhood of residence using a join-count autocorrelation test. Second, we fit a generalized loglinear model to the SES and intentional injury data. DA's with fewer than 250 residents were excluded from both the spatial and socio-economic analysis due to SES data suppression in the Census.

Join-count conceptual framework

Global spatial autocorrelation statistics, *or second-order spatial effects models*, are similar in scope to traditional descriptive statistics such as the mean or the standard deviation, but are specific only to how the data are arranged in space. Similar to a classic correlation coefficient, the autocorrelation outcome statistic acts as an indication of broad spatial trends. A positive coefficient reflects near areas having similarly large or small values and negative coefficients reflect near areas having large inverse values. Positive autocorrelation observations symbolize strong clustering of events while observations of the later suggest dispersion. Typically, tests for spatial autocorrelation are applied in one of two ways: as a preliminary analysis on a set of raw data values, or as a supplementary analysis on residual values from regression analyses. The former is designed for exploratory data analysis while the later provides a mechanism to determine the likelihood that estimates of the standard error are deflated due to confounding effects owing to their location.

The join count statistic is the only global autocorrelation test specifically

designed to measure the spatial arrangement of sparse outcome data. The

statistic is derived from three primary components – classically referenced as the

number of BB, WW, or BW joins. A BB join represents the number of

neighbouring polygons (e.g. census collection areas) where no one was injured,

WW joins represent the number of incidents where two individuals living in

adjacent areas were injured, and BW the number of incidents in which an

individual was injured in one area, but no one was injured in the connecting area.

In practice the BB and WW counts are recoded as 0 and 1 to aid in

computational processing (see figure 4.1). The join-count test statistic is

constrained by how the polygon intersections are derived in the GIS and the

context by which the number of observed joins between neighbouring areas is

contrasted from the expected number of joins. For irregular polygons, such as

census collection boundaries, the polygon joins are measured using Boolean

logic whereby a join is defined by the number of neighbouring polygons that

share a common line segment.

Building autocorrelation methods for binary data

A binary contiguity matrix was constructed to test the likelihood that the spatial

pattern of DA's encompassing individuals who were hospitalized from intentional

injury were significantly non-random. The binary contiguity matrix was assigned

using sampling without replacement and so the probability of the presence or absence of an injury is constrained by the total number of census polygons included in the analysis. The standard error of the expected number of BB, WW, or BW joins gauges if differences between the observed and expected joins are significantly different than random. The number of expected joins is calculated by

$$E_{BB} = \frac{J n_B^{(2)}}{n^{(2)}}$$

,

$$E_{WW} = \frac{J n_W^{(2)}}{n^{(2)}}$$

and

$$E_{BW} = \frac{2 J n_B n_w}{n^{(2)}}$$

where $_B$ and $_W$ refer to the number of black and white polygon joins and J denotes the total number of observed joins between areas.

The standard errors of the O_{BB}, O_{WW}, and O_{BW} joins under randomized sampling are

$$\sigma_{BB} = \sqrt{E_{BB} + \frac{\sum L(L-1)n_B^{(3)}}{n^{(3)}} + \frac{[J(J-1) - \sum L(L-1)]n_B^{(4)}}{n^{(4)}} + E_{BB}^2}$$

,

$$\sigma_{WW} = \sqrt{E_{WW} + \frac{\sum L(L-1)n_W^{(3)}}{n^{(3)}} + \frac{[J(J-1) - \sum L(L-1)]n_W^{(4)}}{n^{(4)}} + E_{WW}^2}$$

and

$$\sigma_{BW} = \sqrt{E_{BW} + \frac{\sum L(L-1)n_B^{(1)}n_W^{(1)}}{n^{(2)}} + \frac{4[J(J-1) - \sum L(L-1)]n_B^{(2)}n_W^{(2)}}{n^{(4)}} + E_{BW}^2}$$

where B, W, J are as previously defined and L represents the total number of

links between polygons (e.g. polygons AB and polygons BA). Note that L is a

constant and always denoted as twice the number of joins. From the classic test

statistic

$$Z_{BB} = \frac{O_{BB} - E_{BB}}{\sigma_{BB}}$$

it is possible to derive the likelihood that the number of O_{BB}, O_{WW}, and O_{BW} are

either significantly clustered, or dispersed. If there are more BB and WW joins

than BW joins the pattern will tend to exhibit stronger clustering rather than

dispersion, with the inverse being true of BW patterns. A more detailed

definition of the join-count algorithm can be found elsewhere (Cliff and Ord 1973;

Goodchild 1987; Griffin 1987). The join count algorithm for this research was

constructed by the authors using VBA computer scripting language inside the

ArcGIS 9.x software designed by *Environmental Systems Research Institute*

(ESRI).

Loglinear Model

A generalized loglinear model was used to measure relative risk of intentional

injury against area SES using SPSS^{TM} version 15. The loglinear model was used

to account for the small number of intentional injuries in greater Vancouver

relative to the total Census population. Incidence of injury were stratified by age

and gender and assessed using quintile scores based on the VANDIX, with the

most affluent areas coded SES 5 and the most deprived areas coded SES 1.

Male and Female aged 55 and older and living in SES 5 areas were used as the

reference category as this age group represented fewer cases of injuries than

populations under the age of 55.

4.5 Results

Of the 3,283 DA's above the population threshold used for this analysis, 339

contained at least one individual hospitalized from an assault compared to 79

containing at least one person who was hospitalized from a self inflicted injury.

Dummy variables were constructed for DA's having more than one individual

injured from an assault (n = 41) or self-harm (n= 3). Severe injuries resulting from

sexual assault by bodily force (n = 1) and injuries stemming from legal

intervention (n = 12) were excluded from the database prior to analysis.

Additional records (n= 97) where the residential postal code was missing were

also omitted. These missing records could be attributable to a person having no

fixed address, a patient from out-of-province, or error in data entry before

inclusion in the BCTR.

Spatial autocorrelation statistics for patients' neighbourhood of residence are

listed in table 4.1. Throughout greater Vancouver, individuals who were

hospitalized from a severe assault-related injury resided in neighbouring areas

1.7 times more often than what would be expected under a random spatial

pattern (z_{ww} = 7.67, p 0.05). When stratified by age, males between the ages of

18 – 34 were 1.4 times likely to reside in neighbouring areas (z_{ww} = 2.63, p0.05).

Neighbourhood clustering of male patients increased to roughly three and five

times more than what would be expected under a random spatial pattern for both

males ages 35 – 54 and those over the age of 55 (z = 8.22_{ww}, p 0.05; z = 3.70_{ww},

p 0.05). No significant clustering or dispersion patterns were found for assault

injuries among female patients. Figure 4.2 illustrates assault-related injuries by

patients' neighbourhood of residence.

Intentional injury from self-harm amongst males and females of all ages followed less significant spatial patterns than assault injuries (z = 1.59$_{bw}$, p > 0.05) and there was no occurrence of spatial clustering when stratified by age and gender. Non-random spatial patterns of self-inflicted injuries for males between 18 - 34 were observed (z = 1.88 $_{bw}$, p0.06), but the significance of the spatial pattern was not significant of clustering beyond a general non-random pattern. Figure 4.3 illustrates intentional self-harm injury patterns by patients' neighbourhood of residence.

Odds ratios from the loglinear model are listed in table 4.2. Males under the age of 35 were five times more likely to be hospitalized from a severe assault injury than males over the age of 55. Area SES was also a statistically significant indicator of increased incidence of assault related injury among males of all ages, with rates two to nearly four times higher for individuals living in areas coded as the most socio-economically deprived (SES 1 and SES 2) relative to the most affluent areas (SES 5). Only among males aged 35 – 54 who were severely injured from an assault and living SES 1 neighbourhoods were hospitalization rates higher than what would be expected given the singular relationship between assault, age group, and neighbourhood SES alone. No significant singular or cross-level effect between assault, age and neighbourhood SES was observed among female patients. Similarly, no statistically significant relationships were observed in the odds ratios for hospitalizations from self-

inflicted injuries among males or females of all ages, respectively. Figure 4.4 is
a map of neighbourhood SES for greater Vancouver generated from the
VANDIX.

4.6 Discussion

The primary aim of this paper was to provide an in-depth illustration of a GIS
spatial autocorrelation technique that might serve as a catalyst for further
research in injury prevention. The autocorrelation tests illustrated that severe
intentional injuries stemming from assault largely follow distinct clusters
throughout greater Vancouver, but that this pattern was considerably less
pronounced for injuries sustained from intentional self-harm. A particular feature
of this study that enabled these separate findings was the use of the join-count
autocorrelation algorithm.

In this study, the lack of a social and spatial pattern among intentional self-harm
injuries is a significant finding. Recent studies suggest that greater risk of
subsequent suicidal behavior for adolescents and young adults stems from
factors associated with living in areas that experience population loss
(Hempstead 2006) and growing up in a family environment characterized by
socio-economic adversity and exposure to adverse, dysfunctional, or abusive
childhood environments,(Fergusson, Woodward et al. 2000) but this evidence
has also produced mixed results when modeled using socio-economic data taken

from the census (Crawford and Prince 1999; Goodman 1999; Cubbin and Smith 2002; Fukuda, Nakamura et al. 2005).

The majority of neighbourhoods (n = 65, 83%) encompassing the home address of a patient hospitalized from a severe injury sustained from self-harm had not experienced a population loss in the five years preceding the 2001 Census. Similarly, the Census areas that encompassed the patients' postal code are all primarily high or semi-urban population areas, reducing the likelihood that the results from this study are confounded owing to a rural/urban divide. The loglinear model highlighted a structural variation in many of the core socio-economic indicators thought to characterize increased prevalence of intentional injuries and also adds to the literature on possible limitations of Census data to produce meaningful indicators of suicide behavior. Additionally, when viewed in conjunction with the varied spatial pattern in the data the results from this study indicate that intentional self-harm injuries affect a highly invisible population. This is a significant finding, possibly reflecting a unique structural variation between the conditions that give rise to para-suicide and suicide mortality. A more detailed survey of these specific neighbourhoods may reveal if these variations can be ascribed to general population trends elsewhere.

While this study has demonstrated the added utility of the join-count autocorrelation test researchers should, however, be aware of two shortcomings

ubiquitous to all autocorrelation coefficients. Global autocorrelation coefficients are initial exploratory data analysis techniques and only provide a general indication of the degree of clustering of a measurable outcome across the entire study area. More localized indicators of spatial autocorrelation (LISA) should be employed to specifically indicate which areas confound standard errors in the regression coefficient between area SES and incident rates (Anselin 2006). In addition, the join-count autocorrelation statistic is not sensitive to geographic size and care should be administered if the approach is used to ascribe meaning from adjacencies between large geographic areas (e.g. state boundaries, health authority units) as well as other caveats related to the modifiable areal unit problem (MAUP) (Openshaw 1984; Openshaw 1984).

To date, spatial autocorrelation of injury patterns has primarily been accounted for using *Moran's I* calculation, but this method is inappropriate for obtaining statistically reliable information from health outcome data that cannot be transformed to fit a 'normal' distribution. The join-count spatial autocorrelation statistic is an underused GIS spatial analysis technique and is ideal for exploring the spatial connectivity of injury patterns that are rare relative to the total population. The algorithm is potentially useful for an array of trauma services and injury prevention research, ranging from highlighting specific regional injury mortality variations between rural and urban populations to aiding in the placement of community outreach or rehabilitation programs. Whilst many health

outcome data will be more suitably addressed using other spatial

autocorrelation techniques, spatial statistic algorithms specifically designed to

handle binary data are another means for quantifying the significance of location.

Research of the aetiology and environmental determinants of intentional injuries

is still emerging (Mair and Mair 2003; Middleton, Sterne et al. 2006). These

studies may be further enriched if also explored using geographic information

technology. One of many strengths of GIS is that it often builds on top of

traditional analytic methods whilst recognizing that these events might also be

spatially linked. The integration of sophisticated spatial analysis into injury

prevention constitutes an important component of modern public health research

into injury surveillance and prevention. The join-count spatial autocorrelation test

is one of many spatial analysis algorithms that can be used in injury prevention

strategies to target areas where risk is concentrated.

4.7 Figures

Figure 4.1 Conceptual model of the join-count spatial autocorrelation test.
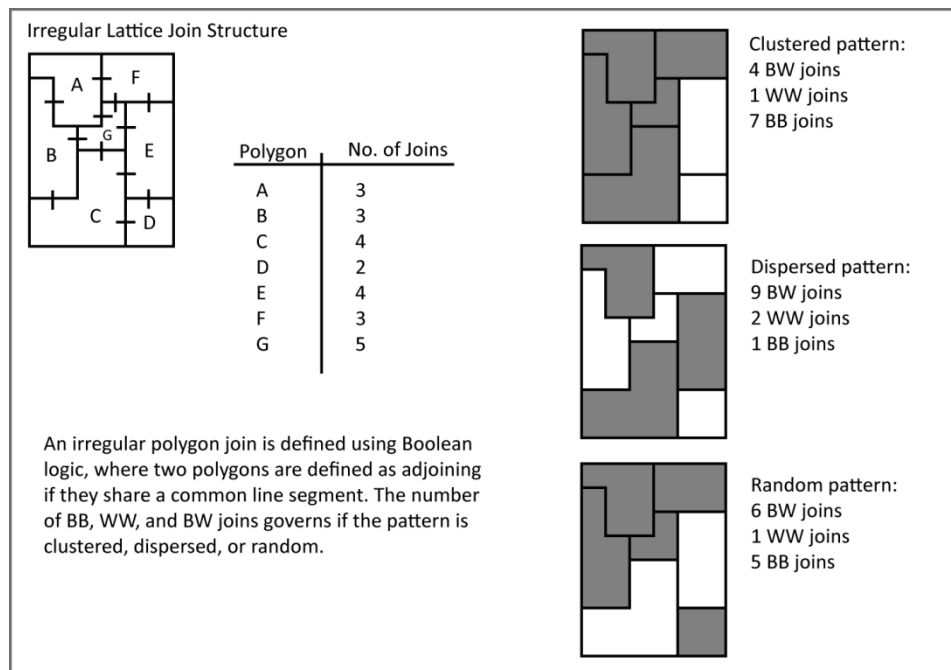
Figure 4.2 Neighbourhoods of residence for patients' who were hospitalized from an assault injury between March 2001 and March 2006.

Figure 4.3 Neighbourhoods of residence for patients' who were hospitalized from an injury caused by self-harm between March 2001 and March 2006.

Key

Injury
(WW, 1)

No Injury
(BB, 0)

10 Km
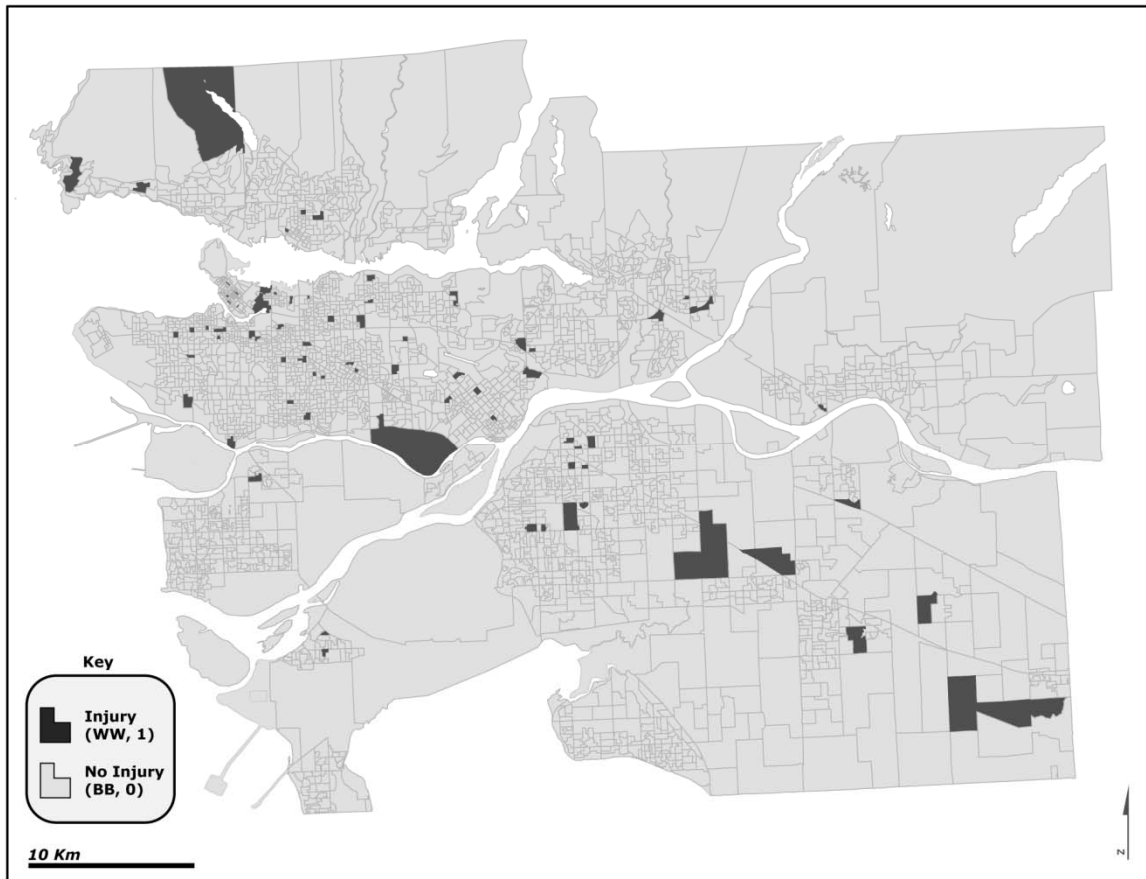
Figure 4.4 Neighbourhood SES scores for the Vancouver Metropolitan Area.

4.8 Tables

Injuries from Assault

Demographic		Injury Counts		Observed Joins			Expected Joins			Standard Error			Join-Count Autocorrelation		
Age	Gender	0 (b)	1 (w)	O_{bb}	O_{ww}	O_{bw}	E_{bb}	E_{ww}	E_{bw}	σ_{bb}	σ_{ww}	σ_{bw}	Z_{bb}	Z_{ww}	Z_{bw}
18 - 34	M	3,093	190	8,945	49	1,124	8,980	34	1,104	27.12	5.70	27.23	-1.29	2.63*	0.73
35- 54	M	3,162	121	9,328	44	746	9,386	14	718	22.20	3.65	22.24	-2.61	8.22*	1.26
> 55	M	3,247	36	9,848	5	265	9,897	1	219	12.48	1.08	12.49	-3.93	3.70*	3.68*
18 - 34	F	3,271	12	10,004	0	74	10,004	0	74	7.27	0.35	7.27	0.00	0.00	0.00
35- 54	F	3,273	10	10,049	0	69	10,056	0	61	6.64	0.29	6.64	-1.05	0.00	1.20
> 55	F	3,278	5	10,088	0	30	10,087	0	31	4.70	0.14	4.70	0.21	0.00	-0.21
DA Total		2,944	339	8,052	184	1,882	8,136	107	1,875	34.23	10.04	34.59	-2.45	7.67*	0.20

Injuries from Self-harm

Demographic		Injury Counts		Observed Joins			Expected Joins			Standard Error			Join-Count Autocorrelation		
Age	Gender	0 (b)	1 (w)	O_{bb}	O_{w}	O_{bw}	E_{bb}	E_{ww}	E_{bw}	σ_{bb}	σ_{ww}	σ_{bw}	Z_{bb}	Z_{ww}	Z_{bw}
18 - 34	M	3,262	21	9,971	0	147	9,989	0	129	9.59	0.63	9.59	-1.88	0.00	1.88†
35- 54	M	3,256	27	9,946	1	171	9,952	0	165	10.85	0.80	10.85	-0.55	1.25	0.55
> 55	M	3,273	10	10,049	0	69	10,056	0	61	6.64	0.29	6.64	-1.05	0.00	1.20
18 - 34	F	3,278	5	10,089	0	29	10,087	0	31	4.70	0.14	4.70	0.43	0.00	-0.43
35- 54	F	3,269	14	10,030	0	88	10,031	0	86	7.85	0.41	7.85	-0.13	0.00	0.25
> 55	F	3,279	4	10,098	0	20	10,093	0	25	4.21	0.11	4.21	1.19	0.00	-1.19
DA Total		3,204	79	9,608	6	504	9,634	6	475	18.21	2.39	18.23	-1.43	0.00	1.59

* $p < 0.05$; † $p < 0.10$

Table 4.1 Join-count spatial autocorrelation results for greater Vancouver. Data mapped by patients' neighbourhood of residence.

Assault Injuries by Dissemination Areas | | | | | | | | **Self-Harm Injuries by Dissemination Areas** | | | | | | |

	Males				**Females**				**Males**				**Females**		
		95% Confidence Interval				95% Confidence Interval				95% Confidence Interval				95% Confidence Interval	
Parameter	OR	Lower Bound	Upper Bound	Parameter	OR	Lower Bound	Upper Bound	Parameter	OR	Lower Bound	Upper Bound	Parameter	OR	Lower Bound	Upper Bound
Age				Age				Age				Age			
18 - 34	5.89*	2.17	16.01	18 - 34	5.12	0.25	106.59	18 - 34	0.60	0.08	4.54	18 - 34	0.34	0.01	8.37
35 - 54	0.76	0.22	2.63	35 - 54	1.87	0.08	45.79	35 - 54	1.61	0.37	6.92	35 - 54	0.62	0.06	5.98
55 +	.	.	.	55 +	.	.	.	55 +	.	.	.	55 +	.	.	.
Area				Area				Area				Area			
SES 1	2.54	0.83	7.80	SES 1	5.14	0.25	107.02	SES 1	0.24	0.01	5.01	SES 1	1.03	0.11	9.87
SES 2	3.11*	1.05	9.26	SES 2	3.28	0.13	80.48	SES 2	1.71	0.34	8.65	SES 2	1.82	0.24	13.79
SES 3	2.88*	0.95	8.69	SES 3	3.54	0.14	86.83	SES 3	0.74	0.10	5.61	SES 3	0.39	0.02	9.65
SES 4	1.15	0.31	4.26	SES 4	3.41	0.14	83.85	SES 4	2.08	0.44	9.74	SES 4	0.38	0.02	9.31
SES 5	.	.	.	SES 5	.	.	.	SES 5	.	.	.	SES 5	.	.	.
18 - 34 +				18 - 34 +				18 - 34 +				18 - 34 +			
SES 1	1.12	0.33	3.74	SES 1	0.56	0.02	16.30	SES 1	21.85	0.66	727.78	SES 1	5.39	0.12	237.94
SES 2	0.42	0.13	1.41	SES 2	0.07	0.00	5.53	SES 2	2.24	0.20	25.36	SES 2	1.81	0.04	79.92
SES 3	0.56	0.17	1.89	SES 3	0.20	0.00	8.77	SES 3	2.51	0.14	43.99	SES 3	8.94	0.10	826.33
SES 4	1.11	0.27	4.52	SES 4	0.46	0.01	16.56	SES 4	2.25	0.21	23.64	SES 4	8.83	0.10	815.66
SES 5	.	.	.	SES 5	.	.	.	SES 5	.	.	.	SES 5	.	.	.
35 - 54 +				35 - 54 +				35 - 54 +				35 - 54 +			
SES 1	5.98*	1.45	24.73	SES 1	0.46	0.01	17.51	SES 1	9.24	0.38	223.41	SES 1	1.37	0.06	33.55
SES 2	1.55	0.37	6.51	SES 2	1.18	0.03	47.70	SES 2	0.37	0.05	2.98	SES 2	1.66	0.10	26.87
SES 3	2.40	0.58	10.01	SES 3	0.61	0.01	26.79	SES 3	1.34	0.13	13.64	SES 3	12.01	0.30	473.90
SES 4	2.08	0.40	10.77	SES 4	0.32	0.01	16.22	SES 4	0.27	0.04	2.06	SES 4	8.69	0.22	349.67
SES 5	.	.	.	SES 5	.	.	.	SES 5	.	.	.	SES 5	.	.	.

* $p < 0.05$

Table 4.2 Generalized loglinear results from contrasting incidence of intentional injury against neighbourhood SES

5: A SMALL-AREA POPULATION ANALYSIS OF SOCIO-ECONOMIC STATUS AND PREVALENCE OF SEVERE BURN/FIRE-RELATED INJURY IN BRITISH COLUMBIA, CANADA

The following chapter has been published in Burns.

Citation details: Bell, N., N. Schuurman and S. M. Hameed (In Press). " A small-area population analysis of socioeconomic status and prevalence of severe burn/fire-related injury in British Columbia, Canada." Burns.

5.1 Abstract

Socioeconomic determinants of injury have been associated with risk of burn injury in the UK and USA, but the relative significance of this impact is largely unknown across Canadian populations. The purpose of this study is to determine the extent to which socioeconomic status (SES) is linked to risk of burn injury in the province of British Columbia (BC) and identify the extent to which these findings are generalizable across both urban and rural population groups. Measures of SES were based on province-wide comparisons using data obtained from the Canada Census using the Vancouver Area Neighbourhood Deprivation Index (VANDIX). Results illustrate that the effects of SES and increased injury risk are substantial, though the most pronounced variations were exhibited across each SES stratum for urban areas and with less demonstrable effect when itemized by injury type within rural areas. Although conservative, the results from this study illustrate that burn injuries disproportionately affect

populations of greater relative socio-economic disadvantage and continued

efforts to also address social inequities and their link to injury prevalence is likely

to be more effective than targeting individual behavior alone when trying to

reduce and eliminate their occurrence.

5.2 Introduction

Burn injuries are a major public health concern. In the US, it has been estimated

that the total direct and indirect costs incurred from burn/fire-related injuries are

nearly four to six times the total costs of treating many cancers or heart diseases

(Baker, O'Neill et al. 1992). The most recent national data from Canada on

annual costs attributed to burns was $143 million – roughly 1 percent of the

estimated $14.3 billion in direct and indirect costs attributed to all injuries (Moore

and Carpenter). As in other countries, efforts to address the frequency and

severity of burn injury in Canada have primarily emphasized the most proximal

causes of injury, highlighting risks that occur in the kitchen (Ryan, Shankowsky et

al. 1992; Backstein, Peters et al. 1993; Wijayasinghe and Makey 1997; Spinks,

Wasiak et al. 2008), from the misuse of cigarettes or alcohol (O'Connor, Bauer et

al. 2007), or resulting from improperly positioned/faulty electrical heaters and

wiring (Gilbert, Dawar et al. 2006), while leaving largely underdeveloped any

theoretical perspectives of why these risks might vary systematically between

socio-economic groups. Although strategies have emphasized specific

populations at an increased risk of burn injury, most notably among Canadian

First Nations peoples (see (Callegari, Alton et al. 1989; Ryan, Shankowsky et al. 1992; Gilbert, Dawar et al. 2006)), children (see (Spinks, Wasiak et al. 2008)), or by occupational setting (see (Mandelcorn, Gomez et al. 2003; Alamgir, Tompa et al. 2007)), adjustment or direct analysis of more distal social or economic determinants associated with their occurrence have been rather scarce. The absence of these indicators is of critical importance as persons with less control over their employment, household, or social circumstances, coupled with the compounded effect of having a lower income, are less likely to be able to change the factors that elevate risk of injury (Shai 2006; Palmieri, Alderson et al. 2008).

Elsewhere, research has shown that linking health outcomes to relative markers of socio-economic status (SES) illuminates important challenges for health policy regarding the interrelationship between seemingly modifiable behavioral indicators with factors linked to socioeconomic circumstances (Hippisley-Cox, Groom et al. 2002; Reimers and Laflamme 2005). Although researchers in Canada have repeatedly documented persistent differences in numerous health outcomes across socioeconomic groups, the rationale for its exclusion here likely parallels prevailing sentiment among injury preventionists that attributes these barriers to data constraints, resources limitations, a lack of generalizability of indicators of SES, as well as the presumption that aspects of SES are not amenable to public health intervention (Cubbin and Smith 2002; Edelman 2007). Using Census and patient data from the provincial trauma registry, our research

objective was to i) investigate the strength in association between SES and risk of severe burn injury in the province of British Columbia (BC), ii) examine if these variations were generalizable across different geographic regions, which in BC cover a full spectrum of rural, resource-based communities to highly clustered and often socioeconomically divided urban metropolitan centres, and iii) contextualize our discussion on SES and offer suggestions for future research linking more proximal indicators within the context of SES. In doing so, our research aim was to gain a better understanding of why some populations continually experience higher risks of burn injury than others and contribute to the growing literature on the social determinants of injury.

5.3 Socioeconomic variations in injury

Researchers from the UK and USA have shown that indicators of increased risk of scalding injury among both children and older adults disproportionately parallels broader factors attributed to individual markers of SES (Delgado, Ramirez-Cardich et al. 2002; Lyons, Jones et al. 2003; Alden, Bessey et al. 2007). Runyan *et al* (1992) previously illustrated that alcohol and poor housing conditions were associated with increased prevalence of fire injury and mortality – factors which are both known to be further amplified when linked to SES (Runyan, Bangdiwala et al. 1992; Miller and Levy 2000; Girasek 2001). These conclusions form part of a growing understanding that social factors are a significant characteristic associated with an increased prevalence of burn injury,

with clear outcome variations as one moves stepwise from patient's in the lowest social stratum upward (Istre, McCoy et al. 2002; Lyons, Jones et al. 2003; Reimers and Laflamme 2005). Few studies in Canada – albeit with two recent and important exceptions pertaining to occupational-related injuries (see (Mandelcorn, Gomez et al. 2003; Breslin, Smith et al. 2007)) – have specifically examined the relationship between SES and burn/fire-related injury as the primary research focus. Similarly, of the few past or recent published studies on ecological patterns of burn injuries throughout BC, the most detailed information is published in work-related injury reports, listing burns among the most serious and costly injuries occurring within resource-based occupations throughout the province (Alamgir, Tompa et al. 2007).

Yet, one of the principle findings in health disparities research over the past two decades has been the relationship between individual indicators for a vast array of diseases and health outcomes and their persistent link to social or economic circumstance (Marmot 1986; Durkin, Davidson et al. 1994; Krieger, Williams et al. 1997; Hertzman 1999; Braver 2003; Krieger, Chen et al. 2003). In the last decade, these findings have fueled a growing demand to disentangle the determinants of injury prevalence, which has been consistently and persistently assessed against individual and contextual measures of income (Pomerantz, Dowd et al. 2001), social status (Lyons, Jones et al. 2003), education (Hasselberg, Laflamme et al. 2001), family structure (Braddock, Lapidus et al.

1991), and unemployment (Van Niekerk, Reimers et al. 2006) using both micro-level and small area data derived from national censuses. The ensuing research models strive to condense multiple indicators of relative social and economic deprivation into either 'social' or 'material' constructs – two separate but interconnected dimensions of class or socio-economic position considered as key determinants of health from the influential findings first published in the UK in the *Report of the Working Group on Inequalities in Health*, more widely referred to today as *The Black Report* (Black, Townsend et al. 1982). This evidence, in turn, is then used to quantify the extent to which health disparities parallel larger effects of a socioeconomic hierarchy or stem from the conditions that lead persons sharing similar behaviours that negatively impact disease or health outcomes to cluster in proximity to one another.

Whilst evidence from this model is widely supported, we posit the influences of SES to be more broadly reflective of the conditions that others have referred to as unequal access to opportunities (e.g. education, social and familial connections) and resources (e.g. employment, wealth, safe housing) in an attempt to frame SES in a context that better allows injury preventionists to understand why some populations may continually experience more injuries than others (Link and Phelan 1995; Frohlich, Ross et al. 2006). For instance, persons living in poor and/or overcrowded housing and who depend on the use space heaters may not have the opportunities or the resources that would allow them to

eliminate the potential harmful effects of their use, regardless of prevention efforts to minimize these effects. Whilst public health efforts in targeting accessible and tangible factors to reduce the risk of injury is central to ongoing efforts in injury prevention and control, it is equally vital that interventionists also continue to address the broader socio-economic characteristics associated with the increased prevalence of poor health outcomes (Pickett, Garner et al. 2002).

5.4 Methods

5.4.1 Patient Characteristics

This is a retrospective study of adults (age ≥ 18 years) who were hospitalized from severe burn/fire-related injury between January 1, 2001 and March 31, 2006. Patient records were obtained from the provincial trauma registry (BCTR). The BCTR collects and maintains data on all severe burn injuries (Injury Severity Score [ISS] ≥ 12 and Abbreviated Injury Score [AIS] ≥ 1) from persons admitted directly or indirectly to any of the provinces eight tertiary, level I, and level II trauma centres as well as persons admitted to BC Children's Hospital. Patients with severe injuries who were triaged out of province – as well as those who died at the scene or while in transit – are not captured by the registry and are listed separately. Only records where the primary mechanism causing the most severe injury were based on exposure and contact injuries due to chemical, corrosive, electrical, or thermal sources were included in the analysis. Injuries due to

hypothermia were excluded. Both injury morbidity and in-facility mortality outcomes listed in the BCTR as well as pre-hospital fatalities from provincial coroner records were examined in order to provide a more complete description of severe injury patterns throughout the province. All work has been approved by the ethical committees at Simon Fraser University and the affiliate ethics committees for the provincial trauma registry associated with the University of British Columbia.

5.4.2 Study Area

In 2001, approximately 51 % of the 4 million persons in BC resided within the Vancouver Metropolitan Area. The interior and northern regions of the province as well as Vancouver Island contain a number of near and isolated urban centres with population concentrations that range from 10,000 to over 300,000. Single resource towns are located throughout the rural and remote hinterlands throughout the northern interior and along pacific outports running north and south along the coast and contain approximately 15 % of the total population. These areas are small, isolated communities largely built around resource-based industries primarily including mining, mill towns, and fishing villages. Figure 5.1 is an illustration of the major population centres throughout the province.

5.4.3 Socio-economic Characteristics

Measures of SES were based on province-wide comparisons using data obtained from the Census Dissemination Areas (DA's) that encompassed the patient's place of residence. DA's are the smallest administrative unit used by Census Canada and are roughly the size of a small number of neighbourhood blocks within high density urban areas and increase in size when encompassing lower density rural and remote populations. On average, DA's classified as urban areas (defined below) contain 634 persons (± 275 SD) while rural areas typically contain 414 persons (± 296 SD).

A provincial measure of SES was constructed using the *Vancouver Area Neighbourhood Deprivation Index* (VANDIX). The VANDIX was previously developed by the authors from a survey of provincial Medical Health Officers (MHO's) as to the Census indicators that best characterized health outcomes throughout the province. The VANDIX is based on the aggregation of seven variables taken from the 2001 National Census. Each variable was standardized by subtracting the regional average from the observed value within each DA and then dividing this sum by its standard deviation. The index was normalized before aggregating such that all negative values represented the least deprived scores. Weights were assigned to the individual indicators based on the level of importance originally assigned by the MHO's. A complete description of the index as well as previous usages can be found elsewhere (Bell, Schuurman et al.

2007; Schuurman, Bell et al. 2008; Bell, Schuurman et al. 2009). The indicators

and their weights are illustrated in table 5.1. While reliance on the census for

proximal data on individual SES characteristics has a number of well-known

limitations it is often the most feasible given the limitations of conducting

retrospective analysis from trauma registry/facility data.

5.4.4 Data Analysis

Age-standardized rates and odds ratios were calculated from aggregated burn

injury records, which were derived by linking the patient's postal code of

residence to the DA that encapsulated its boundary. Outcome variations were

further adjusted according to work-related injuries as well as for an urban or rural

residence. Rural and urban population areas were defined using Statistics

Canada coding provided in the 2006 national postal code conversion file (PCCF).

The PCCF classifies all populations in Canada into one of six codes to describe

the population geography of its location, including: urban core (1), urban fringe

(2), rural fringe inside Metropolitan/Census Areas (3), urban areas outside

CMA/CAs (4), rural fringe outside CMA/CAs (5), and secondary urban core (6).

For this analysis, incidence counts for urban or rural burn injuries were

dichotomized into dummy variables with a rural location characterized by areas 3

and 5 and urban areas characterized by all other classes. Incidence ratios were

directly standardized by weighting incidence rates using the 1996 Canadian

Standard Million population. Dummy variables were constructed from the SES

scores and recoded into high, medium-high, medium-low, and low SES

categories. High SES quartiles (e.g. least deprived) were used as the reference

category. To minimize the effects of ecological fallacy our analysis was not

adjusted by gender as there is no unique identifier linking the BCTR to socio-

economic data within the Census. Patient's who resided in DA's with a population

of less than 250 persons were excluded from the analysis to further protect

confidentiality as well as reduce the effects of sampling error and data

suppression in the Census.

5.5 Results

Between January 1, 2001 and March 31, 2006, for injuries with the mechanism

causing the most severe injury categorized as thermal, there were a total of 205

patients treated in hospital for severe burn injury (ISS ≥ 12, AIS ≥ 1) in BC. Of

these, 35 records were missing or contained incomplete postal code identifiers, 9

cases were due to hypothermia, and 12 occurred in areas that contained less

than 250 persons, leaving 149 records remaining for the analysis. Additionally,

Foothills Hospital (Calgary, AB) responded to surge demands for 14 patients

requiring access to emergency surgical services for burn-related injuries between

2001 and 2005 calendar years and these patients were not captured in the

registry. Though this number is small, it represents a significant majority of burn

injuries in eastern BC whereby the nearest trauma centre is located outside the

province. An additional and significant number of records were recorded in the

provincial coroner's office during the study period whereby 137 persons either died at the scene or while in transit from severe burn-related injury. However, the level of detail of provincial coroner records is substantially coarser than BCTR and data can only be mapped at the Census Subdivision (CSD) geography, which is roughly equivalent in size to a municipality or large urban city. A total of 119 records had complete records and could be linked to the CSD geography, with 72 occurring within urban regions and 36 within CSD's coded as rural. However, 34% of provincial CSD's contain DA's classified with more than one of the six PCCF urban/rural classification schemata, which make accurate estimations of rural/urban injury variations highly susceptible to error using pre-hospital fatality data.

5.5.1   The geographies of burn/fire-related injury in British Columbia

At the DA geography, the age-adjusted severe burn injury morbidity and mortality rate for non work-related injuries for adults across BC was 3.10 per 100,000 (95% CI ± 0.77) and 3.90 per 100,000 (95% CI ± 1.23) for all burn/fire-related injuries, respectively. When itemized by type, inhalation-related injuries were the leading cause of hospitalization among all persons, accounting for 50 percent of hospitalizations from burns throughout the province over a five year and three month period. Mechanical explosions accounted for 20 percent of all burns, of which nearly 60 percent were caused by propane or an unclassified mechanism in the home. Both scaldings and intentional injury were the third and fourth

leading causes of hospitalization from burns in BC, each accounting for roughly 12 percent of all remaining hospitalizations.

When stratified by area SES, the magnitude of the age-adjusted injury rates among all non work-related injuries increased from 2.36 for persons in the highest SES strata to 4.01 among persons n the lowest SES strata (2.36 – 4.01), with a stepwise increase across all SES classes. Overall, this pattern widened when unspecified by work-related incidence, with rates increasing upward from 2.95 to 5.54. The gradation between burn/fire-related injuries and SES class was primarily linked to inhalation-related injuries, which rose stepwise across each SES strata (1.08 – 3.02). Rates were highest among persons in the lowest SES class among both scalds and injuries from explosions, but the gradations between the highest and lowest SES class were mixed. The rate of intentional injury from burns (including both self-inflicted and assault-related injuries) was highest among the high SES cohort, with a stepwise decrease across all SES groups (0.61 – 0.30).

5.5.2 Burn/fire-related injury in urban areas

Similar incidence pattern across SES classes persisted among urban areas throughout the province when itemized by region (2.29 – 3.69). Overall, rates were primarily reflective of inhalation-related injuries, with a stepwise rate across each stratum (1.06 – 2.80), with nearly 75 percent of these injuries occurring in

the home. Again, rates were highest among persons in the lowest SES class among both scalds and injuries from explosions, but the gradations between the highest and lowest SES class were mixed. Though small in number and susceptible to error when stratified across four SES classes, rates of hospitalization from intentional burn-related injuries were twice as high among persons in the highest SES strata from the lowest (0.74 – 0.30).

5.5.3 Burn/fire-related injury in rural areas

Injuries occurring to persons living in rural areas throughout BC accounted for 16% of all hospitalizations for severe burn/fire-related injury between 2001 and 2006. Among all non-work related injuries, morbidity and mortality rates for persons in the lowest SES strata were over three-times higher than among persons in the highest SES strata (8.19 vs. 2.54), though with an attenuated stepwise gradation in SES class as well as a wider variance in the rate when compared to incidence rates within urban areas. Inhalation-related injuries accounted for 44 percent of all hospitalizations within rural areas, with estimated rates highest among persons in the lowest SES class. There was no demonstrable effect between injury prevalence and SES when assessed against burn injuries caused from explosions, intentional mechanisms (either self-inflicted or through assault), or scalds.

5.5.4 Odds Ratios

Generalized log-Odds ratios describing the relationship between SES, urban/rural variations, and overall burn injury incidence are listed in table 5.4. Among all burn injuries there was a minimum increase of 33% of risk of burn injury for each stepwise increase in socio-economic disadvantage (OR 1.0 – 2.24). This association was attenuated when itemized by specific burn injury type and region, though was most pronounced among unspecified and inhalation-related injuries for persons living in urban areas. In contrast, rural areas exhibited a similar but non-significant association between increased injury prevalence and lower SES persisted across all classes, though no itemized stepwise gradation in burn injuries were observed to the same extent as either unspecified or inhalation-related injuries in urban areas.

5.6 Discussion

In this analysis, we examined both prevalence of unspecified and subclasses of severe burn/fire-related injuries across both rural and urban areas throughout BC. There was a statistically significant social gradation in unspecified burn injury prevalence with each increase in SES disadvantage. When itemized by burn injury mechanism, this relationship was most pronounced among inhalation-related injuries primarily occurring in the home and within urban areas throughout the province. Although persons in the lowest SES class, on average, were found

to experience both higher rate and relative odds of severe burn injury, the significance and gradation in this relationship was less pronounced and in many cases absent among persons living within rural areas. The data also illustrated an inverse though non-significant statistical relationship relative to all other analyses between morbidity and mortality from intentional burn injuries and SES, with persons in the least deprived class associated with the highest risk of injury.

The purpose of this study was to examine burn injuries in light of the broader social context surrounding their occurrence in attempt to elicit a better understanding for why some populations continually experience higher rates of injury than others. These initial results fill an important gap with respect to injury prevention and control as burn injury surveillance to date within Canada has primarily focused on the most proximal causal indicators of injury and with relatively few attempts to draw linkages between these indicators with more distal social and economic conditions. Elsewhere, researchers have shown that burn injuries consistently and persistently follow a social gradient from patients in the lowest social stratum upward, and, though difficult to generalize across all injury subclasses in BC, we have shown that similar patterns persist to some effect in Canada.

Importantly, the results from this analysis also suggest that SES may not necessarily serve as a universal indicator for increased or reduced prevalence of

all burn injuries. Throughout BC there was little commonality as well as significant variability according to VANDIX and injury prevalence across both urban and rural populations. Examples from the literature have pointed to general distinctions as to the strength of particular SES mechanisms in predicting injury prevalence (see Ballard, Koepsell et al. 1992; Lyons, Jones et al. 2003) in addition to a lack of generalizability of the indicators between rural and urban areas see (see Gilbride, Wild et al. 2006 for a Canadian example) and both factors may be attributable to findings here. A possible explanation for the latter observation may rest in differences in both market values and the predominant resource-based economy outside of urban areas throughout the province as the VANDIX is heavily weighted by both educational attainment and home ownership, with the availability and necessity of both variables strikingly different between both areas.

While further analysis of rural and urban SES variations according to all injuries and specific injury subclasses both in BC and elsewhere in Canada is of critical importance within ongoing injury prevention and control, the low frequency of burn injury morbidity and mortality within rural areas make statistical inferences from these regions difficult due to the high level of variability associated with the small numbers. As this and other studies typically separate burn injuries into 4 or 5 class strata associated with area SES scores, the small numbers problem is exacerbated. This shortcoming points to the difficult need of having to conduct

injury surveillance using a large number of historical records that may or may not be feasible given the ongoing delays transforming patient records into digital form. Moreover, data limitations in provincial coroner records in BC limit more complex and sensitive analysis of significant proximal or distal socio-economic conditions associated with pre-hospital injury mortality below a municipal scale, thereby contributing to the difficulty of monitoring rural/urban injury variations. These limitations are compounded by a significant – though unavoidable – limitation in the use of areal SES as proxy measure for individual socio-economic position, which may have further affected our analysis in rural areas where the spatial extent of DA's may be too large to reflect the scale and scope of SES differences in BC. These limitations are well-known and difficult to minimize in absence of more robust prospective studies, but these results should nevertheless be interpreted with some importance given the well-known association between variations in SES and burn injury prevalence documented elsewhere.

Symptoms from severe burn injuries significantly impact a patient's ability to return to work, with post-injury rates of recovery in most instances requiring at least 6 to 12 months for full or partial neurological, and musculoskeletal recovery, which may be further amplified due to the added strain of accepting the recurrent mental and social stigmas from suffering a physically debilitating injury (Esselman, Askay et al. 2007; Jarrett, McMahon et al. 2008; Moi and Gjengedal

2008; Theman, Singerman et al. 2008). Factors such as depression and anxiety also intensify as a result of changes to or loss of employment after injury (Victorson, Enders et al. 2008). Coupled with the added barriers of poorer educational, social and employment hardships, burn injuries are all likely to be significantly compounded as ones level and access to opportunities and social resources wanes.

Importantly, the impact of burn injuries has been shown to not only affect those faced with substantially more social and economic barriers, but has produced a demonstrable effect across social scales (Findley and Sambamoorthi 2004). Within the context of this analysis, the prevalence of inhalation-related injuries among persons in the lowest SES class throughout urban areas in the province does provide some indication that these populations may be at further risk of unnecessary and potentially deteriorating health and economic outcomes as a result of suffering a severe burn injury. However, current data limitations in provincial health care records and access delays limit a more robust analysis pairing patient outcomes with other indicators, such as the use of smoke alarms, space heaters, or faulty/poor electrical wiring that might otherwise be available within registry data from other jurisdictions. Nonetheless, these initial results provide an entry point in examining burn injury prevalence in light of broader SES conditions and should be considered in future analyses.

5.7 Conclusion

Despite significant improvements in the prevention and treatment of injuries, premature mortality as a result of sustaining severe injury is the leading cause of death among Canadians under the age of 45 (CIHI 2001). A limited but growing number of studies within Canada have demonstrated the intransigent relationship between SES and injury disability and mortality (see for example Frohlich and Mustard 1996; Pickett, Garner et al. 2002; Soubhi, Raina et al. 2004; Simpson, Janssen et al. 2005); yet little is still known as to the extent that these indicators are generalizable among prevalence rates of burns. While conservative, the results from this analysis suggest that burn/fire-related injuries stemming from inhalation injuries continually and disproportionately affect persons at a greater socio-economic disadvantage. Broadening future injury prevention efforts to also examine broader socio-economic conditions alongside more proximal indicators associated with severe burn injury is likely to be more effective than targeting individual behavior alone when trying to reduce and eliminate their occurrence.

5.8 Figures

Figure 5.1 Province of British Columbia, Canada and major populated areas
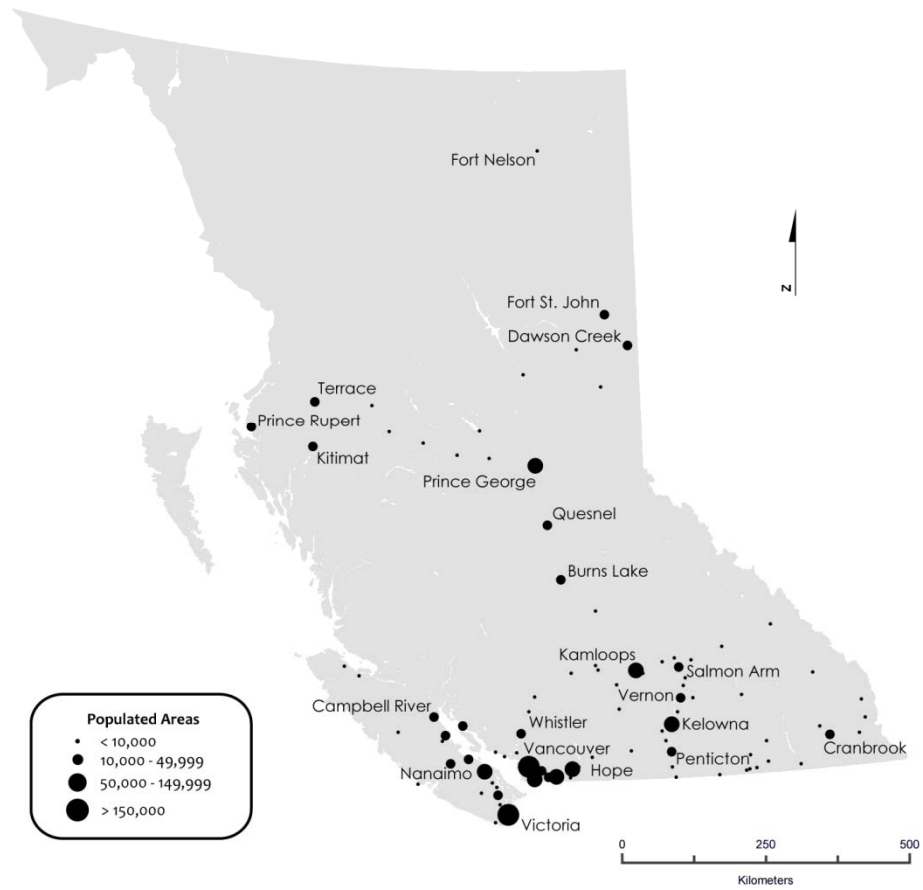
5.9 Tables

Census Indicators	Weight (%)
Average Income	0.089
Home Ownership	0.089
Single Parent Family	0.143
No High school Completion	0.250
With a University Degree	0.179
Employment Ratio	0.036
Unemployment Rate	0.214

Table 5.1 Seven individual Census variables used to construct the VANDIX. Variables weights are based on the proportion of MHO responses from the original survey. A full description of the VANDIX can be found in (Bell, Schuurman et al. 2007).

	Age Group			
Burn Injury Cause	18 - 29	30 - 59	60 +	All Ages
Exposure to Smoke, Flame	31	24	19	74
Explosion	11	16	3	30
Contact with Hot Substance	5	5	8	18
Intentional	13	5	1	19
Other	6	2	0	8
Total	*66*	*52*	*31*	*149*

Table 5.2 Primary causes of major burn injuries in British Columbia between January 1, 2001 and March 31, 2006.

Prevalence of major burn/fire-related injuries in British Columbia by SES class

Region	All Injuries	Non-Work Related	Inhalation	Explosions	Scalds	Intentional
Age-Adjusted Rate	3.1 (2.33 - 3.87)	3.9 (2.66 - 5.13)	1.94 (1.44 - 2.44)	0.77 (0.45 - 1.08)	0.46 (0.38 - 0.53)	0.53 (0.15 - 0.91)
Provincial						
High SES	2.95 (1.89 - 4.01)	2.36 (1.33 - 3.38)	1.08 (0.71 - 1.45)	0.73 (0.48 - 0.99)	0.32 (0.28 - 0.35)	0.61 (-0.08 - 1.31)
Med-High SES	3.27 (2.03 - 4.5)	2.73 (1.78 - 3.68)	1.45 (1.03 - 1.87)	0.75 (0.36 - 1.15)	0.29 (0.09 - 0.48)	0.53 (0.18 - 0.89)
Med-Low SES	3.96 (2.8 - 5.12)	3.38 (2.4 - 4.36)	2.21 (1.55 - 2.87)	0.57 (0.11 - 1.03)	0.59 (0.41 - 0.78)	0.5 (0.21 - 0.79)
Low SES	5.54 (3.53 - 7.55)	4.01 (3.3 - 4.72)	3.02 (1.98 - 4.05)	1.08 (0.55 - 1.61)	0.62 (0.54 - 0.7)	0.45 (0.07 - 0.83)
Urban Areas	*n = 112*	*n = 88*	*n = 59*	*n = 19*	*n = 12*	*n = 15*
High SES	2.93 (1.83 - 4.02)	2.29 (0.96 - 3.62)	1.06 (0.81 - 1.3)	0.36 (0.15 - 0.57)	0.39 (0.34 - 0.43)	0.74 (-0.1 - 1.57)
Med-High SES	3.04 (2.22 - 3.86)	2.78 (2.23 - 3.33)	1.16 (0.95 - 1.37)	0.83 (0.31 - 1.36)	0.38 (0.12 - 0.64)	0.37 (0.15 - 0.6)
Med-Low SES	4.01 (2.34 - 5.68)	3.82 (2.1 - 5.54)	2.61 (1.53 - 3.7)	0.38 (0.15 - 0.62)	0.24 (0.1 - 0.38)	0.65 (0.27 - 1.02)
Low SES	4.9 (3.17 - 6.63)	3.69 (3.21 - 4.18)	2.8 (2.04 - 3.55)	0.95 (0.52 - 1.39)	0.54 (0.33 - 0.75)	0.3 (-0.04 - 0.64)
Rural Areas	*n = 25*	*n = 20*	*n = 11*	*n = 7*	*n = 3*	*n = 4*
High SES	5.03 (-0.66 - 10.73)	2.54 (-0.33 - 5.41)	0 (0 - 0)	0.29 (-0.04 - 0.63)	0 (0 - 0)	0 (0 - 0)
Med-High SES	6.33 (0.31 - 12.35)	4.56 (-0.6 - 9.71)	4.08 (0.58 - 7.57)	0 (0 - 0)	0 (0 - 0)	0.29 (-0.04 - 0.63)
Med-Low SES	4.62 (3.88 - 5.36)	2.73 (1.14 - 4.31)	0.58 (-0.08 - 1.24)	0.36 (-0.05 - 0.78)	0.4 (0.12 - 0.68)	0 (0 - 0)
Low SES	8.19 (5.25 - 11.13)	8.19 (5.25 - 11.13)	5.17 (2.54 - 7.81)	0.27 (-0.04 - 0.58)	0 (0 - 0)	0.25 (0.1 - 0.41)

Table 5.3 Age-standardized injury rates (per 100, 000) of major burn injuries in British Columbia across SES classes sub-classified by the leading causes of severe injury.

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Odds Ratios for major burn/fire-related injuries in British Columbia by SES class

Region	All Injuries	Inhalation	Explosions	Scalds	Intentional
Provincial					
High SES	reference	reference	reference	reference	reference
Med-High SES	1.33 (0.79 - 2.26)	1.92 (0.84 - 4.39)	0.75 (0.24 - 2.34)	1.01 (0.23 - 4.42)	1.50 (0.46 - 4.9)
Med-Low SES	1.67 (1.01 - 2.74)*	2.34 (1.09 - 5.02)*	1.24 (0.40 - 3.85)	3.00 (0.79 - 11.48)	0.99 (0.3 - 3.24)
Low SES	2.24 (1.39 - 3.61)*	3.67 (1.75 - 7.67)*	1.38 (0.48 - 3.95)	1.33 (0.33 - 5.38)	1.44 (0.41 - 5)
Urban Areas					
High SES	reference	reference	reference	reference	reference
Med-High SES	1.05 (0.6 - 1.85)	1.01 (0.41 - 2.47)	1.87 (0.51 - 6.85)	1.01 (0.23 - 4.4)	0.64 (0.17 - 2.44)
Med-Low SES	1.38 (0.81 - 2.34)	2.15 (1.00 - 4.63)*	0.99 (0.23 - 4.37)	0.75 (0.17 - 3.27)	0.99 (0.3 - 3.24)
Low SES	1.74 (1.04 - 2.9)*	2.34 (1.09 - 5.03)*	2.22 (0.62 - 7.89)	1.39 (0.31 - 6.15)	0.47 (0.11 - 2.1)
Rural Areas					
High SES	reference	reference	reference	reference	reference
Med-High SES	1.22 (0.28 - 5.25)	4.22 (0.23 - 78.43)	0.09 (0 - 1.95)	0.47 (0.01 - 23.65)	2.35 (0.11 - 48.87)
Med-Low SES	1.20 (0.29 - 5.02)	1.20 (0.05 - 29.42)	0.56 (0.11 - 2.84)	2.80 (0.14 - 54.15)	0.40 (0.01 - 20.13)
Low SES	1.97 (0.5 - 7.83)	6.11 (0.34 - 108.37)	0.47 (0.08 - 2.71)	0.47 (0.01 - 23.67)	2.35 (0.11 - 48.91)

* $p \leq 0.05$

Table 5.4 Odds ratios for burn injury prevalence by SES class and urban/rural residence.

6: ANALYZING PLACE EFFECTS OF INJURY: DOES THE CHOICE OF GEOGRAPHIC SCALE AND ZONE MATTER?

The following chapter has been submitted to Open Medicine.

Citation details: Bell, N., N. Schuurman and S. M. Hameed. "Analyzing place effects of injury: does the choice of geographic scale and zone matter?" Open Medicine (submitted, November 2009).

6.1 Abstract

Background: Recent studies have shown that injury morbidity and mortality are related to proxy measures of socio-economic status (SES). Little attention has been given to the modifiable artifact of both scale and how the data are partitioned when drawing inferences of this association. Both are, however, strong influences on the relationship between place effects and incidence patterns of injury. Methods: A Poisson generalized linear model, stratified by age and gender, was used to analyze the relationship between four different area measures of socio-economic status (SES) and incidence patterns of pedestrian injury, including Canadian Census Dissemination Area (DA), Census Tract (CT), a custom defined Census Tract (MCT), and Census Subdivision (CSD) boundaries. SES was measured using the Vancouver Area Neighbourhood Deprivation Index (VANDIX). A geographical information system (GIS) was used

to reassign DA boundaries into the modified set of Census Tracts (MCT).

Results: Results of place effect on incidence pattern of pedestrian injury are not

universal, and can vary according to both the scale of the analysis and how areal

units are partitioned. At different scales and zones, the relationship between area

SES and pedestrian injury followed both dichotomous, a negative social gradient,

and a positive socio-economic association. Conclusions: Results from this

analysis demonstrate that there is significant variability when applying different

administrative boundaries as proxy measures of place effects on incidence

patterns of injury. Hypothesized effects of the influence of the urban environment

on place effects of injury are best observed using small-area boundaries of the

census, but researchers should be aware of the inherent variability that remains

even among the more homogenous population units.

6.2 Introduction

6.2.1 Background

To understand the burden of injury fully, researchers have used national

censuses to explore the relationship between injury hospitalization and mortality

patterns and relative disparities in social and economic factors (Braddock,

Lapidus et al. 1991; Durkin, Davidson et al. 1994; Gunnell, Peters et al. 1995;

Crawford and Prince 1999; Laing and Logan 1999; Howe and Crilly 2001; Istre,

McCoy et al. 2001; Pomerantz, Dowd et al. 2001; Lyons, Jones et al. 2003; Marcin, Schembri et al. 2003; Van Niekerk, Reimers et al. 2006; Breslin, Smith et al. 2007; Bell, Schuurman et al. 2009). Evidence has shown that the strength in association between socio-economic indicators and injury are differentially related to age (Wright and Kariya 1997), gender (Hijar, Kraus et al. 2001), ethnicity (Loomis 1991), occupation (McCullough, Henderson et al. 1998), population density (Fife, Faich et al. 1986), and behavior (Soubhi, Raina et al. 2004) and each of these characteristics interact differently according to the specific cause of trauma (Potter, Speechley et al. 2005). Despite these nuances, findings point out that increased risk of injury corresponds with relative disparities in factors such as income, education, employment, demographics as well as neighbourhood socio-economic conditions (Cubbin, LeClere et al. 2000; Cubbin and Smith 2002).

The literature on geographic variation in injuries is also growing, aided in particular through advancements in the spatial analysis of hospital registry data using geographic information systems (GIS) (Noland and Quddus 2004; Schneider, Ryznar et al. 2004; Morency and Cloutier 2006). This technology has tremendous potential to increase our understanding of socio-economic risk factors that influence injury, as evident by the growing application of its tool set for analyzing how environmental factors can shelter or expose individuals to potentially harmful events (Geurts, Thomas et al. 2005; Gruenewald and Remer

2006; Cusimano, Chipman et al. 2007; Treno, Johnson et al. 2007; Schuurman, Bell et al. 2008). To date, however, the research intersection between GIS and injury prevention has focused primarily on identifying ecological processes associated with increased risk. There has been little attention directed toward the sensitivity of ecological models to variation that arises out of the reliance on administrative data.

While health effects are fundamentally associated with the individual, research on the socio-economic determinants of injury primarily involves the use of population-level administrative data taken from the census. Consequently, the strength of ecological analyses emphasizing place effects on injury is susceptible to the magnitude of data aggregation and the ways in which the areal units are subdivided. This problem, referred to as the modifiable areal unit problem (MAUP), can be condensed into two distinct, but closely related issues. The first is the scale effect, which points to the different statistical results obtained from the same set of geographic units when they are organized into increasingly larger (or smaller) groups (Openshaw 1984). The second problem is the zoning effect. This refers to the problem of basing a hypothesis from areal geographic units, which, if subdivided differently at the same spatial extent, would lead the investigator to conclude differently (Openshaw 1984). Figure 6.1 is an illustration of these two problems.

6.2.2 Objectives

The MAUP has received increased attention in other health outcomes studies due in part to the reliance on census data for inferring meaningful information regarding place effects on health (Nakaya 2000; Soobader, LeClere et al. 2001; Krieger, Chen et al. 2002; Schuurman, Bell et al. 2007). Despite this importance, little attention has been given the affect of the MAUP on the relationship between socio-economic position and injury. A review of its consequences of the MAUP is of particular importance given the increasing application of GIS technology for drawing linkages between the urban environment and injury. To illustrate the effects of MAUP, we investigated the variation in SES within a metropolitan area in Canada using four different geographic scales from the census and a custom designed repartitioning of the administrative data. Our analysis is based on a case study using pedestrian injury data, where issues of the MAUP are of particular importance due to the increasing use of GIS for characterizing how both poverty and aspects from the built environment correspond with incidence patterns of pedestrian injury (LaScala, Gerber et al. 2000; LaScala, Johnson et al. 2001; Lightstone, Dhillon et al. 2001; LaScala, Gruenewald et al. 2004).

6.3 Methods

6.3.1 Participants

This is a retrospective study of the variability in association between population socio-economic factors and incidence patterns of severe non-fatal pedestrian injuries among adults (age ≥ 18 years) within Metropolitan Vancouver, British Columbia (BC), Canada. This study includes aggregated patient records from January 1, 2001 through March 31, 2006. Records from patients who sustained a single or multisystem injury with an Injury Severity Score (ISS) ≥ 12 were selected for analysis. Records were obtained from the provincial trauma registry (BCTR). Patient records from BCTR were sub-classified according to the injury mechanism using ICD-10 classification codes. Table 6.1 defines the coding used to identify pedestrian injuries from the BCTR.

6.3.2 Measurement of socioeconomic status

SES was modeled using the Vancouver Area Neighbourhood Deprivation Index (VANDIX). The VANDIX was previously developed by two of the authors from a survey of provincial Medical Health Officers (MHOs) on which Census indicators they believed best characterized negative health outcomes throughout the province. A complete description of the VANDIX can be found elsewhere (Bell, Schuurman et al. 2007). The final index is based on the aggregation of the seven most frequently selected variables chosen by the MHOs, including *having a high*

school education, *unemployment rate*, *having a university degree*, *being a lone parent*, *average income*, *home ownership*, and the *employment ratio*. Each variable was weighted according to the frequency of the expert responses. All seven variables were then summed to create a single marker of relative SES. Variables were standardized by subtracting the regional average from the observed value within each administrative unit and then dividing this sum by its standard deviation. The seven indicators and their weights are shown in table 6.2. The VANDIX is currently being employed by a number of health authorities throughout BC and has previously been used as a population-level indicator of SES and risk of injury in BC (Bell, Schuurman et al. 2008; Schuurman, Bell et al. 2008; Bell, Schuurman et al. 2009; Bell, Schuurman et al. 2009).

6.3.3 Study Size

Representations of the socio-economic conditions where each injury occurred were based on four different aggregations of census administrative boundaries using 2001 Census records. The smallest geographic boundaries used for this analysis were Census Dissemination Areas (DAs). DAs are the smallest administrative unit used by Census Canada and are roughly the size of a small number of neighbourhood blocks within higher density urban areas. On average, a single DA contains in Metropolitan Vancouver contains 605 (± 235 SD) persons. Three additional measures of SES were derived from Census Tract (CT), a modified Census Tract (MCT) created using GIS, and Census

Subdivision (CSD) administrative boundaries. On average, there are 12 DAs within each CT and 21 CTs within each CSD throughout Metropolitan Vancouver. CTs are relatively small and stable administrative boundaries that contain on average of 5,185 (± 1,927 SD) persons. To construct the MCT's, we used the the *Districting for ArcGIS* add-on tool to re-assign every DA within Metropolitan Vancouver to a modified set of CT's. This is a freely available tool available through *Environmental Systems Research Institute* (ESRI$^{©}$). The Districting tool also allows the new units to maintain a desired range of population counts. For this analysis the modified CT boundaries were designed to be continuous spatial areas containing an average of 12 DAs and within one standard deviation of the average population of the official CT units. CSDs are equivalent in size to an urban municipality with an average population in Metro Vancouver of 50, 304 (± 104,882 SD). Within Metropolitan Vancouver, CSD's are designated for city boundaries, regional district areas, reserves, and villages.

The BCTR also contains geographic information on the location of the injury, recorded by street address, street intersection or postal code. Using GIS, we employed address matching to link the incident location information with Statistics Canada Postal Code Conversion File (September 2006 version). Once assigned a spatial identifier, each patient record was linked with each of the four Census boundaries that encapsulated its location. All work has been approved

by the ethics committees at Simon Fraser University and the University of
British Columbia.

6.3.4 Statistical Analysis

A Poisson generalized linear models (GLM) was used to assess the relationship
between variables from the urban environment associated with increased
likelihood of pedestrian injury. Injury rates were stratified by gender and
partitioned into four age groups, including: 18 – 39, 40 – 59, over 60, and ages
18 and up. Dummy variables were constructed from the SES scores and recoded
into high, medium-high, medium-low, and low SES categories. High SES
quartiles (e.g. least deprived areas) were used as the reference category. Injuries
occurring in areas with a population of less than 250 persons were excluded from
the analysis to reduce the effects of sampling error and data suppression in the
Canadian Census. This resulted in a suppression of nine pedestrian injury cases
from the analysis.

6.4 Results

6.4.1 Participants and descriptive data

In this study, 61% (n = 262) of the 425 non-fatal pedestrian injuries throughout
the province occurred within Metropolitan Vancouver. Injury counts by gender
and age group are shown in table 6.3. Despite clear similarities, across all spatial

scales, the relationship between area SES scores and incidence patterns of

pedestrian injury varied according to both the direction of the association (e.g.

positive or negative social gradient), the range of risk associated with each SES

quartile, and statistical significance (95% CI) of the association. Age stratified

odds ratios for all four geographic areas are listed in tables 6.4-6.6.

6.4.2 Main results

At the smallest spatial scale (Census DA), when unspecified according to

gender, the relationship between area SES and incidence pattern of pedestrian

injury rose stepwise along a social gradient among all age groups accept among

both males and females ages 18 - 39. When unspecified by age group, this

relationship was statistically significant across all area SES scores ($p < 0.01$).

When stratified by gender, the significance of the relationship between area SES

and injury was strongest among areas classified as low SES among both males

and females, with little to no significance among areas classified as medium-low

SES or medium-high SES.

At the CT scale, increased odds ratios were highest among areas categorized in

the lowest SES quartile and this relationship was statistically significant among

both males and females in all age groups ($p ≤ 0.05$). However, the range in

relative risk of injury by area SES was reduced by an average of 39% among

males and 15% among females in contrast to the same findings measured at the

DA scale. No stepwise social gradient was observed between area SES scores and incidence patterns of injuries when measured at the CT geography accept when the model was unspecified by gender and among patients in the 40-59 age group.

The greatest number of statistically significant relationships between area SES and incidence patterns of injury were observed using the modified CT administrative units (MCT). Similar to both the DA and CT administrative units, MCT areas assigned to the lowest SES quartile produced the greatest likelihood of injury. In comparison to CT area scores, however, the average range in relative risk across all SES groups grew by 32% among males and 20% among females. When compared with DA units, the range in relative risk among males decreased by 9% , but increased by 8% among females. Using the MCT geographies, a social gradient was observed between area SES and likelihood of injury among all age groups except among males 40 – 59 and females over 60.

Observations from the CSD administrative units were not consistent with findings from the smaller administrative units. At the CSD scale, statistically significant positive associations between area SES scores and incidence patterns of injury were observed among males in the 18 – 39 age group. However, across all age groups, no consistent relationship between area SES and incidence pattern of injury was observed at the CSD scale.

6.5 Discussion

6.5.1 Key results

Results from this analysis demonstrated that the well-known association between relative disparities in socio-economic conditions and increased incidence patterns of pedestrian injury are not universal, and can vary according to both the scale of the analysis and how areal units are partitioned. In this analysis, one of the strongest relationships between place effects on injury was found when using geographic areas other than those designed by the census. In addition, the results demonstrated that increased homogeneity of the DA geographies produced a remarkably dichotomous and statistically significant relationship between low SES and high SES areas, but that this pattern began to transform into a graded relationship when measured using modified versions of the larger Census Tract geographies. Of additional importance was the inverse relationship between area SES and risk of injury when modeled using CSD administrative units. In fact, the CSD aggregation scheme would suggest that there is no relationship between socio-economic risk factors from the urban environment and increased likelihood of pedestrian injury.

6.5.2 Limitations

While we have shown that the relationship between area SES and incidence pattern of injury is susceptible to the MAUP, we were not able to assess this relationship at the scale of the individual due to the lack of socio-economic data that corresponds with individual patient records in the BCTR. In this event, a multi-level model could have been used to identify the amount of variation between SES and incidence patterns of pedestrian injuries at the different spatial scales (Pickett, Garner et al. 2002; Haynes, Reading et al. 2003; Simpson, Janssen et al. 2005). However, as with many registry databases, the BCTR contains no information on patient-level socio-economic factors, such as income, employment status, level of education, or family structure. This limitation is common to most studies of trauma registry data and necessitates the reliance on population-level data from the census to measure place effects on injury. Appropriately, many studies cite the inherent limitations from inferring individual-level relationships from ecological data, but do not discuss the susceptibility of more robust models, such as multi-level or hierarchical models, to the geographic bounding parameters used to contextualize place effects on injury. As this study has demonstrated, reorganizing areal data introduces an added level of variation.

In addition, additional care must be given to the injury locations whenever geographic boundaries have been imposed onto the dependent variables. Areas that are close together tend to have similar characteristics, or are said to be

autocorrelated, which increases the likelihood of type-I error as the assumption of variable independence among the dependent variables cannot be sustained (Goodchild 1987). One approach is to measure for the level of spatial autocorrelation between the proximity of injury locations (Gruenewald and Remer 2006; Treno, Johnson et al. 2007). This approach has been used to both justify the selected regression model as well as identify place effects on injury (Rezaeian, Dunn et al. 2006; Bell, Schuurman et al. 2008). While measuring for spatial autocorrelation can be used to specify the regression model, typically the residuals in the regression of spatial data are simply an artifact of the model (e.g. linear, logistic, Poisson regression), which assume the observations are independent of their location (Fotheringham, Charlton et al. 2002).

Currently, one technique that can minimize this limitation and that is receiving increasing attention in epidemiology is geographically weighted regression (GWR) (Maroko, Maantay et al. 2009). The strength of GWR is that it enables researchers to identify if there is any inherent local variation in SES and frequency of injury on an area-by-area basis, similar in scope to multi-level models. An important strength of this approach for injury prevention is it allows researchers to quantify how different hypothesized effects of incidence patterns of injury vary from one area to the next in response to the same stimuli. This technique could allow researchers to generate meaningful information regarding how population-level factors, such as neighbourhood cohesion or residential

zoning, may influence pedestrian injury patterns *on an area-by-area basis*, effectively reducing problems of the MAUP. One caveat, however, is that GWR are extremely data hungry, which may necessitate that databases with low counts should not be sub-classified by injury mechanism (e.g. assault, falls, motor vehicle) to ensure there are enough parameter estimates to perform the analysis.

6.5.3 Interpretation

The problems of the MAUP should be interpreted as applicable to population-level socio-economic research among all age groups as is the need to carefully consider the geographic variability inherent in the analysis when relying on the census to measure place effects on injury. Increasing attention has been placed on socio-economic risk factors of the urban environment that increase the likelihood of injury to pedestrians (LaScala, Gruenewald et al. 2004). For example, unemployment holds a direct link to community wealth and the ability to determine, in part, local access to healthcare services as well as procuring the means to pay for goods such as pedestrian traffic lights and safe playgrounds (Cubbin, LeClere et al. 2000). As this analysis has demonstrated, hypothesized effects of the influence of the built environment on place effects of injury are best observed using small-area boundaries of the census, but researchers should be aware of the inherent variability that remains even among the more homogenous population scales.

6.5.4 Generalisability

In many analyses, reliance on the smallest areal units provided by the census
has a tendency to introduce rate instability because the base population used to
derive the rate is smaller and more variable. Larger census units, such as census
tracts or wards provide a more stable base population, but may also mask
meaningful geographic variation that is made evident when mapping health
outcomes using smaller block face, dissemination, or enumeration areas
(Nakaya 2000). However, it is difficult – if not impossible – to generalize the
effects of the MAUP from one dataset to another. A priori frameworks for
analyzing place effects on risk of injury are required in the analysis of place
effects on injury, but such frameworks are rarely made explicit in analysis of
socio-economic risk factors associated with its occurrence. Results from this
analysis demonstrate that there is significant variability when applying different
administrative boundaries as proxy measures of either neighbourhood or
population socio-economic position.

6.6 Figures

Figure 6.1 Illustration of the scale and zoning effect of the modifiable areal unit problem (MAUP). Changes in either scale or zoning will bring about changes in the geographical distribution of the variable in question. This is illustrated in figure 1 using area unemployment rates as an example.

6.7 Tables

V01	Pedestrian injured in collision with pedal cycle
V02	Pedestrian injured in collision with two- or three-wheeled motor vehicle
V03	Pedestrian injured in collision with car, pick-up truck or van
V04	Pedestrian injured in collision with heavy transport vehicle or bus
V05	Pedestrian injured in collision with railway train or railway vehicle
V06	Pedestrian injured in collision with other nonmotor vehicle
V09	Pedestrian injured in other and unspecified transport accidents

Table 6.1 ICD-10 codes for identifying pedestrian injury cases from the BCTR

SES Variables	Weight [%]
Average Income	0.089
Home Ownership	0.089
Single Parent Family	0.143
No High school Completion	0.250
With a University Degree	0.179
Employment Ratio	0.036
Unemployment Rate	0.214

Table 6.2 The VANDIX socio-economic index was constructed from a survey of British Columbia's Medical Health Officers (MHOs). Each variable is standardized using z-scores. The VANDIX is constructed by summation of the seven variables and used as proxy measure of area SES.

Injury Counts				Dissemination Areas		Census Tracts		Modified Census Tracts		Census Subdivisions	
Age	Males	Females		Range	n	Range	n	Range	n	Range	n
18 - 39	54	35	Low SES	(3.52 - 0.36)	819	(1.92 - 0.52)	96	(1.64- 0.50)	100	(0.45- 0.11)	7
40 - 59	49	31	Med.Low SES	(0.00 - 0.36)	845	(0.52 - 0.20)	96	(0.50 - 0.20)	100	(0.01 - 0.11)	7
≥ 60	47	46	Med. High SES	(-0.40 - 0.00)	799	(-0.03 - 0.20)	97	(-0.08 - 0.20)	101	(0.01 - 0.01)	7
total	150	112	High SES	(-2.37 - 0.40)	812	(-1.06- -0.03)	96	(-1.15 - -0.08)	99	(-0.91 - 0.01)	7

Table 6.3 Effects of the Modifiable Areal Unit Problem (MAUP) and incidence patterns of severe injury by SES quartile. CSD = Municipal boundary.

Variation in pedestrian injury among males measured by area SES				
	Ages 18 - 39	Ages 40 - 59	Over 60	Ages 18 and Over
Census Subdivisions				
Low SES	0.28 (0.08-0.99)*	2.59 (0.15-43.52)	1.35 (0.23-7.96)	1.27 (0.47-3.45)
Medium-Low SES	0.59 (0.20-1.75)	2.64 (0.16-43.26)	4.03 (0.78-20.71)	2.22 (0.86-5.71)
Medium-High SES	0.34 (0.09-1.39)	3.70 (0.21-64.75)	4.78 (0.84-27.14)	2.24 (0.80-6.25)
High SES	--	--	--	--
Modified Census Tracts				
Low SES	2.67 (1.24-5.72)*	3.65 (1.73-7.67)Ŧ	2.61 (1.07-6.39)*	3.26 (2.06-5.16)Ŧ
Medium-Low SES	2.11 (1.02-4.34)*	1.16 (0.50-2.67)	2.07 (0.83-5.13)	2.08 (1.30-3.32)**
Medium-High SES	1.61 (0.66-3.9)	1.40 (0.56-3.45)	1.19 (0.42-3.41)	1.51 (0.87-2.61)
High SES	--	--	--	--
Census Tracts				
Low SES	2.24 (1.06-4.74)*	2.41 (1.04-5.6)*	2.30 (0.99-5.34)*	2.33 (1.45-3.74)Ŧ
Medium-Low SES	0.86 (0.40-1.85)	1.13 (0.48-2.68)	1.87 (0.79-4.44)	1.26 (0.77-2.04)
Medium-High SES	0.89 (0.36-2.2)	0.74 (0.27-2.04)	0.76 (0.25-2.28)	0.75 (0.42-1.35)
High SES	--	--	--	--
Dissemination Areas				
Low SES	4.76 (2.18-10.4)*	3.85 (1.52-9.79)**	2.79 (0.89-8.76)	4.93 (2.89-8.42)Ŧ
Medium-Low SES	2.10 (0.93-4.75)	1.39 (0.52-3.75)	2.56 (0.82-80)	2.60 (1.5-4.50)Ŧ
Medium-High SES	2.45 (1.07-5.63)*	0.95 (0.33-2.72)	0.89 (0.25-3.15)	1.74 (0.96-3.15)
High SES	--	--	--	--

*$p \leq 0.05$ **$p \leq 0.01$ Ŧ$p \leq 0.001$

Table 6.4 Variation in association between area SES of pedestrian injuries among males.

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Variation in pedestrian injury among females measured by area SES			
	Ages 18 - 39	Ages 40 - 59	Over 60	Over 18
Census Subdivisions				
Low SES	0.64 (0.09-4.35)	0.61 (0.03-11.34)	2.45 (0.44-13.72)	1.75 (0.46-6.63)
Medium-Low SES	2.48 (0.48-12.77)	2.89 (0.18-47.58)	2.76 (0.54-14.24)	4.33 (1.23-15.22)**
Medium-High SES	0.42 (0.04-4.02)	1 (0.05-19.29)	2.91 (0.49-17.21)	2.09 (0.53-8.32)
High SES	--	--	--	--
Modified Census Tracts				
Low SES	4.99 (2.05-12.18)Ŧ	3.89 (1.36-11.1)*	3.1 (1.4-6.85)**	4.13 (2.44-6.97)Ŧ
Medium-Low SES	3.66 (1.46-9.19)**	1.47 (0.46-4.72)	1.79 (0.74-4.34)	2.27 (1.28-4.02)**
Medium-High SES	1.97 (0.61-6.35)	1 (0.29-3.47)	0.92 (0.33-2.54)	1.4 (0.72-2.73)
High SES	--	--	--	--
Census Tracts				
Low SES	4.92 (2.04-11.88)Ŧ	4.5 (1.59-12.77)**	2.5 (1.18-5.31)**	3.15 (1.89-5.25)Ŧ
Medium-Low SES	1.98 (0.79-4.96)	2.29 (0.73-7.17)	1.16 (0.46-2.92)	1.41 (0.8-2.5)
Medium-High SES	0.87 (0.24-3.08)	1.08 (0.27-4.36)	0.52 (0.19-1.42)	0.59 (0.29-1.19)
High SES	--	--	--	--
Dissemination Areas				
Low SES	4 (1.55-10.32)**	3.95 (1.46-10.64)**	2.33 (0.94-5.78)	3.36 (1.92-5.87)Ŧ
Medium-Low SES	1.76 (0.63-4.88)	1.71 (0.6-4.88)	1.81 (0.72-4.55)	1.8 (1-3.23)*
Medium-High SES	2.4 (0.88-6.5)	1.13 (0.33-3.93)	1.78 (0.67-4.74)	1.88 (1.01-3.5)
High SES	--	--	--	--

* p ≤ 0.05   ** p ≤ 0.01   Ŧ p ≤ 0.001

Table 6.5 Variation in association between area SES of pedestrian injuries among females.

Variation in pedestrian injury among all populations measured by area SES

	Ages 18 - 39	Ages 40 - 59	Over 60	Over 18
Census Subdivisions				
Low SES	0.4 (0.13-1.19)	3.1 (0.19-51.57)	2.19 (0.58-8.33)	1.53 (0.67-3.5)
Medium-Low SES	1.09 (0.42-2.83)	5.44 (0.34-88.06)	3.93 (1.11-13.92)*	3.12 (1.43-6.82)*
Medium-High SES	0.39 (0.11-1.37)	4.27 (0.25-72.93)	4.31 (1.13-16.51)*	2.31 (0.99-5.41)
High SES	--	--	--	--
Modified Census Tracts				
Low SES	3.51 (1.96-6.3)Ŧ	4.37 (2.37-8.04)Ŧ	2.94 (1.61-5.36)Ŧ	3.66 (2.59-5.17)Ŧ
Medium-Low SES	2.7 (1.52-4.79)Ŧ	1.57 (0.79-3.13)	1.94 (1.03-3.66)*	2.25 (1.57-3.25)Ŧ
Medium-High SES	1.78 (0.87-3.64)	1.36 (0.65-2.86)	1.03 (0.49-2.17)	1.48 (0.97-2.27)
High SES	--	--	--	--
Census Tracts				
Low SES	3.27 (1.83-5.83)Ŧ	3.25 (1.67-6.33)Ŧ	2.48 (1.41-4.38)**	2.73 (1.93-3.86)Ŧ
Medium-Low SES	1.3 (0.72-2.36)	1.6 (0.79-3.23)	1.55 (0.83-2.89)	1.39 (0.96-2.01)
Medium-High SES	0.96 (0.46-2.02)	0.86 (0.37-1.98)	0.59 (0.28-1.26)	0.71 (0.45-1.12)
High SES	--	--	--	--
Dissemination Areas				
Low SES	4.48 (2.43-8.26)Ŧ	4.47 (2.24-8.9)Ŧ	2.66 (1.3-5.45)**	4.11 (2.79-6.05)Ŧ
Medium-Low SES	1.96 (1.03-3.75)*	1.86 (0.89-3.87)	2.41 (1.17-4.96)**	2.26 (1.51-3.37)Ŧ
Medium-High SES	2.36 (1.24-4.51)	1.15 (0.51-2.58)	1.4 (0.64-3.09)	1.72 (1.12-2.65)**
High SES	--	--	--	--

* p ≤ 0.05   ** p ≤ 0.01   Ŧ p ≤ 0.001

Table 6.6 Variation in association between area SES of pedestrian injuries among all populations.

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7: INJURY ON RESERVES IN BRITISH COLUMBIA AND THE DANGERS OF HOMOGENIZING RISK

The following chapter has been formatted for submission to the Canadian Journal of Public Health.

7.1 Abstract

Background: Aboriginal Canadians and populations living on Reserves are widely

understood to have poorer health outcomes than non-Aboriginal Canadians. To

date, and for a number of reasons, monitoring health outcomes on Reserves has

primarily been in reference to regional or provincial populations. We discuss key

limitations of this approach and demonstrate the benefits and challenges of

investigating health outcomes on Reserves on a community basis. Methods:

Data from the British Columbia Trauma Registry and Coroner database were

analyzed for intentional and unintentional fatal and non-fatal injuries. A

geographic information system (GIS) was used to link incident location records to

the Census areas that encapsulated its location and identify injury and population

counts from areas adjacent to Reserves. Incident rates on Reserves were

contrasted against adjacent non-Reserve communities using a Poisson

probability mapping model. Results: Significantly high and low incidence rates on

Reserves were most pronounced when contrasted with smaller, adjacent non-

Aboriginal communities rather than when evaluated in reference to regional

populations. 50% of all Reserves within our case study experienced significantly

lower injury morbidity and mortality rates than among the adjoining communities.

Two Reserves accounted for nearly 68% of the unintentional and 25% of

intentional injuries. Discussion: Severe unintentional and intentional injury

morbidity and mortality within Aboriginal Reserves in BC is far more concentrated

than homogenous. Although the continued use of macro-level analysis of health

outcomes across the provinces is important, this protocol is less effective in

indentifying local variations in health outcomes at the community level.

7.2 Introduction

Each year in British Columbia (BC), roughly $12 billion is allocated to the

provincial health authorities for the administration of all healthcare services, with

less than one percent of these funds designated to the stewardship of these

services and monitoring and reporting on the health of the entire population (BC

Ministry of Health 2006). A key component of this allocation is addressing

inequalities in health status among segments of the population, particularly

among BC's Aboriginal population, whose health outcomes are broadly

acknowledged to lag behind the national population (Callegari, Alton et al. 1989;

Ryan, Shankowsky et al. 1992; Spady, Saunders et al. 2004; Cameron, Purdie et

al. 2005; Karmali, Laupland et al. 2005; Gilbert, Dawar et al. 2006). However,

allocation formulas for distributing healthcare resources and prevention models

on Reserves – though reimbursed federally – are largely derived from provincial and health region statistics, which are the largest of the health authority catchment units and deficient in identifying local variations in utilization or need of healthcare services by population sub-groups.

We propose a methodology for exploring community-based health outcomes among populations living on Reserves designed around a geographic information system (GIS). The GIS was chosen due to its ability in adapting statistical models to analyses that can derive comparative relationships between spatially adjacent areas. Our case study is based on fatal and non-fatal intentional and unintentional injury and mortality throughout BC, though the framework can be adapted to investigate any number of health outcomes. The specific aim of this research is to (i) examine the spatial distribution of fatal and non-fatal injuries on Aboriginal Reserves in BC in reference to local and regional health outcome patterns, (ii) determine if, and to what extent, incidence rates on Reserves are most representative of the burden of injury when assessed against geographically similar communities, and (iii) compare and contrast health outcomes on Reserves using a methodology that would enable provincial health authorities to prioritize local health initiatives without re-inventing how jurisdictions monitor the health and well-being of their community members.

7.3 Methods

Fatal and non-fatal injuries were measured using individual patient records (adults ages 18+; 01/01/2001 – 31/03/2006) from the British Columbia Trauma Registry (BCTR) and from the BC Coroner's database over the same period. The BCTR houses patient data on all individuals who have been injured from multisystem trauma requiring 2 or more days of hospitalization and with an Injury Severity Score (ISS) greater than 12. The ISS score is one of the most widely used measures of physical injury severity (Kuhls, Malone et al. 2002; Gittelman, Pomerantz et al. 2006). Injury morbidity and mortality were dichotomized into either intentional or unintentional categories. All in-facility fatalities were removed from the BCTR to avoid double counting in the coroner dataset. All causes of death from the coroner database that were listed as an intentional or unintentional injury were included in the analysis regardless of its classification being listed as a trauma.

Incident locations from the BCTR and BC Coroner database were linked to the 2006 Statistics Canada Postal Code Conversion File (PCCF) in the GIS through geocoding. This enabled us to obtain demographic data from the 2001 Census area that encapsulated its boundary and identify whether the incident took place on or off a Census area classified as a Reserve. The spatial adjacency functions of GIS were also employed to identify injury and population counts from the adjacent off-Reserve communities, thus providing a window to contrast health

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outcomes on Reserves relative to populations that are likely to be more socially, economically and geographically relative communities than the broader regional populations. Level of detail from coroner records is substantially coarser than the BCTR and data were analyzed at the municipal level, stratified for on/off Reserve fatalities using 2006 Census Subdivisions (CSD) and following the same methodology. As a comparison metric to test the robustness of the small-area analysis, both fatal and non-fatal injuries on reserves were separated and contrasted against rates using provincial Health Service Delivery Areas (HSDA) that encapsulated the Reserve.

Crude incidence rates of fatal and non-fatal injury classifications were analyzed using a probability mapping model (Choynowski 1959). This model was selected to help reduce bias as a result of examining community health outcome variations and deriving statistical significance from low population denominators. Poisson probability maps are similar to a standard mortality ratio, but reveal the likelihood that the incidence rate would be significant if it were the same for the spatially adjacent reference population. Further description of the Poisson probability mapping technique can be found elsewhere (Choynowski 1968; Cromley and McLafferty 2002).

7.4 Results

Provincial DA Census records documented 61,191 persons living on 294 of the 617 Census units classified as a Reserve in 2001 (Statistics Canada 2003). All injuries were removed from both the Reserve and off-Reserve populations if they were listed as occurring in an area with no recorded population. Among Reserves this reduced the number of occurrences from 11 intentional and 74 unintentional non-fatal injuries on 33 Reserves to 9 intentional and 53 unintentional non-fatal injuries within 24 Reserves. Off-Reserve injury occurrences were reduced from 48 intentional and 662 unintentional injuries within 210 DA's to 47 intentional and 534 unintentional injuries within 190 areas. Among injury mortality records, counts were reduced from 28 intentional and 98 unintentional records among 29 Reserves to 19 and 59 cases from 21 areas, respectfully. No records were removed from the adjacent Census Subdivision reference population groups. No cases were reported where a non-fatal and fatal injury occurred within the same Reserve and so a total of 45 Reserves (n = 294; 15% of all populated Reserves) affected by severe non-fatal and fatal injury should be considered. Descriptive statistics for fatal and non-fatal injuries on Reserves and adjacent areas are listed in Table 7.I.

Poisson probability scores for statistically significantly elevated or reduced rates of non-fatal and fatal injuries on Reserves and adjacent areas are listed in tables 7.2 and 7.3. In total, only 10 of the 36 Reserves with a significantly higher or

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lower injury incidence rate were similarly identified when assessed using the HSDA regions as the reference population. In other words, nearly 80% of reserves (n = 26) that had comparatively different incidence rates than their immediately adjoining communities would have gone under noticed if incidence rates would have been analyzed using regional populations as the reference group. These scale effects were least pronounced when analyzing data from the BC coroner dataset. However, this is likely due to the size of the census subdivisions, which are closer in population size to health regions than Census DA's and often include a number of urban areas (e.g. Vancouver, Victoria).

7.5 Interpretation

7.5.1 Main Results

Statistically significantly elevated or reduced rates of fatal and non-fatal injuries across Reserves were most pronounced when incidence rates were assessed against DA population data from the adjacent communities rather than when evaluated in reference to regional populations. Among those Reserves that either recorded an injury or death or were adjacent to a community that experienced a similar incident, 50% experienced morbidity and mortality rates that were statistically lower than the adjoining non-Aboriginal communities. Of these, two Reserves accounted for nearly 68% of the unintentional injuries and 25% of

intentional injuries that were statistically higher or lower than the adjacent

communities.

7.5.2   Explanation for the findings

Previous research on health outcomes among First Nation's Peoples in British

Columbia has demonstrated the importance of focusing more closely on

communities rather than regional populations when addressing health

inequalities (Chandler and Lalonde 2008). For example, Mao et al (1992)

previously demonstrated that mortality concentrations on Reserves are

potentially more reflective of actual risk levels if the reference populations

exclude major urban centres, which tend to downgrade small area rates in favour

of the larger populations (Mao, Moloughney et al. 1992). A local perspective of

monitoring health outcomes is now emerging as a jointly shared philosophy by

both provincial health authorities and aboriginal communities alike and

constitutes a shift toward the achievement of self-determination among

Aboriginal communities in monitoring and improving health (Government of

British Columbia 2005; Government of British Columbia 2005). However, these

more nuanced approaches remain limited as no attempts have been made to

address the challenges of working with small populations/counts on Reserves or

establishing benchmarks for highlighting significantly high or low incidence rates

on reserves. Moreover, the predominant tendency when emphasizing

community-based monitoring of health outcomes on Reserves has been to derive

a disproportionate number of macro-level results from a single community (Young 2003). As many healthcare resources are administered provincially, particularly emergency health services, it is vitally important that small-area risk estimations bridge these two limitations to enable an increased responsiveness to local health needs.

While the results presented in this analysis may in fact be deflated because we could not control for status Aboriginals within the BCTR, the results suggest that recent counts of severe injury morbidity and mortality within Aboriginal communities are contained among a more clustered segment of the population than had previously been imagined. While this is not to say that the injuries are not disproportionately felt among aboriginal peoples' – they are in fact the leading contributors for potential years of life lost among aboriginal Canadians (Indian and Northern Affairs Canada 2003; Canadian Institute of Health Information 2004) – the results demonstrate that there are significant spatial variations across Reserves and that severe injury or mortality as a result of intentional or unintentional injury, while a significant public health concern, is far more concentrated throughout BC than widespread. Moreover, a number of Reserves experienced significantly lower rates of injuries relative to adjacent communities, which offers some evidence that targeting 'Reserves' as a single indicator of elevated health risks may again be too broad of an approach toward understanding or reducing risk patterns than more community-specific initiatives.

7.5.3 Limitations

While there is no singular approach toward monitoring health outcomes of persons living on Reserves, micro-level analysis of health outcome data among population sub-groups has continually lagged behind macro-level healthcare monitoring. Small-area comparisons of population sub-groups using reference areas that are likely to be the most similar socially, economically, and also in terms of isolation or rurality serve as important indicators for monitoring systems performance measures or healthcare needs among communities. One limitation of this approach, however, is that in becoming so nuanced we might invariably lead health authorities farther away from understanding the population-wide prevalence of negative health outcomes among Aboriginal communities. To date, however, there is a dearth of research that specifically focuses on how best to bridge micro- and macro-level public health surveillance and the proposed methodology attempts to mediate this limitation. Prevailing challenges in meeting these objectives are largely conceptual, as few protocols have been developed that can balance the use of a finer scale while also minimizing the challenges associated with working with small numbers. Typically, as the scale of the investigation narrows, population denominators decrease and invariably introduce a large random component that may influence the analysis (Elliott and Wartenberg 2004). Whilst empirical Bayes analysis offer a second lens for conducting small-area analyses, the Poisson mapping applications are likely to be just as effective when similar populations (e.g. rural vs. rural) are contrasted

against one another. In BC, small-area census boundaries throughout rural and remote areas that run adjacent to Reserves are, on average, similar in size. A far more daunting challenge stems from restrictions in obtaining the necessary patient records to methodically explore injuries or other health outcome data among aboriginal Canadians at a commensurate spatial extent.

7.6 Conclusion

While rates and risk of negative health outcomes are widely known to be disproportionately higher among Aboriginals than their non-Aboriginal counterparts, comparisons between Reserves with their adjacent communities has remained auspiciously absent from most health profiles of Aboriginal communities. This is a vitally important research area that poses many important questions regarding population health equity that may not necessarily be mutually exclusive between both communities. Integrating GIS technology with hospital registries provides a mechanism for analyzing what were previously under realized trends in Aboriginal community health outcomes. Database and spatial linkage tools in GIS can be used to merge registry data with additional spatial identifiers, thus expanding the amount of demographic information that corresponds to the patient database. Once integrated, the data can then be further investigated using an array of inferential and exploratory analysis techniques, providing researchers with a more dynamic portrayal of the variation

in health outcomes across specific populations and geographies, both large and small.

The proposed framework has a wide number of applications that can be used to better understand variations across Aboriginal communities and identify from those communities populations that could either benefit from more direct prevention and outreach resources as well as those communities that are comparably better off. In the former event, this provides evidence in support of building local initiatives and prioritizing population health interventions. In the latter event, these comparisons position provincial health authorities to better appraise the effectiveness of Aboriginal community or provincial service mechanisms that may have helped contribute to better individual health outcomes. Given the current economic strain on healthcare resources in both BC and throughout Canada, identifying the extent that healthcare needs surpass resources currently allocated for prevention in light of understanding that risk is not homogenous among all communities is a much needed component in ongoing efforts to reduce health inequalities and optimize the delivery of provincial healthcare resources.

7.7 Figures

Figure 7.1 Adjacency model and Poisson probability calculation. Geographic Information Systems (GIS) allow identification of adjacent DA's for each Reserve.
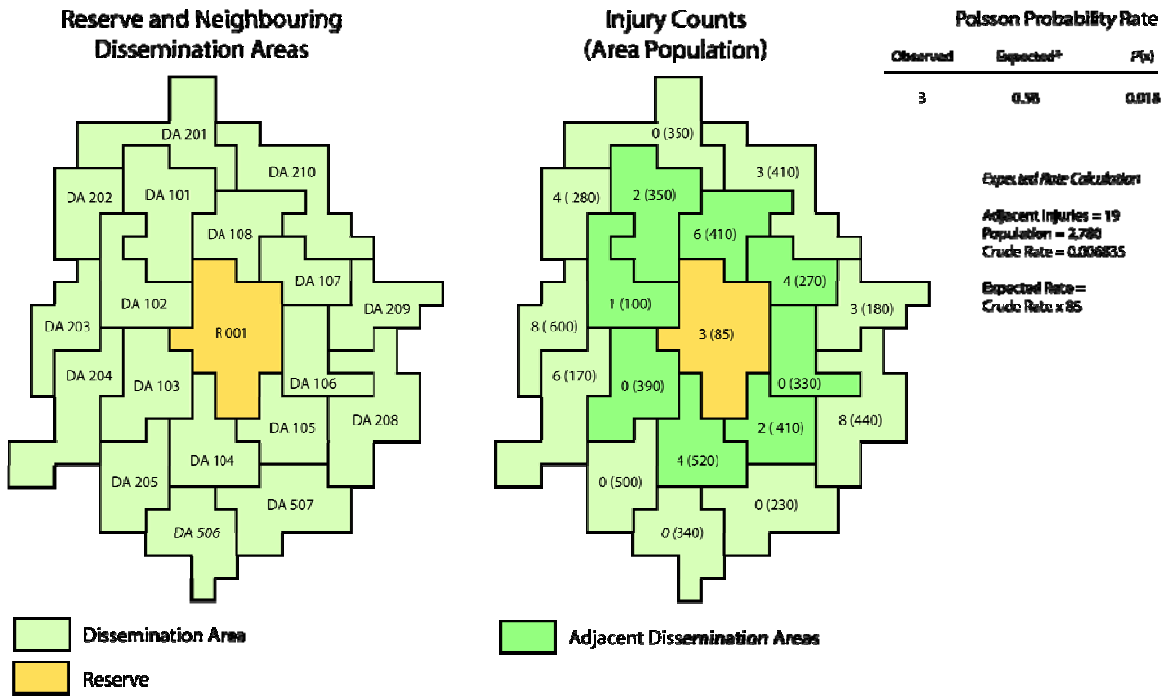
Figure 7.2 Distribution of fatal and non-fatal severe injuries on Reserves in BC (adults, ages 18 +) occurring at higher or lower than expected rates given the incidence rate of the adjacent non-Aboriginal communities. Adjacent rates measured using Census Dissemination Area and Subdivision populations.
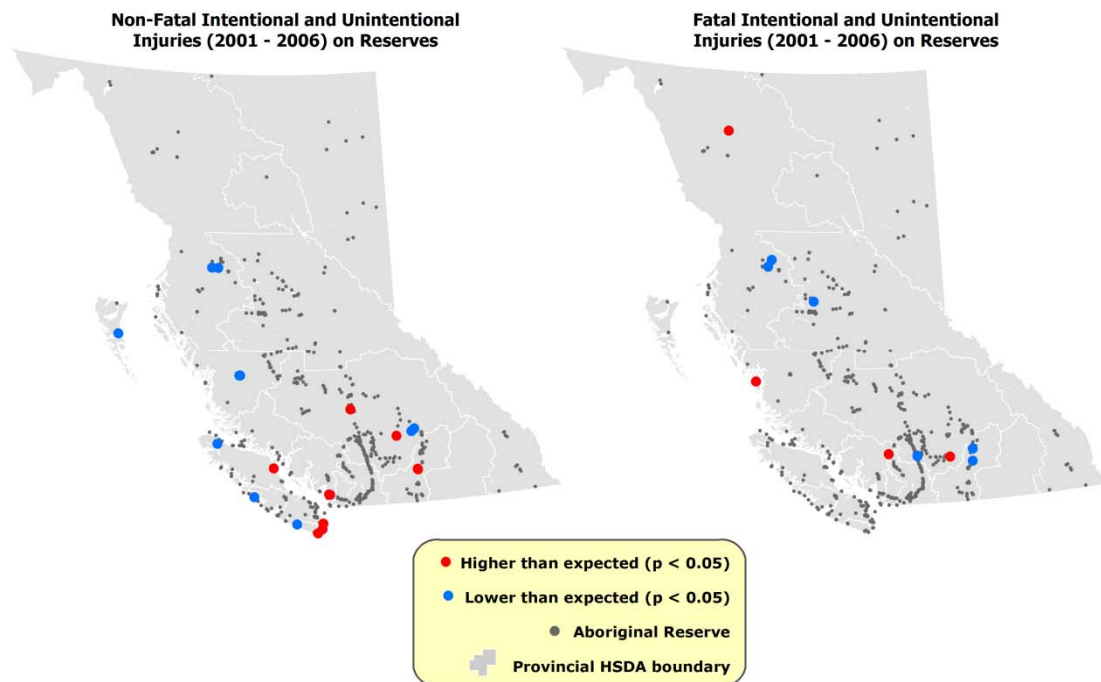
7.8 Tables

	Reserves	Adjacent Areas
Dissemination Areas		
No. of Populated Areas	295	512
Population	61,141	254,295
Mean Population	99 (± 16 SD)	481 (± 16 SD)
No. of Intentional Injuries	9	47
No. of Unintentional Injuries	53	534
Census Subdivisions		
No. of Populated Areas	181	65
Population	54,645	2,473,509
Mean Population	302 (± 41 SD)	38,054 (± 10,387)
No. of Intentional Injury Fatalities	19	1,760
No. of Unintentional Injury Fatalities	59	3,159

Table 7.1 Descriptive statistics for Reserve and adjacent population areas. Population differences between DA and CSD geographies among Reserves stem from poorer precision in geocoding place names when using the provincial coroner database.

	Non-Fatal Intentional Injury			Non-Fatal Unintentional Injury		
Population	Observed	Expected	p	Observed	Expected	p
466	0	0.00	1.000	5	0.48	*0.000*
615	0	0.00	1.000	0*	3.92	*0.020*
339	1	0.00	*0.000*	2	0.54	0.086
937	1	0.00	*0.000*	2	0.85	0.154
659	1	0.00	*0.000*	0	2.66	0.070
107	2	0.00	*0.000*	20	0.22	*0.000*
105	0	0.00	1.000	0*	3.26	*0.038*
557	0*	10.92	*0.000*	0*	10.92	*0.000*
212	0	0.07	0.928	1	0.00	*0.000*
59	1	0.00	*0.000*	1	0.00	*0.000*
52	0	0.00	1.000	1	0.02	*0.024*
253	0	0.00	1.000	0*	25.12	*0.000*
550	0	0.00	1.000	2	0.00	*0.000*
965	1	0.00	*0.000*	3	1.98	0.179
318	1	0.00	*0.000*	2	0.31	*0.036*
142	0	0.00	1.000	0*	3.92	*0.020*
88	0	0.00	1.000	0*	8.74	*0.000*
198	0*	4.66	*0.009*	0*	9.32	*0.000*
329	0	0.00	1.000	0*	4.68	*0.009*
192	0	0.00	1.000	0*	3.45	*0.032*
562	0	0.00	1.000	0*	6.90	*0.001*
426	0	0.00	1.000	0*	3.27	*0.038*
287	0	0.00	1.000	0*	3.42	*0.033*

* rate significantly lower than expected (p <0.05).

Table 7.2 Acute intentional and unintentional non-fatal injuries on BC Reserves relative to incidence rates among adjacent communities.

	Fatal Intentional Injury			Fatal Unintentional Injury		
Population	Observed	Expected	p	Observed	Expected	p
100	0	0.03	0.972	3	0.01	*0.000*
937	2	0.00	0.000	3	0.00	*0.000*
171	2	0.00	*0.000*	0	0.00	1.000
79	0	0.00	1.000	0*	4.63	0.010
101	0	0.00	1.000	0*	5.93	0.003
1979	0	1.78	0.168	0*	3.99	*0.018*
1860	0	1.72	0.178	0	3.62	*0.027*
1253	1	0.00	*0.000*	4	0.00	*0.000*
693	0*	4.02	0.018	0	8.03	*0.000*
432	0	1.73	0.178	0	4.03	*0.018*
593	0	1.82	0.162	0	7.58	*0.001*
66	1	0.00	0.000	9	0.00	*0.000*
100	0	0.00	1.000	3	0.00	*0.000*

* rate significantly lower than expected (p <0.05).

Table 7.3 Acute intentional and unintentional fatal injuries on BC Reserves relative to incidence rates among adjacent Census Subdivisions.

8: CONCLUSION

8.1.1 Summary

At its core, this dissertation focused on the incidence patterns of severe injury

and ways to illustrate its relationship across both social and spatial lines through

GIS. Maps have long played an important role in the geographical study of

disease and injury. They have provided important clues as to how to approach

disease etiology, model its diffusion across the landscape, or assess small-scale

trends in various health outcomes. GIS is a powerful medium for conveying

trends in population health and offers an expansive set of tools for exploring a

variety of questions pertaining to the spatial patterning of health and wellness.

Ultimately, the goal is to draw linkages to features in the communities that might

lead to explanations for individual health experiences and build from these

findings future strategies for health promotion. Geographers undoubtedly play a

key role in furthering our understanding of how social and spatial processes

influence health outcomes and there is great potential to further embrace the

strengths of this technology.

This dissertation examined incidence patterns of severe injury among adults

throughout urban, rural, and remote populations in British Columbia, Canada.

Injuries are the leading cause of death and potential years of life lost in the first

four decades of life in North America and around the world. This dissertation offers timely evidence that prevalence of injury does not affect all populations equally and disproportionately occurs among lower socio-economic populations. However, risk of injury is not only limited to persons in the tailings of the socio-economic ladder. Many causes of injury, including burns and interpersonal violence, follow a social gradient and this relationship varies among urban, rural, and remote populations.

The objective of this dissertation was to provide three contributions to our current understanding of injury and its social and spatial determinants. The first purpose was to examine incidence patterns of injury against variations in geographic scale and SES. Both multi-level models and spatial adjacency functions in GIS were used to analyze this relationship. A social gradient was found among assault and pedestrian injury patterns when analyzed at different small-area boundaries of the census, but this relationship was not universal among other injury classes, including falls and motor vehicle collisions. When taking into consideration the affects of the MAUP, the relationship between SES and incidence risk of injury also varied, but the effect of this variation was most pronounced as the data was aggregated into larger administrative units. This suggests that many of the administrative boundaries currently used for health surveillance are potentially failing to monitor and identify populations in need.

The second objective of this dissertation was to identify if the relationship between injury and SES would possibly go unnoticed if that data were not also analyzed using GIS. Explicit representation of spatial adjacency was analyzed using intentional injury data within greater Vancouver. Analysis identified geographic location of increased incidence of self-inflicted injury in greater Vancouver occur in dispersed patterns and difficult to identify using information about the location alone. This was a significant finding as it pointed to a potentially hidden population group as a separate analysis linking incidence patterns of intentional injury with socio-economic data from the census was unable to identify a significant trend.

Lastly, this dissertation attempted identify if GIS could be used to better explain relationships between incidence patterns of injury and social and demographic data over and above non-spatial surveillance practices. A spatial adjacency model was used to analyze incidence patterns of injury on reserves throughout the province. The results demonstrated that incidence patterns of injuries on reserves are contained among a more clustered segment of the population than had previously been imagined.

This dissertation also reinforces the need to manipulate and think past the spatial constraints imposed by the Census when analyzing the relationship between individual or collective SES factors and their interaction when analyzing the

relationship between SES and incidence patterns of injury. One of the tenets of the public health approach toward prevention as identified by the Center for Disease Control (CDC) is to identify the characteristics that increase the likelihood of a person experiencing a negative health outcome (CDC 2009). Within population health research, this entails focusing on the social and economic determinants of health, using evidence-based approach to identify conditions that best address factors leading to high risk of injury. However, and as this thesis has shown, when modelling risk using administrative data it is first helpful to (i) rationalize at which spatial extent does the relationship exist, (ii) test whether it is necessary or appropriate to alter or amalgamate adjoining administrative units when analyzing this relationship, and (iii) test whether the statistical significance between the indicators and incidence patterns of injury is an artefact of scale or the way in which the data are partitioned.

This thesis has shown that the relationship between SES is not universal across all spatial extents, that an assessment of risk requires both an understanding of socio-economic and spatial data, and that if we are to help governments and community groups alike build toward health promotion it is first necessary to vigorously analyze how the same dataset, when analyzed differently using different administrative boundaries, may lead to policy and service concerns that do not adequately represent real life. In addition, this thesis provided one of the first in-depth analyses of social and spatial variations in severe injury among sub-

population groups in Canada. GIS is an emerging technology used by injury preventionists to better understand the ecology of injury (Macpherson, Schull et al. 2005). has not been used to further our understanding of the graded relationship between socio-economic status and injury. The results from this dissertation suggest there is much future potential for GIS to serve as a means of analysis and communication of health patterns and their graded nature.

8.1.2 Spatial limitations and considerations

Census data and their associated spatial boundaries are used for a wide range of purposes. This research utilized GIS to explore numerous associations between social and economic processes with incidence patterns of injuries. This analysis was primarily based on population-level data and in reference to postal code, census, and provincial health authority boundaries.

In interpreting the results of population-level analysis it is important to remain vigilant that evidence gained from these analyses are drawn from ecological data. In effect, many of the analyses presented in this dissertation were based on global assumptions regarding the relationship between independent variables of SES and the extent that they correlated with that same area's incidence rate of injury. While informative, global regression coefficients assume stationarity – that is we presume that our observations throughout the entire study area are independent of their location. The particular relevance of this limitation was that it

partially undermined the ability to identify if similarly classified neighbourhoods

sheltered individuals from increased risk of injury while others led to greater

exposure.

One potential solution to this limitation now emerging in health outcomes studies

is geographically weighted regression (GWR) (Maroko, Maantay et al. 2009). The

benefit of GWR is that it allows researchers to identify if there is any inherent

local variation in community context and frequency of a particular health outcome

on a community-by-community basis. This is in contrast to producing a single

coefficient representing the prevalence of injury across all areas or sub-classified

areas (e.g. low SES, med SES, high SES). One particular advantage of this

approach is that it allows researchers to quantify how different hypothesized

effects of community-level indicators, such as cohesion or fragmentation, may

vary from one area to the next in response to the same stimuli (Fotheringham,

Charlton et al. 2002). However, the transition toward more location-specific

models of social space does not necessarily guarantee that more meaningful

information will be obtained. In fact, data and access limitations often prohibit this

level of detail.

Despite this limitation, it can be argued that spatial representations of social

processes generated from areal data remain valid and relevant given both their

widespread use and the explicit capacity of the spatial environment to limit

behaviour (Raper 2001). In the context of researching the relationship between social processes and injury, for example, digital representations of real-world objects, such as bars or homeless shelters can be linked with both individual perceptions of feelings of 'safety' and street network data in a GIS to study problematic social phenomena such as pedestrian injuries or crime. In fact, this analysis has already been started by Schuurman et al (2009) in their study of pedestrian injuries in relation to the built environment (Schuurman, Cinnamon et al. 2009). Coupling this methodology with personal responses (see for example: Ryb, Dischinger et al. 2007) could lead to the definition of new, and possibly more relevant, social units for the study of injury.

8.1.3 Medical limitations and considerations

Many persons are at risk for acute hospitalization and long-term complications owing to illness or injury. This study identified all persons who were hospitalized from a severe injury in British Columbia over a five year period and offers both evidence and protocols for establishing surveillance programs to monitor future trends.

However, these results have limitations. Persons with no fixed address at the time of discharge from hospital were excluded from our analysis, thus potentially under representing both the homeless and hard to house populations from the results. Secondly, in our analysis of injuries of reserves status and non-status

aboriginal groups could not be identified from the registry data and risks of double counting when estimating the burden of injuries on reserves remains. Thirdly, this study failed to take into consideration the relative incidence rate of non-severe injuries throughout the province. Lastly, our analysis was limited to severe injury as measured using the ISS. However, the ISS does not discriminate between patients having multiple injuries located in the same body region (e.g. chest) and reports on only the most severe injury and ignores secondary and tertiary lesions.Combined, these limitations imply that results from this study provide only a conservative view of the burden of injury in British Columbia.

8.1.4 Future research

This research focused exclusively on the social and spatial dimensions of acute illness, which is only one segment along the continuum of population health and the provision of health care. Advances in critical care medicine, including the creation of multi-disciplinary healthcare teams and increased capabilities of multi-system life support, have pushed the frontiers of medical practice and have increased survival of after severe illness to unprecedented levels. The effect of critical illness and associated influence on long-term patient outcomes will likely become even more apparent as our population ages and becomes increasingly illness prone.

With improved survival after critical illness, the need to understand outcomes and quality of life becomes highly relevant (Herridge 2002). Unfortunately, far fewer resources have been devoted to improving outcomes after discharge and systems are not in place to facilitate the patient's transition from the acute to the chronic phase of their illness (Kahn and Angus 2007). Instead, after discharge survivors must re-enter a health system where little is known about potential vulnerabilities in meeting chronic health needs. In fact, despite a decade of transferring responsibility away from acute and institutionally based services toward locally administered community care facilities we know relatively little about their capacity for helping individuals manage chronic illnesses on a day-to-day basis (Mhatre and Deber 1992). In particular, future research identifying vulnerable patients and caregivers who are possibly on the receiving end of a poor systems model represents an important opportunity to help optimize our investment in care for the critically ill.

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