Factors Associated with Severe and Fatal Cycling Injuries in North America

by

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A thesis submitted in partial fulfillment of the requirements for the degree of

Master of Science

in

Epidemiology

School of Public Health
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Abstract

Background: Cycling is an increasingly popular recreational activity and mode of transportation, and many North American municipalities are implementing policies and infrastructure to encourage cycling participation for all ages. Crashes while cycling, however, can have devastating consequences including debilitating injury and death. The factors relating to the occurrence of severe injury events are not well studied, making it difficult to refine and implement successful injury prevention strategies. This thesis aims to compile the current evidence on cycling fatalities, examine the role of age in their occurrence compared to severe injury, and describe their occurrence in a sparsely populated area with a northern climate.

Methods: Three studies were completed to investigate severe and fatal cycling injuries in North America. First, a scoping review was conducted to explore the current literature on fatal cycling injuries in North America. Second, a systematic review was conducted to examine the burden of injury due to cycling fatalities in adults compared with children. Finally, a descriptive observational study was conducted using chart review methods to extract data from fatality case files of the Office of the Chief Medical Examiner of Alberta, and population-based fatality rates by age category and by region were calculated using census data.

Results: The scoping review identified 25 studies documenting cycling fatalities in North America, of which 21 used data from US populations, four used data from Canadian populations, 19 included both child and adult cyclists, four included only children, and two reported only on adults. Studies most commonly reported on: sex (n=16), motor vehicle involvement (n=12), lighting condition (n=12), alcohol use (n=10), and occurrence of head injury (n=9).

Of the 46 eligible studies of severe and fatal cycling injuries in North America identified in the systematic review, data were available from 27. Overall, children had a lower weighted proportion of fatalities (3.0%; 95% CI: 2.3-3.8%) than adults (7.2%; 95% CI: 5.6 - 8.7%). Heterogeneity was very high, except for pediatric studies conducted in Canada (I^2=27) and pediatric studies in regions where mandatory helmet legislation existed (I^2=0).

One-hundred and one cycling-related deaths over 14 years in Alberta were identified. Most (87%) deceased cyclists were male, median age was 47 years (inter-quartile range: 25, 58), and 25% wore helmets. Collisions with motor vehicles and cyclist-only crashes accounted for 67% and 22% of fatalities, respectively; 12 (12%) crashes had “other” mechanisms, such as a collision with a train, light rail transit, pedestrian, or other cyclist. The population-based fatality rate was highest for the ≥65 age group.

Conclusions: There are few high-quality studies examining the factors associated with cycling fatalities, especially compared with nonfatal injuries. Overall, studies of severe and fatal cycling injury events provide only weak evidence, have inconsistent reporting of results and efforts to standardize them are warranted. In cases of severe injury, adults appear to have a higher burden of fatality than children, and older adults (≥60 years old) had the highest fatality burden. Injury prevention strategies should target male cyclists, helmet use and avoidance of substance use while cycling. Future studies should focus on improved methods, including use of comparison groups and prospective study designs, and more detailed reporting of known or suspected risk factors.

Keywords: Bicycle, Injury, Death, Alberta, North America

Abstract Word Count: 524 words

Preface

Chapter 4 of this thesis was published on November 17, 2015: L. Gaudet, N. T. R. Romanow, A. Nettel-Aguirre, D. Voaklander, B. E. Hagel, B. H. Rowe, "The epidemiology of fatal cyclist crashes over a 14-year period in Alberta, Canada," *BMC Public Health.* 2015;15(1):1142. For this manuscript, L Gaudet collected data, conducted the statistical analysis, and wrote the manuscript. Contributions to the article were also made by: N. Romanow and A. Nettel-Aguirre, who contributed to conception and design of the study and intellectual revision of the manuscript; D. Voaklander, who contributed to interpretation of the data and intellectual revision of the manuscript; and B. E. Hagel and B. H. Rowe who contributed to the conception and design of the study, interpretation of the data and intellectual revision of the manuscript.

Dedication

To my sister, Brianne: for commiserating with me before we could see light at the end of the tunnel.

To my husband, Patrick: for his continued love and support in everything I do.

Acknowledgements

This thesis was generously supported by a Student Project Research Grant from Knowledge Translation Canada; a Graduate Student Scholarship from the University of Alberta Emergency Medicine Research Group, and a Graduate Studentship from the Western Regional Training Centre for Health Services Research.

I would like to thank Dr. Brent Hagel and Dr. Donald Voaklander for their contributions as collaborators and members on the supervisory committee for this thesis. I would also like to express my appreciation to Scott Kirkland, Nicholas Arrotta, Chris Alexiu, and Ferdinard Operke for their assistance as reviewers for the scoping and systematic review chapters; to Kathryn Webb for her help with data collection at the Medical Examiner's office; and to Dr. Cristina Villa-Roel for her continuing advice and open door. Finally, I would like to express my sincerest appreciation to Dr. Brian Rowe for all of his support and guidance over the years, and for supervision of this thesis.

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List of Abbreviations

BAC=– Blood Alcohol Content

CI = Confidence Interval

DOA = Dead on Arrival

ED = Emergency Department

EMS = Emergency Medical Services

EPHPP = Effective Public Health Practice Project

FARS = Fatality Analysis and Reporting System

HCUP-NIS – Healthcare Cost and Utilization Project National Inpatient Survey

IQR = Interquartile Range

ISS = Injury Severity Score

ME – Medical Examiner

MHL - Mandatory Helmet Legislation

MVCC – Motor Vehicle/Cyclist Collision

NCHSMCD = National Center for Health Statistics Multiple Cause of Death data file

NVSS = National Vital Statistics System

OCME – Office of the Chief Medical Examiner

List of Abbreviations

PCR = Patient Care Report

RCMP – Royal Canadian Mounted Police

TRIS = Transportation Research Information System

Chapter 1 Introduction

1.1 THE HISTORY AND BENEFITS OF CYCLING

The bicycle was developed and popularized in the mid-to-late nineteenth century in Europe. A popular bicycle design at the time included a large front wheel and much smaller rear wheel putting the rider high above street level and enabling him/her to travel at high speeds. The height above ground and velocity with which so-called “penny-farthings” could travel made cycling a dangerous activity mainly reserved for the adventurous. In the 1880s, this design was reversed and models of bicycle that had a large rear wheel and much smaller front wheel began to appear. The so-called “safety bicycle” allowed people of all ages and abilities, including women, to more safely use a bicycle for transportation. Cycling steadily increased in popularity in both Europe and North America until the 1910s, when automobile began to replace bicycles as a mode of transportation in North America. Cycling for transportation gained popularity again in North America during the 1960s and 1970s as more people became aware of the benefits of regular exercise and emerging environmental issues of the time.

Today, cycling is a popular recreational activity and mode of transportation that is enjoyed by people of all ages in North America. In addition to an enjoyable recreational activity, cycling is also an environmentally friendly and healthy mode of transportation that has many benefits. While data on cycling rates in Canada are sparse, a 2004 survey indicated that 82% of Canadians cycle for leisure or recreation and 64% at least occasionally cycled to reach a routine destination, with 17% of respondents cycling at least half the time.[1] Fourteen percent of Canadians cycle to work at least once per year.[1] Cycling has minimal impact on the environment compared with motor vehicles, and shifting transportation trips to bicycles would reduce traffic congestion, greenhouse gas emissions, and overall air pollution, which could reduce air quality-related morbidity and mortality.[2] Cycling is also an economical option compared to operating a motor vehicle. Cycling increases physical fitness including cardiovascular function and contributes to reducing obesity and maintaining a healthy weight.[3-5] Regular cycling may also reduce the risks of cardiovascular disease, diabetes, cancer mortality and all-cause mortality.[4-7] For these reasons, cycling is increasingly viewed as a viable and beneficial alternative to motor vehicles as a mode of transportation, especially over short trips. The large number of health and environmental benefits presented by regular cycling are motivating North American cities to implement plans and policies aimed at encouraging cycling among their residents[8]; however, the public health consequences of these efforts have not been thoroughly examined. It is possible that higher rates of cycling may increase the frequency of cycling-related injuries presenting to emergency departments (ED) and therefore utilize more health resources.

1.2 CYCLING IN CANADA

In Canada, bicycle ownership and ridership is more prevalent among children and adolescents than among adults; ownership among children and adolescents is reported to be 88% compared with 60% for adults.[1] Cycling among adults is mostly recreational; in a 2004 survey, only 17% of adult Canadians reported cycling to work at least once in the preceding 12 month period.[1] Canadian commuter cyclists are most commonly highly educated and socioeconomically-advantaged white males.[9, 10] From census data, the proportion of Canadian bicycle commuters varies across the country, from a high of 2.8% in the Yukon to a low of 0.1% in Nunavut (Table 1). The national average of 1.4% has remained relatively stable since 2006.[11] It should be noted that where individuals use more than one mode of transportation for commuting, the census only reports on the main mode of transportation used by that individual; therefore, it is likely that the proportion of trips made by cyclists in Canada may be higher than what is reflected by the census numbers.

Rates of bicycle injury are difficult to accurately calculate, as there are significant challenges to determining the affected population and defining the “exposure” (e.g. owning a bicycle vs. number of trips vs. km cycled), therefore estimated rates may vary significantly depending on the data source. For instance, estimates calculated using traffic crash reports may significantly underestimate the number of bicycle-only collisions depending on a region's crash reporting requirements, and hospital treatment records may underestimate minor injuries due to the overrepresentation of severe injuries presenting for medical treatment, compared with minor injuries. Overall, Canadian adolescents aged 11–15 years old experience the highest rate of bicycle-related injury, followed by children 1–10 years old and persons aged 16 and older.[12] Considering that the majority of cyclists are male and that most injuries presenting for medical treatment occur in males, it is not surprising that males also make up the majority of bicycle-related injuries and fatalities, although this proportion is highest in youth (80.7%) compared to adults (76.7%) or children (66.1%).[12-18]

1.3 THE INJURY PYRAMID

While cycling has many well documented benefits, loss of control and a subsequent fall or collision with another object (including a moving or stationary motor vehicle) can have catastrophic consequences such as severe isolated head injury, multisystem trauma and/or death. Additionally, cycling-related injuries are among the most common sports and recreation injuries presenting to EDs in Canada and the United States.[19-21] Cycling injuries that present to EDs are "just the tip of the iceberg"; in general, the number of patients with injuries who seek medical treatment represent a small proportion of the total number of injuries that occur (Figure 1). In this regard, cycling injuries are no different from other types of injury; up to half of all bicycle-related injuries do not require the attention of a medical professional and up to half of cycling injuries that present for treatment are minor injuries that do not require extensive treatment.[21-25] Because of the speeds involved and the height of the cyclist off the ground when mounted, head injury after a bicycle crash is common, especially when helmets are not used and among severely injured cyclists.[21, 23, 26] Fatal cycling crashes are rare, but remain disproportionate to road usage; while only ~1.5% of Canadians cycle on a regular basis, cyclists account for ~3% of fatalities and ~4% of serious injuries among Canadian road users.[11, 13, 27] Cycling-related fatalities usually involve a collision with a motor vehicle.[16, 17, 25, 28] Finally, although bicycle ownership and ridership is more prevalent among children and adolescents than adults, a large portion of injury burden is borne by adults who are more frequently injured after a collision with a motor vehicle and have higher rates of bicycle-related severe injury and fatality compared with children and adolescents.[16, 17, 21, 29, 30]

The high incidence of injuries that occur during cycling is not surprising given its popularity and highlights the important public health implications of an increase in cycling activities.

1.4 HADDON'S MATRIX

Many factors contribute to the occurrence of an injury event. Bicycle crashes and the resulting injuries are ultimately the result of one or more environmental (e.g., road condition, weather, etc.), mechanical (e.g., brake failure, flat tire, etc.) or behavioural (of either/both cyclists and motorists) factors, most of which are preventable. The factors and prevention strategies associated with cycling injury can be categorized based on their relationship to the cyclist, the agent of injury (i.e. the bicycle in cyclist-only crashes or motor vehicle in MVCCs), and the physical or social environment leading up to or present during and/or after the event, as described by Haddon's Matrix (Table 1.1).

It is important to note that while there are always theoretical measures that could be implemented to address any of the factors associated with cycling crashes and injuries, not all measures are feasible. For example, cyclists' increased vulnerability compared to motor vehicles could be addressed by requiring all bicycles to be fitted with protective devices; however, such an approach would require significant resources from both cyclists (in order to purchase and/or install a cage and the increased encumbrance of cycling with such) and law enforcement agencies (as enforcement is an important part of a law's effectiveness as a public health intervention). Additionally, some factors associated with one of the four columns in the matrix may be effectively addressed by interventions from another column; for example, drinking prior to cycling - like other risk-taking behaviors such as non-use of helmets - may be more effectively curbed by a societal intervention such as targeted drinking-and-biking legislation than by individual-level interventions.

The remainder of this chapter presents a selection of factors associated with cycling injury occurrence and severity and some of the interventions that have been applied to address them. Cyclist-related factors include modifiable characteristics, such as risk-taking behavior and physical fitness, and non-modifiable characteristics (e.g., age, sex, socioeconomic status, etc.) which are not generally subject to change. Bicycle-related factors, while specific to the bicycle, may also be altered by cyclist behavior, such as using a bicycle that correctly fits the cyclist and ensuring proper bicycle maintenance. Environmental and societal factors are difficult to alter as they require significant temporal and financial resources to be effective, but these ecologic approaches may also have the greatest overall impact on cycling safety.

1.5 CYCLIST FACTORS

1.5.1 Sex

The majority of cyclists are male; therefore, it is no surprise that the majority of cycling injuries and fatalities also occur in males.[16, 17, 26, 28, 31] Male cyclists are involved in bicycle crashes more frequently than females, but also at a higher per-trip rate than female cyclists.[32] Males' higher frequency of cycling crashes correlates with their increased risk-taking behavior compared to females of a similar age, especially among adolescents and young adults.[33, 34] On the other hand, a Spanish study of fatalities calculated rate based on time spent travelling and found that females may experience a higher rate of cycling-related fatality, per person-hour spent cycling.[35]

1.5.2 Age

Children and adolescents are most often involved in bicycle crashes.[36, 37] Bicycle-only crashes, however, which typically result in less severe injuries than collisions with motor vehicles, are more prevalent among children than adults.[25] This may be due to childrens' inexperience making decisions in a traffic environment, and undeveloped bicycle-riding skills.[37-39] To combat these problems, different bicycle-training programs have been implemented among school-aged children in different jurisdictions to varying degrees of success.[40-45] Education-based safety training programs have been shown to increase children's safety knowledge, such as proper helmet fit, which is in turn associated with reduced risk-taking behaviors (including wearing a helmet). These courses, however, may not improve motor skills required for safe cycling,[44, 46, 47] although there is evidence to suggest that children who participate in a skills-based training programs show significant improvement in the physical skills needed to safely operate a bicycle.[40]

While young people experience the largest number of crashes, older adults also experience significant risk while cycling. Adults over the age of 65 have greatest exposure-adjusted risk of injury and are also disproportionately represented among cycling fatalities. Likely, increased reaction time, decreased coordination, increased co-morbidities including sensory deficits (i.e., visual and hearing impairment), and decreased balance makes them less able to avoid a crash, and their increased physical frailty results in increased injury severity, decreased ability to recover, and therefore poorer outcomes compared with younger cyclists.[48-50]

1.5.3 Use of Bike Helmets

Head injuries account for a large portion of bicycle injuries and fatalities, and there is overwhelming evidence for the effectiveness of helmets at protecting against head injury in the event of a crash.[31, 36, 51-54] Helmets, however, are not universally worn, and there is evidence that their use varies by sex, age, as well as social determinants (e.g., socioeconomic status and race).[18, 33, 38, 55, 56] For optimal protection the helmet should be fitted properly and worn correctly; however, many cyclists do not wear a properly fitted helmet, putting themselves at increased risk of head injury.[57-59] While mandatory-helmet legislation (MHL) increases helmet use and reduces bicycle-related head injuries and fatalities,[54, 60-65] it does not guarantee the helmet will be fitted or worn properly.[58] Mandatory helmet laws may have a minimal effect on helmet use in the long term in those with low socioeconomic status, [66] as helmet use is affected by social environment, cultural elements, socioeconomic status, and race, among other factors.[38, 57, 67] Non-legislative community-based interventions have shown promise in promoting helmet use and may have a greater impact on helmet use among groups resistant to legislation.[68] While helmets are an effective intervention for mitigating injury severity, they do not prevent bicycle crashes or non-head cycling injuries;[51, 54, 62] therefore, to further reduce cycling injury rates, additional injury prevention strategies need to be implemented in conjunction with approaches to encourage helmet use in order.

1.5.4 Alcohol Use

It is well documented that cycling while intoxicated increases risk of a crash, severity of injury, and risk of head injury.[36, 52, 69-73] Consumption of alcohol prior to cycling also correlates with not wearing a bike helmet.[10, 52, 70, 71, 74] Additionally, the majority of cyclists who sustain a cycling injury after reportedly consuming alcohol are legally intoxicated.[70, 75] Cyclists with a BAC >0.10% who sustained a severe injury are at 2.81 times increased odds of death compared to cyclists who were not consuming alcohol immediately prior to being injured.[70] In a study by Li *et al*. cyclists who were legally intoxicated at the time of the crash were significantly more likely to have previously had their driver's license suspended or revoked compared with cyclists who were injured while riding sober.[76] Cyclists may view bicycles as a safe alternative for transportation after they have consumed alcohol, a theory supported by the increased frequency of injury events during the early morning hours of Saturday and Sunday morning compared to the early hours during the rest of the week.[37, 72, 77] Relatedly, Johnson et al. conducted a study on the attitudes towards alcohol use of injured cyclists presenting to an ED, and when interviewed the vast majority of cyclists agreed that alcohol impairs their ability to ride a bicycle, including 94% of cyclists who reported that they ride a bicycle home after imbibing.[78] Despite the strong evidence for the increased risk of cycling while intoxicated, following extensive literature searching (e.g., EMBASE, Medline, CINAHL), no reports of interventions targeting alcohol use as a risk factor for injury were identified. Even though most cyclists acknowledge that alcohol likely impairs their ability to ride a bicycle, cyclists may not recognize that drinking and cycling increases risk of a crash, so public awareness campaigns about the dangers of drinking and cycling may also reduce cycling injury rates.

1.6 AGENT FACTORS

1.6.1 Bicycles

The fit and style of a bicycle may contribute to bicycle crashes. While there has been research in the area of ergonomics about the role of bicycle fit in over-use injuries, the role of bicycle fit in acute injury has not been well studied. It is possible that a bicycle that is too large or too small may lead to fatigue, over-use injury that handicaps the cyclist while riding, or loss of control, resulting in a fall or crash.

Similarly, poor bicycle maintenance can lead to a crash though mechanical failure, such as the bike chain detaching or a brake failure. Mechanical failure of a bicycle has been reported in 11-13% of bicycle crashes that resulted in an injury requiring medical treatment, and bicycle brake failure increases this risk.[36, 79-81] Promoting proper bicycle fit and regular bicycle maintenance may reduce bicycle crashes resulting from loss of control or mechanical failure.

1.6.2 Motor Vehicles

Involvement of a motor vehicle in a bicycle crash is strongly associated with severe injuries, poor outcomes (e.g., admissions to hospital and fatalities), and disability. Collisions involving motor vehicles more often result in a serious injury or death than cyclist-only crashes.[16, 22] Approximately one quarter to one third of severe bicycle injuries result from a collision that involved a motor vehicle.[13, 17, 27, 82, 83] Moreover, the majority of bicycle-related fatalities involve collision with a motor vehicle and the size of the motor vehicle may affect survivorship of the cyclist involved in a MVCC.[13, 14, 16, 17, 28, 84, 85] Cyclist collisions with motor vehicles travelling at higher speeds are also associated with increased severity.[49, 86-88] The separation of bicycles and motor vehicles by bicycle-targeted infrastructure has been shown to reduce crash rates on streets compared to those without bicycle-friendly infrastructure in place.[89-91] Not all bicycle-infrastructure is equally protective; structures such as cycle tracks and paved off-road trails that physically separate cyclists from motor vehicle-dominated roads reduce the risk of MVCCs more than on-road bike lanes.[89, 92] Furthermore, on-street bike lanes may have a greater protective affect against collision with a motor vehicle when implemented on low-speed, low-traffic flow roads compared to high traffic thoroughfares.[89, 91, 92]

1.7 FACTORS OF THE PHYSICAL ENVIRONMENT

1.7.1 Climate, Weather, and Visibility

In a northern climate like Canada, seasonal cycling presents unique challenges for cyclists. Despite this, heterogeneity in climate across regions results in markedly different cycling activity throughout the year. Harsh winter weather conditions in much of Canada leads to poor road conditions including snow and/or ice. Road maintenance practices such as plowing snow to the side of the road and using sand or gravel for traction are designed to improve road conditions for cars; however, cyclists report that they feel these practices make cycling unsafe because plowed snow may obstruct bike lanes forcing cyclists to ride with motor traffic and gravel can decrease handling ability for cyclists.[93, 94] A study conducted in northern Sweden found that the majority of bicycle injuries in the winter were attributed to poor road maintenance.[95] Winter road maintenance strategies that keep cyclists in mind may increase winter cycling rates and reduce occurrence of cycling injuries due to road conditions.

Finally, road conditions (e.g., gravel debris, pot holes, etc.) in the post-winter period can lead to dangerous cycling conditions.

In addition to poor road conditions, the winter months also have longer periods of darkness than other seasons, which decreases visibility of cyclists and has been shown to be a factor in bicycle crashes, especially collisions with motor vehicles.[49, 96] Cyclists can mitigate the risk of riding in darkness by wearing reflective clothing, mounting reflectors on their bicycle, and installing (and using) bicycle lights.[77, 97] In an effort to “reduce serious injury and deaths caused by its new cars to zero by 2020”, the car maker Volvo recently released a highly reflective “safety spray” designed to coat the bicycle, cyclist, and protective equipment to enhance the cyclist’s visibility in the dark, although to-date there has been no study of the paint’s effectiveness at reducing cyclist-motor vehicle conflicts.[98, 99]

Rain and strong winds may also increase the risk of a crash.[49] The role of poor weather in bicycle crashes has not been well studied, although poor weather likely plays only a small role in cycling injuries since the large majority of injury events occur during times of fair weather.[16, 49]

1.7.2 Infrastructure

The built environment includes traffic signals, road surface, and transportation infrastructure, all of which influence the occurrence of cycling injuries. Involvement of road defects or wet/slippery surfaces in a bicycle crash is uncommon.[49, 88] While each crash event and injury is unique, the majority of bicycle injuries and fatalities occur on a paved surface, mainly roads, and especially in intersections.[92] This is not a surprise since severe injuries and fatalities often result from injury events involving cyclist-motor vehicle collisions,[21, 25, 37, 88, 92, 100, 101] and collisions between motor vehicles and cyclists are most likely to occur at intersections.[86] Bicycle-specific infrastructure physically separates motor vehicles from more vulnerable road users, thereby reducing cyclist-motor vehicle interactions and subsequently reducing the risk of a crash.[89, 90, 102]

1.8 THE SOCIAL ENVIRONMENT

1.8.1 Behavior and Attitudes of Road Users

Road users overestimate their own safety and the safety of road users in their own group compared to other groups of road users.[103] Road users also place a greater level of responsibility for safety of all road users on groups of road users other than their own.[103] The inability of road users to take responsibility for their own safety suggests that they are likely to make them resistant to behavioral changes affected through educational interventions and has implications for the potential effectiveness of educational road safety interventions targeting interactions between groups of road users, such as campaigns to encourage motorists to share the road with cyclists.

Increasing the number of cyclists on the roads may decrease the risk of injury and death for cyclists though the “safety in numbers” principle, which states that an increase in injury incidence due to an increase in the number of cyclists will be less than the increase in cycling. In other words, the risk of injury to an individual cyclist decreases inversely with an increasing number of cyclists.[104, 105] On the other hand, the individual-level protection afforded by increased cycling volume is only effective if the increased levels of participation can be sustained; in Victoria, Australia participation in cycling decreased following the implementation of mandatory helmet laws and cycling injury rates subsequently increased.[106]

1.8.2 Legislation

Legislation is one injury prevention strategy that can be successful at reducing injury rates. For example, legislation for the mandatory use of protective equipment such as seat belts and child car seats, as well as prohibition of high-risk activities like impaired driving, has influenced incidence of traffic-related injuries.[107-112] As previously mentioned, helmets are highly effective; summary evidence suggests they reduce head and brain injury by 65-88%, and upper facial injury by 65%.[113]

Despite their effectiveness, the use of appropriately sized and properly fit helmets is often low. One of the most controversial areas of legislation is MHLs for cyclists. While these legislative interventions have significantly increased helmet use in areas where they have been implemented, bicycle helmets do not significantly affect the occurrence of other types of bicycle injuries. In some cases, it may be that other legislation to reduce bicycle injuries is already in place but enforcement is lacking. For example, in many regions cycling under the influence of alcohol is prohibited either by targeted "bicycling under the influence" legislation or under the same drinking and driving legislation that also prohibits motorists from driving while intoxicated,[114, 115] but cyclists are rarely prosecuted under these laws. Given that helmet legislation has proved effective at increasing helmet use, legislating use of other safety equipment such as bicycle mounted lights and high-visibility clothing at night may increase their use, and including cyclists in regular check stop programs may discourage cyclists from cycling while intoxicated.

1.9 AIMS OF THIS THESIS

Although cycling provides many health and environmental benefits, limited information is available about severe and fatal injury events in adults. Additionally, cycling injuries are multi-factorial and likely involve interactions between risk factors. As all levels of North American governments implement policies and strategies to increase cycling among residents, it is necessary to assess the possible public health outcomes that may result from increasing the number of cyclists in North America. In addition, further elucidation of the risk factors for cycling injury and how those factors may interact is necessary to develop effective injury prevention and control interventions. Furthermore, although cycling is popular in some northern regions in North America (the Yukon has the highest cycling rate in Canada), cycling injuries are very rarely studied in cold, northern, and mostly rural regions.

Edmonton is one Canadian city encouraging increased cycling participation. Edmonton has a continental climate that reaches -35°C in winter and the harsh winter weather results in poor road conditions year-round. Until recently, bicycle-specific infrastructure was infrequent, and cycling on roads remains common. Helmet use in adults is lower than in children/adolescents, and bicycle helmet use has not been mandatory for adult cyclists in the current legislation (except in the City of St. Albert).

The aims of this thesis are to: i) define the current literature bicycle fatalities and the factors reported to be associated with them; ii) review the burden of severe and fatal bicycle injuries in North American adult cyclists compared to children cyclists; and iii) describe the epidemiology of bicycle fatalities in the province of Alberta and their associated factors.

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TABLE 1.1 PROPORTIONS OF COMMUTERS USING CYCLING AS THEIR PRIMARY MODE OF TRANSPORTATION IN CANADA BY PROVINCE.

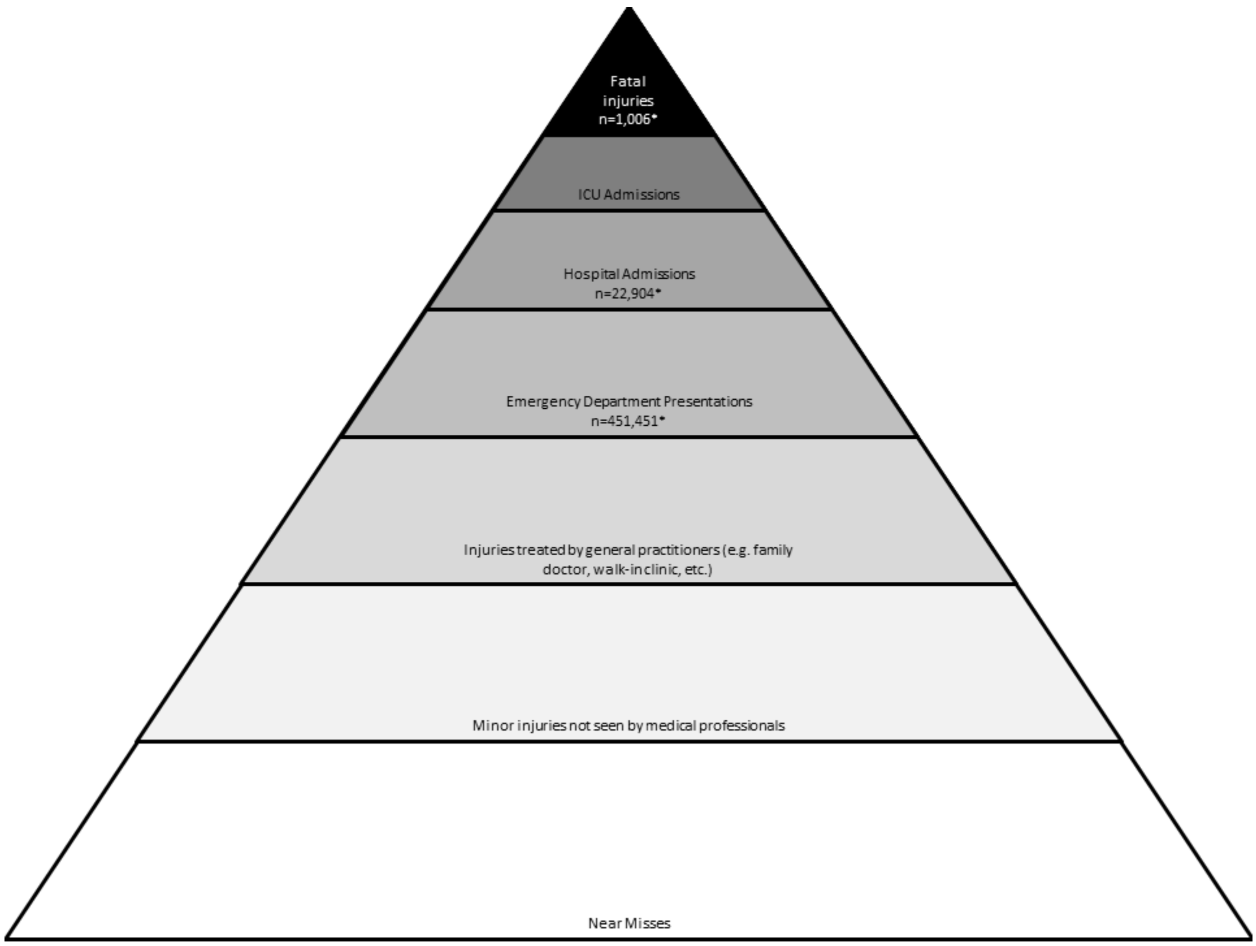
	Proportion of residences cycling as a primary mode of transportation to work
Canada	1.4%
British Columbia	2.3%
Alberta	1.2%
Saskatchewan	1.3%
Manitoba	1.8%
Ontario	1.2%
Quebec	1.4%
New Brunswick	0.5%
Nova Scotia	0.7%
Prince Edward Island	0.4%
Newfoundland and Labrador	0.2%
Territories	
Yukon	2.8%
Northwest Territories	2.1%
Nunavut	0.1%

Note: Data compiled from Statistics Canada, 2011 National Household Survey, Statistics Canada Catalogue no. 99-012-X2011064.

TABLE 1.2 HADDON'S MATRIX DESCRIBING PRE- AND POST-EVENT FACTORS THAT MAY AFFECT INJURY OCCURRENCE AND/OR SEVERITY AND SUGGESTED INTERVENTIONS TO REDUCE THE ROLE OF EACH FACTOR.

		Cyclists	Bicycle/Motor Vehicle	Environment	Legislation/ Society
Pre-crash	Cause	Impairment Age (traffic knowledge and experience, decision making skills)	Bicycle fit Mechanical soundness	Surface/infrastructure Weather Light conditions	Driver attitudes towards cyclists
	Prevention	Alcohol abstinence Educational/training programs Requiring a bicycle license	Ensure proper bicycle fit Regular bicycle maintenance	Cycling infrastructure Separation of cyclists and moving vehicles Use of visibility aids	Helmet laws Alcohol laws Safety-in-Numbers
Crash	Cause	Not wearing protective equipment (e.g. helmet, wrist guards)	Size of bicycle Type of bicycle Strength of frame Size of motor vehicle	Surface type Car design Design of curbs, grates, rail track crossings	Emergency medical services
	Prevention	Protective equipment Helmets Cyclist conspicuity	Design of bicycle (protective cage) Design of car bumper	Surface repair Design of curbs, grates, rail track crossings Installation of shock-absorbing surfaces	Universal access to healthcare
Post-crash	Cause	Age (elderly) Physical condition	Protective clothing Availability of first aid care	Location/access to medical services	Access to rehabilitation services
	Prevention	Physical conditioning	Required first aid training for drivers and cyclists	Universal access to emergency medical services (EMS) and 911 ATLS training Trauma programs/centers	Universally accessible rehabilitation services Social programs for assisted living during rehabilitation

FIGURE 1.1 THE INJURY PYRAMID INCLUDING THE NUMBER OF FATALITIES, ADMISSIONS, AND EMERGENCY DEPARTMENT PRESENTATIONS IN THE UNITED STATES IN 2004. *DATA FROM NAUMANN *ET AL.* 2010.[30]



Chapter 2 Scoping Review of Cyclist Fatalities in North America

2.1 BACKGROUND

Cycling is a common recreational activity and expanding mode of transportation that has many environmental and health benefits. Cycling increases cardiovascular function and reduces obesity, risk of cardiovascular disease, and risk of diabetes.[1-6] Cycling does not contribute to air pollution and reduces production of greenhouse gas emissions and traffic congestion by removing cars from the road.[7] Because of the public health and environmental benefits, municipalities in North America seek to harness these benefits for their residents by implementing policies and plans to encourage cycling within their communities.[8]

The public health implications of increasing numbers of cyclists in North America have not been fully examined. Cycling is not without risk, as cycling injuries are one of the most common sports and recreation injuries presenting to Canadian emergency departments (ED).[9-11] While cycling fatalities are uncommon, they represent a disproportionate number of traffic fatalities compared to other road users,[12, 13] and the proportion of fatally injured road users in Canada who were cyclists nearly doubled from 1.7% in 2008 to 3.2% in 2013.[12, 14] Additionally, cycling fatalities have high per-event medical, loss-of-productivity, and quality of life costs compared to nonfatal cycling injuries,[15] and the estimated total yearly cost of the relatively few fatal cycling injuries has been estimated to be higher than the total due to nonfatal injuries.[16]

Despite their significant costs to individuals and healthcare providers, there is little research being done on fatal cycling injuries. Most cycling injury research in the past decade has focused on children and bicycle helmets, including helmet effectiveness and legislation mandating their use.[17-23] There is conflicting evidence, however, regarding the role of bicycle helmets in prevention of cycling fatalities. In addition, studies of factors other than helmet use that may relate to cycling fatalities have been sporadic. Although there have been several studies of severe and fatal cycling injuries in North America, to date there has been no comprehensive review describing the epidemiology of severe and fatal cycling injuries or the factors associated with the crashes from which they result.

The aims of this scoping review are to describe the current literature on cycling fatalities in North America, including the factors associated with them, in order to compile the current knowledge, highlight gaps in the evidence, and provide direction for future research and policy development.

2.2 METHODS

2.2.1 Protocol

This scoping review was conducted as part of a larger review on severe and fatal cycling injuries, the protocol for which was developed *a priori* and is registered in the National Institute of Health Research's Center for Reviews and Dissemination PROSPERO database (Reg. No:CRD42014013769), which creates a permanent electronic record of the protocol for the review.[24]

2.2.2 Study Eligibility Criteria

This review focuses on injuries that occur during utilitarian and non-competitive recreational bicycling. Activities such as mountain biking, BMX bicycling, trick biking, and competitive road cycling are not likely to be impacted by public policies or infrastructure aimed at increasing bicycling; therefore, studies focusing on these disciplines have also been excluded.

Only studies that specifically identified cycling fatalities either as all or a part of their study sample were included in this review. A study was determined to be specifically examining cycling fatalities if medical examiner/coroner's reports, death certificates, or a fatality database were comprehensively searched for cycling deaths. Previous studies indicate that a large portion of fatally injured cyclists are killed at the scene of the crash and not treated in hospital;[25, 26] therefore a large portion of cycling fatalities may not be reported by hospital-based studies unless they also used external data sources. Studies that specifically stated that they intended to include deaths in the study, accessed appropriate data sources, and reported no deaths during the study period were considered relevant to framing the scope of the issue and are also on reported here.

Considerable social and geographic differences related to bicycling exist between North America and the rest of the developed world, especially Europe, where there is strong popular and government support for healthy, safe, and environmentally friendly modes of transportation and the views on the mandatory use of personal safety equipment differ.[8] The social perceptions of cycling in Europe may lead to substantial differences in the epidemiology of cycling injuries,[27-29] therefore, this review has been limited to studies of cycling injuries and fatalities occurring in Canada and the United States. Additionally, because road safety is vastly different between developing nations and developed nations,[30, 31] studies of cycling injuries in nations of limited economic and social development, including Mexico, were not included.

2.2.3 Data Sources and Search strategy

A detailed search strategy, which included searches of electronic databases, hand searching, and grey literature, was developed in consultation with an experienced medical librarian. Search terms included bicycle, bicycles, bicycling, bicycled, bicyclist, bicyclists, cyclist, cyclists, injury, injuries, injured, trauma, traumatic, wound, wounds, wounded, morbidity, mortality, fatal, fatality, fatalities, dead, dies, died, deaths, Canada, Canadian, United States, American, North America. An example of the detailed search strategy can be found in Appendix A. Primary literature databases searched included: Medline and EMBASE, Sports Discus, Transportation Research Information System, and the multidisciplinary database SCOPUS. PROQuest Theses and Dissertations and Google Scholar were also searched. References of included studies were hand searched for relevant articles, as were the past three years of the journals *Academic Emergency Medicine, Canadian Journal of Emergency Medicine, Annals of Emergency Medicine* and *Injury Prevention,* and the proceedings from the annual meetings of the Society for

Academic Emergency Medicine and the Canadian Association for Emergency Physicians. Index search terms included bicycle, injury, injuries (bicycle), and cyclist(s). Studies were not excluded by language or year of publication, nor by publication type or status.

2.2.4 Data Collection

Data were abstracted from included studies independently by two trained researchers (LG, FO) onto standardized forms. Data extraction was piloted by independent double-data extraction from five typical studies, and discrepancies were resolved by consensus.

When available, extracted data included: publication year, country and region where the study was conducted, study period, demographics of study population (e.g., proportion adult, proportion male), types of injuries including the nature of injury and affected anatomy, use of protective equipment (e.g., helmet), mechanism of injury including involvement of motor vehicles, and crash details, including day of the week, time and/or light condition, and rural vs. urban.

2.2.5 Definitions

The mechanism of the crash (e.g., motor vehicle-cyclist collision [MVCC], cyclist-only, mid-block ride-out, etc.), as well as “weekend”, and “darkness” were documented; however, not all studies that reported on these factors provided category definitions. For example, some studies listed cycling fatality occurrence by day of the week or by hours of the day, without defining “weekend” or “nighttime” periods. In order to categorize this data, common definitions were used to categorize data from studies that did not provide a definition. In these cases, times of darkness were considered to be between 8 PM and 6 AM, or the time categories reported by the authors that accounted for the substantive majority of that time period. Unless otherwise specified, “weekend” was considered to be anytime on Saturday or Sunday. Where available, the study’s definition of adult cyclists was used. In mixed population studies that did not clearly differentiate between children and adult age categories, the boundary closest to 18 years between categories was used to divide adults from children.

2.2.6 Analysis

Where appropriate, weighted proportions and 95% confidence intervals (CIs) for factors of interest were calculated under a random effects model using the Microsoft Excel tool developed by Neyeloff *et al.* for meta-analysis of descriptive studies.[32]

2.3 RESULTS

2.3.1 Search Results and Characteristics of Studies

The systematic searches were conducted on July 18, 2014 and resulted in 2264 unique entries. After screening titles and abstracts, the full texts of 61 papers were reviewed and 22 unique studies were included. Three additional studies were identified in the grey literature, for a total of 25 studies. All studies were published in the English language. Studies were published between 1983 and 2013 with a median year of publication of 1998 (interquartile range [IQR]: 1995, 2012). Characteristics of the included studies are presented in Table 2.1.

Most studies were published as one or more articles in a peer reviewed journal; however, one dissertation, one conference abstract and two conference papers were also identified (Table 2.1). Two studies were published both as peer-reviewed papers and as government-issued reports on cycling injury and fatalities: one in New York City and one in Ontario.[33, 34] Ten of the 25 studies collected data on both injuries and fatalities (Table 2.1); however, only data on fatalities were included in the meta-analysis.

2.3.2 Study Designs and Definitions

Studies used data collected from the years 1956 to 2011. The duration of included studies ranged from 1 to 23.8 years with a median duration of 5.5 years (IQR: 2.9, 10). All except one of the included studies were retrospective. The majority of studies (21 [84%]) were observational studies that used a descriptive design to examine the incidence of cycling fatalities and factors associated with fatal cycling events. Three studies employed a case-control design to: compare alcohol use in fatal and nonfatal cycling injuries;[26] examine characteristics of the striking vehicle between cyclist road deaths compared to non-cyclist road deaths;[35] and compare helmet use between head-injured and non-head injured fatally injured cyclists.[34] Zhu *et al.* conducted a retrospective cohort study to examine traffic injury rates among different types of road users (including cyclists) in Appalachia.[36] Other study designs included: one cost analyses of the lifetime costs of pedestrian and cyclist injuries;[15] a cost analysis of all-terrain vehicles compared to cyclist injuries;[37] an ecologic study examining nonfatal and fatal injury rates resulting from motor vehicle collisions across different road-users;[13] a multi-level analysis examining the correlations between cycling fatalities and state-level traffic laws;[38] and one before-after study examining a school-based educational intervention for traffic injury prevention intervention.[39] Mechanisms of injury were most often defined as involvement (or not) of a motor vehicle in the crash-event. Three studies used more detailed categories to describe collisions between cyclists and motor vehicles (Table 2.1).[25, 33, 40] Seven studies did not report on the mechanism of the crash event. The definition of "adult" ranged from 14 to 24 and the most common categorization for "adult" was 16 years or older (Table 2.2). The weekend was generally considered all-day Saturday and Sunday, and the reported periods of "night" or "darkness" varied, but generally began between 6pm and 8pm and ended between 6am and 8am (Table 2.2).

2.3.3 Study Data Sources and Populations

Data sources used by each study to gather information on cycling fatalities are listed in Table 2.1. Some studies examined fatality data from multiple sources (Table 2.1), for example using record linkage methods to ensure completeness and validity of the data,[33, 41] or to compare different sources for reporting accuracy.[42] The National Highway Traffic Safety Administration's Fatality

Analysis and Reporting System (FARS) was the most common, as it was used by eight studies. The next most common source of data was records from the Office of the Chief Medical Examiner of the jurisdiction where the study was carried out (n=7). Other sources of data included regional trauma databases (n=4), the National Center for Health Statistics Multiple Cause of Death database (n=3), regional death certificates records (n=3), autopsy reports (n=2), the National Vital Statistics System (n=1), and data from the New York Police Department and New York Department of Transportation (n=1).

Most studies (n=19 [76%]) included both child and adult cyclists. Four studies focused on injuries or fatalities in children and two reported deaths only in adult cyclists. Overall, four studies were conducted in Canada and 21 studies involved US samples. Eleven of the US studies used nation-wide samples. Fourteen of the 25 included studies were conducted solely in one state or province: Ontario (3) and Alberta (1), California, Connecticut, Florida, Indiana, Maryland, New York (2), Oregon (2), and Washington DC were also identified. Five of the fourteen “regional” studies were restricted to one metropolitan area: San Diego County, CA; Washington DC; New York City, NY (n=2); and Dade County, FL.

The median sample size of all cyclists (of any injury severity) in all studies was 394 (IQR: 225, 1964). The sample sizes of fatality-only studies ranged from 36 to 4924, with a median of 394 (IQR: 151, 1788). The median number of cyclist fatalities reported across all included studies was 212 (IQR: 62, 917).

2.3.4 Factors Associated with Fatal Cycling Injuries

Two studies were excluded from further analysis because they reported that there were no cycling-related deaths during their respective study periods.[39, 41] An additional four studies were excluded from the meta-analysis due to unavailable data on associated factors.[13, 19, 43, 44]

Commonly reported factors associated with cycling fatalities are described in Table 2.3 and Figure 2.2. In general, fatally injured cyclists were predominantly male, were most often not wearing a helmet, and were in a collision involving a motor vehicle. Studies reporting on the occurrence of head injury indicated that head injuries in fatally injured cyclists were common (Table 2.3).

Because a large portion of studies used the same datasets over similar time periods, a sensitivity analysis was conducted to determine whether the overlap in data may influence the estimates. Weighted proportions for each factor of interest were calculated from all studies reporting them and compared with the data from studies for which no overlap was a reasonable assumption (data not shown). A Pearson's chi-squared test determined that the differences in weighted proportions between the overlapping and no-overlap samples were not significant (p=0.98).

2.4 DISCUSSION

This is the first comprehensive review of the primary studies and factors involved in cycling fatalities in North America. Using an *a priori* protocol, comprehensive search strategies to avoid publication bias, and strategies to mitigate selection bias, 25 studies were identified for inclusion. Overall, most studies reporting on cycling fatalities were retrospective; a third studied both fatal and nonfatal injuries. Fatally injured cyclists were mainly adult, mainly male, and rarely wore helmets (although the latter may slowly be changing, as newer studies generally reported higher proportions of helmet use than older studies). Using pooling techniques to adjust for sample-size variation, multiple factors were quantized and could be used by injury prevention planners and policy makers to explore ways to reduce fatal and severe cycling injuries.

Overall, there were relatively few studies reporting on cycling fatalities using sources of medical data, and the quality of evidence provided by studies that were found was, anecdotally, poor, as most studies were descriptive, a study design that is prone to multiple biases. The majority of identified studies were descriptive, nearly all were retrospective, and few examined the etiology of cycling fatalities, all of which are common to studies typically at high risk for bias. Additionally, only one study that examined interventions to reduce cycling fatality rates was identified; Meehan *et al.* reported the correlation in state cycling fatality rate with the presence or absence of traffic laws that may impact cycling safety and found state cycling fatality rates to be associated with the presence or absence of a state-wide helmet law.[38] The dearth of evidence for interventions to prevent cycling fatalities is likely due to the difficulties in studying etiology of a rare outcome and the obvious ethical issues associated with conducting controlled trials to study fatal injuries. Study designs exist to circumvent such issues; for example the before-after study design that uses the same population as its own control before and after an intervention is effective for examining ecologic-level interventions such as regulation or public safety campaigns.

Nonfatal cycling injuries are among the most common sports and recreation injuries presenting to emergency departments in North America, and injured cyclists can often be directly interviewed to identify the events and environment surrounding the injury, both of which make nonfatal cycling injuries much easier to study than fatal cycling injuries. Obtaining accurate event and environmental data is often difficult for fatal collisions, as the majority of fatally injured cyclists die before arriving at or while in the ED.[25] Even if the cyclist were conscious when medical personnel arrived, they may be otherwise unable to accurately recall the event, and it may also be unethical to interrogate a patient (or witness) for details about such a traumatic event.

An understanding of the causes of and risk factors for cycling fatalities is necessary to further prevent them. Among studies included in this review, reporting of factors associated with cycling fatalities was highly inconsistent. Without knowledge of the factors associated with cycling fatalities, injury prevention specialists will have a difficult time developing and implementing successful strategies to reduce the occurrence of cycling fatalities. While some factors, such as sex and age, are not modifiable, their distribution among cyclists could be used for indicative prevention strategies to target those most at risk, as well as directing future research to determine why these groups are at the most risk. Based on the results of this review, more than 80% of fatally injured cyclists are male. Conversely males make up 60% of cyclists in North America,[45] suggesting that other factors may account for their disproportionate contribution to cycling fatalities; for example, male cyclists ride more often on shared infrastructure with motor vehicles,[46] which may be associated with increased risk of a crash.[47]

Although cycling fatalities are relatively rare events, they are associated with high costs in medical expenses, lost productivity, and quality of life years lost. Together, these costs have been estimated at US$2-4.5 million per event.[15, 37] Even though fatalities are much rarer than nonfatal cycling injury events, the total cost from fatalities has been estimated to be greater: $3.3 billion per year compared to $2.8 billion in 2012.[16] Even a small reduction in cycling fatality rates will have a noteworthy impact on reducing the overall cost of these tragic events on society and the individuals to whom they occur.

Much of the current literature focuses on providing evidence for the use of helmets and implementation of legislation for their mandatory use. In this review, helmet use was low, and head injuries were frequent. Consequently, it makes intuitive sense that injury prevention strategies include helmet use. While helmets do protect against head and facial injuries[48], they do not prevent injury to other areas of the body or reduce the overall risk of severe injury from a cycling crash.[49] Overlooking crash prevention strategies may result in failures to address important factors that contribute to bicycle-related mortality and morbidity. For example, since a large portion of cycling fatalities result from collisions with motor vehicles, North American traffic safety officials may consider targeting prevention strategies at motorists as well as cyclists, or developing educational programs such as those implemented in Europe, to teach courteous and safe road interactions between all types of road users.[50] Finally, based on these results, use of alcohol avoidance (e.g., educational campaigns), cycling during darkness (e.g., focus on cyclist conspicuity), weekend cycling activities (e.g., boulevard/road closures during weekends), and other factors should be considered when forming a comprehensive injury prevention strategy.

2.4.1 Strengths

This review fills a gap in the current evidence, as no comprehensive review of the factors involved in cycling fatalities in North America has been previously published. The large gaps in cycling fatality knowledge have been highlighted, giving direction for future research. Finally, pooled data provides stronger evidence for the association of previously indicated risk factors with cycling fatalities in North America.

2.4.2 Limitations

One of the main limitations of this review is the degree of heterogeneity among studies, which precludes, in most cases, the validity of the weighted proportions in the real world. As a scoping review, this study aimed to report on the status of the current literature, including commonly studied factors associated with cycling fatalities and presents the proportion of fatalities occurring alongside factors that are anecdotally reported in the literature to be associated with cycling fatalities. Absence of comparison groups in the majority of cycling fatality studies, however, made it impossible to determine which factors may be more strongly associated with fatalities compared with cycling injuries of other severities. This review is not able to measure the effect of any factor on cycling fatality risk, as very few studies included in this review were designed to examine etiology; however identifying causal relationships is not traditionally one of the objectives of a scoping review, nor was it a specific objective of this review.

2.5 CONCLUSIONS

Although many descriptive studies have been conducted on cycling fatalities, there are few studies examining the etiological nuances involved in cycling fatalities, especially compared to nonfatal injuries. Reporting of associated factors varies widely, but fatally injured cyclists are most often male and are involved in a collision with a motor vehicle. Overall, the evidence regarding cycling fatalities is limited and generally of low quality, and efforts to standardize them are warranted. Injury prevention strategies should target male cyclists, and future studies should focus on improved methods, including use of comparison groups and more detailed reporting of known or suspected risk factors.

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TABLE 2.1 CHARACTERISTICS OF 25 STUDIES REPORTING ON CYCLING FATALITIES IN NORTH AMERICA

First author, year	Publication status	Design	Injury Type	No. deaths	Study Period	Region, Country	Pop.	Source(s) of Fatality Data*	Mechanism Coding
Ackery, 2012	Article	Case-Control	Fatal	711	2008	USA	Mixed	FARS‡	Motor-Vehicle/Bicycle
Beck, 2007	Article	Ecologic	Fatal	695	1999-2003	USA	Mixed	FARS	Motor-Vehicle/Bicycle
Cheng, 2000	Article	Descriptive	Fatal and Nonfatal	0	1996-1998	DC, USA	Children	OCME# of the District of Columbia, Department of Vital Statistics	Not Reported
Durkin, 1999	Article	Before/After	Fatal and Nonfatal	0	1983-1999	NY, USA	Children	Northern Manhattan Injury Surveillance System	Not Reported
Eichelberger, 2013	Conference paper	Descriptive	Fatal	2907	2007-2011	USA	Adult	FARS	Motor-Vehicle/Bicycle
Fife, 1983	Article	Descriptive	Fatal	173	1956-1979	FL, USA	Mixed	Autopsy Records	Motor-vehicle involvement
Frank, 1995	Article	Descriptive	Fatal and Nonfatal	15	1989	OR, USA	Mixed	Oregon Injury Registry	Not Reported
Hawley, 1995	Article	Descriptive	Fatal	36	1984-1993	IN, USA	Mixed	Autopsy Records	Struck by Motor Vehicle
Helmkamp, 2009	Article	Descriptive/ Cost Analysis	Fatal	4924	2000-2005	USA	Mixed	NCHSMCD‖	Not Reported
Kraus, 1987	Article	Descriptive	Fatal and Nonfatal Brain injury	5	1981	CA, USA	Mixed	Coroner's reports, death certificates	Not Reported
Li, 1994	Article	Descriptive	Fatal	2694	1987-1991	USA	Adult	FARS	Motor-Vehicle/Bicycle
Li, 1996	Article	Case-Control	Fatal and Nonfatal	63	1985-1997	ME, USA	Mixed	OCME of Maryland, Shock Trauma Center database	Not Reported
Gaudet, 2015	Abstract	Descriptive	Fatal	101	1998-2011	AB, Canada	Mixed	OCME of Alberta	Mid-block ride out, Cyclist inattention, Driver inattention
Meehan, 2013	Article	Cross-sectional/ Multi-level	Fatal	1612	1999-2010	USA	Mixed	FARS	Bicycle-Motor vehicle

Miller, 2004	Conference Paper	Descriptive/ Cost Analysis	Fatal and Nonfatal	866	2000	USA	Mixed	National Vital Statistics System fatality census, FARS	Bicycle-Motor vehicle
Ni, 1996	Dissertation	Descriptive	Fatal and Nonfatal	62	1989-1995	OR, USA	Children	Oregon Trauma Registry	Not Reported
Nicaj, 2009	Article, Government Report	Descriptive	Fatal	225	1996-2005	NY, USA	Mixed	New York (NY) Police Department, NY Department of Transport, NY Vital Statistics, OCME of NY	Crash with moving motor vehicle, Bicycle-only, crash with parked Motor vehicle
Persaud, 2012	Article, Government Report	Case-control/ Descriptive	Fatal	129	2006-2010	ON, Canada	Mixed	OCME of Ontario	bicycle-motor vehicle collision
Rodgers, 1995	Article	Descriptive	Fatal	917	1991	USA	Mixed	NCHSMCD and FARS[†]	Motor vehicle traffic-related
Rowe, 1995	Article	Descriptive	Fatal	212	1986-1991	ON, Canada	Mixed	OCME of Ontario	Mid-block ride out, Cyclist inattention, Driver inattention
Sosin, 1996	Article	Descriptive	Fatal and Nonfatal Head Injuries	1278	1989-1992	USA	Children	NCHSMCD	Collision with motor vehicles on public streets
Spence, 1993	Article	Descriptive	Fatal	81	1985-1989	ON, Canada	Children	OCME of Ontario	Collision with Motor Vehicle
Stimpson, 2013	Article	Descriptive	Fatal	394	2005-2010	USA	Mixed	FARS	Struck by Distracted Driver
Zavoski, 1995	Article	Descriptive	Fatal and Nonfatal	49	1987-1992	CT, USA	Mixed	Death certificates	Motor-vehicle involvement
Zhu, 2013	Article	Cohort	Fatal	1964	2008-2010	USA	Mixed	FARS	Motor-Vehicle/Bicycle

[*] Sources used to collect data on nonfatal injuries that may be included in each study are not listed.
[†] Data from NCHSMCD was used for meta-analysis
[‡] FARS = National Highway Traffic Safety Administration Fatality Analysis and Reporting System
[#] OCME = Office of the Chief Medical Examiner
[‖] NCHSMCD = National Center for Health Statistics Multiple Cause of Death data file

TABLE 2.2 STUDY DEFINITIONS FROM 25 STUDIES REPORTING CYCLING FATALITIES IN NORTH AMERICA

Author, year of publication	Adult Cut-off Age	Definition of "Darkness"	Definition of "Weekend"
Ackery, 2012	Not Reported	8:00 PM-8:00 AM	Not reported
Beck, 2007	15*		
Cheng, 2000	16	-	-
Durkin, 1999	17	-	-
Eichelberger, 2013	16	9:00 PM – 6:00 AM	Saturday-Sunday
Fife, 1983	17	6:00 PM -6:00 AM	-
Frank, 1995	21	-	-
Hawley, 1995	16	-	-
Helmkamp, 2009	16	-	-
Kraus, 1987	Not Reported	-	-
Li, 1994	15	Not Reported	Saturday-Sunday
Li, 1996	20	7:00 PM to 6:59 AM	Saturday-Sunday
Lovstrom, 2013	20	6:00 PM to 6:00 AM	Saturday-Sunday
Meehan, 2013	16	-	-
Miller, 2004	20	-	-
Ni, 1996	16	-	-
Nicaj, 2009	18	-	-
Persaud, 2012	20	8:01 PM - 6:00 AM	-
Rodgers, 1995	16	"Dark"	-
Rowe, 1995	20	8:00 PM t to 8:00 AM	4:00 PM Friday to 8:00 AM Monday
Sosin, 1996	20	-	-
Spence, 1993	16		-
Stimpson, 2013	25	6 PM – 5:59AM	-
Zavoski, 1995	20	Not Reported	-
Zhu, 2013	Not Reported	-	-

*Did not report age-specific cycling fatality data

TABLE 2.3 FACTORS REPORTED IN 25 STUDIES REPORTING NORTH AMERICAN BICYCLE FATALITIES

Variable	No. Studies	Sample size n	Median Proportion % (IQR)	Range
Male sex	16	13631	85.8 (80.5, 88.1)	69.1, 100
Adult ages*	15	10093	66.7 (53.2, 80.8)	30.9, 85.3
MVCC†	12	4096	90.5 (79.8, 92.3)	68.3, 100
Darkness	12	8607	37.8 (28.8, 45.6)	12.0, 56.5
Alcohol use‡	11	6636	24.8 (11.4, 29.5)	0, 33.3
Helmet use#	9	1035	3.0 (0.0,17.0)	0, 26.4
Head Injury	9	1872	69.4 (55.0, 75.0)	45.3, 86.1
Urban location	7	8225	70.7 (64.1, 80.9)	54.8, 94.4
Weekend	6	6688	32.0 (28.8, 37.4)	28.0, 46.0

*Mixed population studies only
† MVCC = Motor vehicle-cyclist collision; data from studies using only data from the Fatality Analysis Reporting System, which only reports cycling-crashes that involve motor vehicles, was excluded.
‡Excludes one study (n=36 cyclists) that reported that all cyclists had a negative toxicology screen.
#Excludes four studies (n=305 cyclists) that reported that zero cyclists had been wearing a helmet.

FIGURE 2.1 PRISMA FLOW CHART OF SCOPING REVIEW SEARCH RESULTS

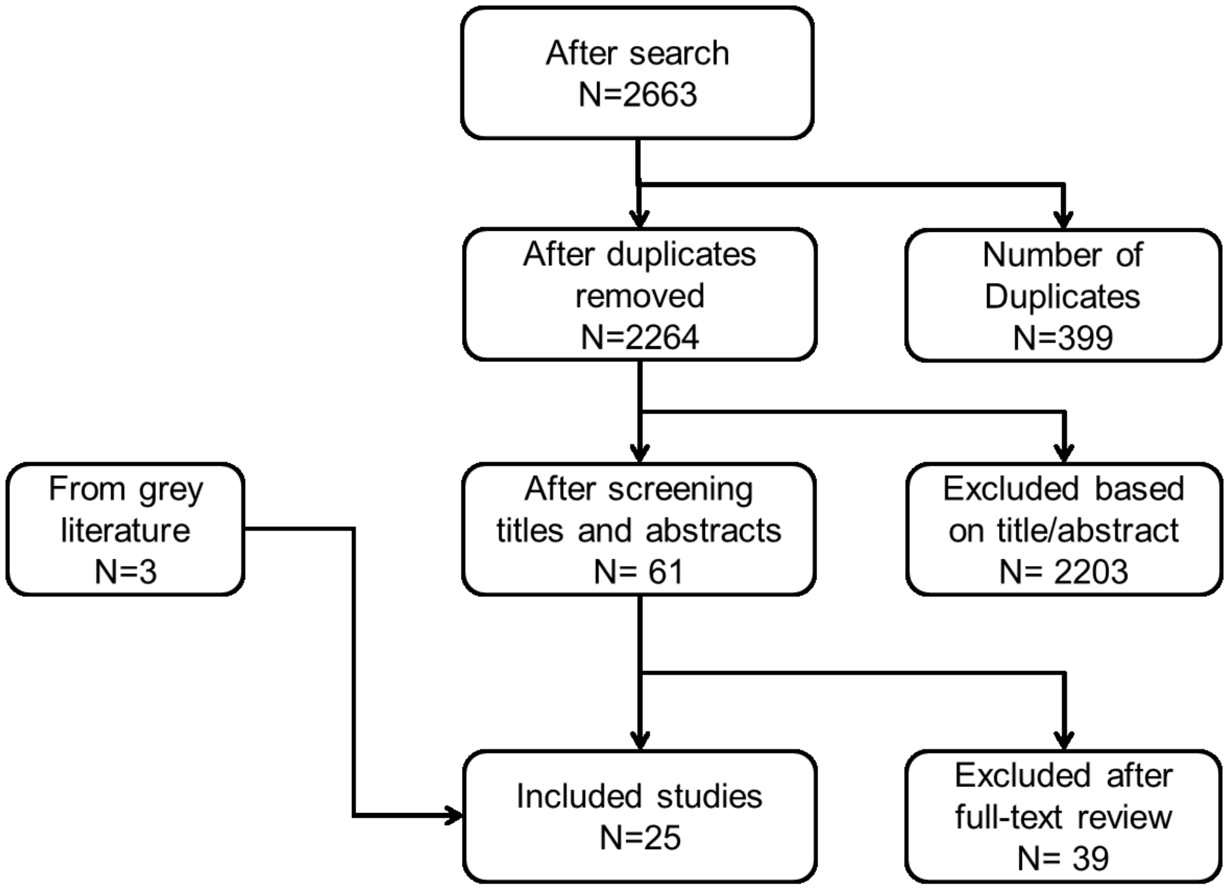
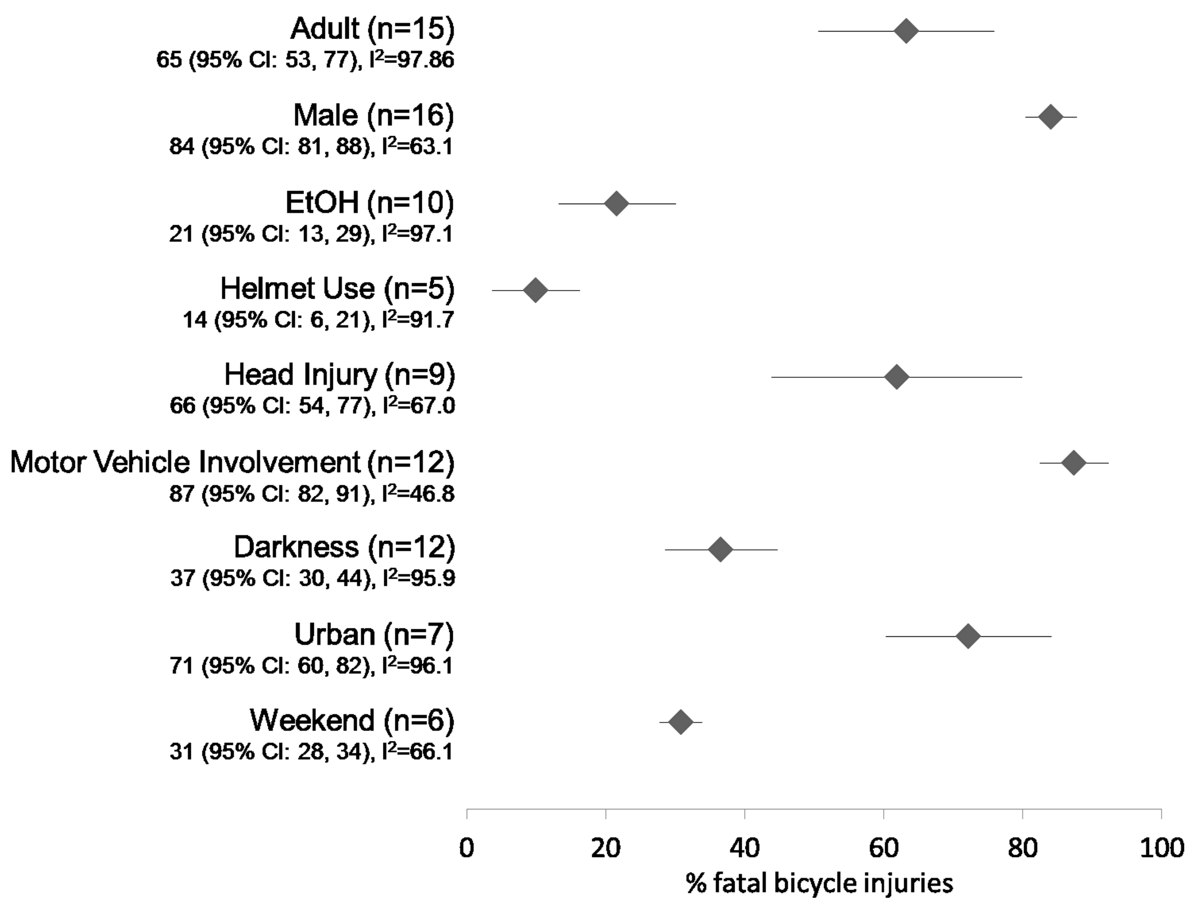


FIGURE 2.2 WEIGHTED PROPORTIONS OF FACTORS ASSOCIATED WITH CYCLING FATALITIES IN NORTH AMERICA



Chapter 3 Systematic Review of Severe and Fatal Cycling Injuries in Adults Compared with Children

3.1 BACKGROUND

The health and environmental benefits of bicycle riding, a popular recreational activity, are well documented,[1-4] and many North American governments are currently implementing development plans and policies to encourage cycling in their communities.[5] Cycling is not, however, without risk; collision with the ground or objects in the environment, including a moving or stationary motor vehicle, and subsequent injuries are ultimately the result of one or more environmental (e.g., road conditions, weather), mechanical (e.g., brake failure, a flat tire, etc.) or behavioural (of both cyclists and motorists) causes, most of which are preventable. Injuries from bicycle crashes are one of the most common sports and recreation injuries presenting to North American emergency departments (ED) and can range in severity from minor to severe.[6-9] Fatal cycling injuries, while uncommon, have larger per-event and total annual costs to the health-care system than non-fatal injuries,[10, 11] and contribute to the perception of cycling as a dangerous activity which is one barrier to increasing participation.[12] Given the lack of protection and the energy transfer, injuries from crashes are common and can be serious; therefore, a large uptake of regular cycling could have substantive public health implications.

While it may be ideal to implement multiple concurrent injury prevention interventions to maximize the safety of cycling in North America, most stakeholders interested in injury prevention have limited resources to allocate to this issue, so identification of the most important factors associated with bicycle injuries will help policy- and decision-makers focus on interventions for the types of injuries or road users are a priority for each organization. Studies of sports and recreation injuries report that incidence rates differ across age groups.[13, 14] These differences may be due to variation in the incidence or level of exposure of associated risk factors. While there is previous evidence that some factors, such as alcohol use[15] and cycling location (on-road vs. non-road),[16] may differ with age, few studies of cycling injuries have directly compared these factors in both adults and children. Age-based injury occurrence data could be used by organizations and regional governments invested in preventing bicycle injuries to tailor injury prevention strategies based on age.

Although there have been several studies of severe non-fatal and fatal cycling-related injuries in North America,[17-23] there has been no comprehensive review comparing the epidemiology of severe and fatal cycling injuries between adults and children. This systematic review aims to compare the proportion of fatalities between severely injured adult and pediatric cyclists in North America.

3.2 METHODS

3.2.1 Objectives

This review aimed to compare the proportion of deaths among severe cycling injuries in children compared with adults in North America and describe the factors reported to be associated with injury in each group.

3.2.2 Outcome of Interest

The primary outcome of interest was the proportion of severe bicycle injuries that were fatal and the comparison of fatal events between children and adults. For this review, “severe injury” was defined by the authors of each study or, when a definition was not provided, by either: an Injury Severity Score (ISS) ≥12 or an injury that required hospitalization. Secondary outcomes included the proportion of cyclists in each study who were reported to be wearing a helmet, who were reported to have consumed alcohol prior to being injured/killed, who sustained a head injury, who sustained trunk (thoracic, abdominal, or spinal) injury, who were injured/killed in crashes that occurred at night or on the weekend, at urban and rural locations, and the mechanism of the crash (e.g., motor vehicle-cyclist crash, cyclist-only crash/fall).

3.2.3 Study Eligibility Criteria

To be included in the review, studies must have reported on both severe and fatal cycling injuries using comprehensive data from ED/hospital enrolments, medical records, trauma registries, or medical examiner's/coroner's documentation. Studies had to report on fatalities and in the case of reporting that no fatalities occurred, provide evidence of a comprehensive search for fatal events. Studies focusing strictly on fatalities were not included. While some cycling injury studies use police reports as their primary source of data, police data may notably under-report the occurrence of cycling as often authors only reported on bicyclist crashes involving a motor vehicle.[24, 25] In addition, police data does not reliably report injury severity in non-fatal cases.[26] Therefore, only studies using medical records to determine injury severity were included in this review. To ensure that included studies met this criterion, only primary reports of research that sufficiently described the data sources and methods of the study were included.

Studies of overuse or repetitive-stress injuries were excluded. Cyclists engaged in competitive or recreational cycling races encounter different circumstances than the average cyclist (e.g., many cyclists riding close together at very high speeds); therefore, studies of injuries occurring during organized cycling events were excluded. Mountain biking, BMX biking, trick-biking, and competitive road cycling are unlikely to be impacted by policies intended to increase day-to-day cycling and were also excluded.

Due to social and geographic differences, cycling differs significantly between developed and developing nations, and also between North America and Europe;[27] therefore, studies using data from countries other than Canada and/or the United States were not included. Studies were not excluded by publication status, year of publication, or language.

3.2.4 Data Sources and Search strategy

The search strategy was developed in consultation with medical librarians and carried out on October 26, 2015 by LG. Five databases were searched: Medline and EMBASE, Sports Discus, Transportation Research Information System (TRIS), and SCOPUS. In addition, PROquest Theses and Dissertations and Google Scholar were searched for relevant grey literature, and a web-based search for non-indexed research on bicycle injuries was also conducted. Search terms included bicycle, bicycles, cycling, bicycled, bicyclist, bicyclists, cyclist, cyclists, injury, injuries, injured, trauma, traumatic, wound, wounds, wounded, morbidity, mortality, fatal, fatality, fatalities, dead, dies, died, deaths, Canada, Canadian, United States, American, North America. A detailed example of the systematic search strategy can be found in Appendix A.

References of included studies were hand searched for relevant articles. The previous three years (2011-2014) of the journals *Academic Emergency Medicine, Canadian Journal of Emergency Medicine, Annals of Emergency Medicine* and *Injury Prevention* were hand-searched for relevant articles, and the proceedings from the annual meetings of the Society for Academic Emergency Medicine, the Canadian Association for Emergency Physicians, the American College of Emergency Physicians and the World Conference on Injury Control and Prevention were also reviewed for relevant abstracts. Hand searching involved scanning the index of each issue for articles indexed under bicycle, injuries (bicycle), or cyclist(s).

3.2.5 Data Collection

Data were abstracted independently and in duplicate from included studies by two of the trained researchers (LG, NA, CA) onto standardized forms. Data extraction was piloted on five typical studies and any disagreements were discussed and resolved by consensus. During the initial round of validation, the inclusion criteria were updated to better reflect the objectives of the review. A second round of validation, with discrepancies being resolved by discussion and consensus, was done before data was extracted from the rest of the included studies, and any remaining discrepancies were resolved through discussion. In cases where data of interest was potentially collected but not reported in the publication, three attempts to contact the study authors were made.

The following data were extracted, where available: country of first author, publication year, country and region where the study was conducted, study period, number of male cyclists, number of patients with a head injury, number of patients with a torso (thoracic, abdominal, or spinal) injury, number of cyclists injured or killed by location (rural vs. urban), by mechanism of injury (i.e., involvement of motor vehicle, cyclist-only crash, fall from bicycle, etc.), by time of crash (at night or on the weekend). The definitions of injury severity, mechanism (motor vehicle-cyclist collision [MVCC], cyclist-only, mid-block ride-out, etc.), "urban," and "weekend" used by each study were also carefully documented. Presence of mandatory helmet legislation (MHL) during the study period (for regional studies only) was obtained from relevant government websites.

3.2.6 Quality Assessment

Overall quality of included studies was assessed using an amended version of the Effective Public Health Practice Project (EPHPP) assessment tool,[28] which has high overall inter-reviewer reliability and moderate validity for assessment of quantitative studies.[29] Studies were assessed independently by two trained reviewers (LG, SK); assessment was piloted on five sample studies; disagreements were discussed and resolved by consensus.

3.2.7 Analysis

High levels of heterogeneity were expected; therefore, further analyses are predominantly descriptive. To avoid Simpson's paradox, a type of confounding that causes apparent reversal of an effect when data across studies are aggregated without weighting,[30] counts and categorical variables are reported as weighted proportions with 95% confidence intervals (CI) and were calculated using the Microsoft Excel tool developed by Neyeloff *et al.* for meta-analysis of non-comparative studies.[31]

Where ordinal variables (i.e., ISS) were reported as three or more categories, the mean was estimated by weighting the midpoint of each category by the number of patients in each category. Continuous variables are reported as the median of the medians and interquartile ranges or as a weighted mean and 95% CI, as appropriate, and were calculated using STATA Statistical Software Release 12.0 (Stata Corporation; College Station, TX, USA).

Data from mixed-population studies were used to calculate the odds ratio of fatal to nonfatal severe injury in children compared with adults using a random effects model in Review Manager Version 5.3 (Copenhagen: The Nordic Cochrane Centre, The Cochrane Collaboration, 2014).

3.3 RESULTS

3.3.1 Search Results

Results of the search strategy are presented in Figure 3.1. The comprehensive database searches returned 2925 results, of which 418 were duplicates. The titles and abstracts of the remaining 2507 articles were screened for relevance; ultimately, the full texts of 142 articles from the systematic search and eleven reports from the grey literature were reviewed. Overall, 46 unique studies met the inclusion criteria; of these 27 had sufficient data to be included in the analysis.

3.3.2 Description of Included studies

Descriptive characteristics of the included studies are presented in Table 3.1. Thirteen studies limited their study population to children and/or adolescents, ten studies included cyclists of all ages, and four studies were limited to adults. Two of the pediatric studies[32, 33] and one mixed-population study[34] reported that there were no pediatric fatalities. These studies have still been included because Cheng *et al.* and Durkin *et al.* made attempts to identify pre-hospital deaths by accessing the District of Columbia Office of the Chief Medical examiner and Vital Statistics data, and New York state death certificate data, respectively, and Thompson *et al.* reported adult fatalities.[32, 33] Twenty studies used data from American samples, six studies used data from Canada, and one study reported using data from both the US and Canadian samples. Ten studies used national-level databases and 17 examined regional samples including: Alberta (n=1), British Columbia (n=2), California (n=1), Connecticut (n=1), District of Columbia (n=1), Florida (n=2), Massachusetts (n=1), Maryland (n=1), New York (n=1), Ohio (n=1), Ontario (n=2), Oregon (n=1), and Washington (n=2).

Most studies (n=16) were descriptive in design; six studies used a cohort design, three were case-control studies, and there was one ecologic trend analysis and one descriptive cost analysis included. Studies ranged in duration from one to sixteen years with a median of five years (IQR 2.6-9.1). The median publication year was 2001 (IQR: 1997-2008). Overall, data from the years 1983 to 2009 were used. All but one of the included studies were published as one or more peer-reviewed journal articles; Miller *et al.* was published as a conference paper.[10]

3.3.3 Study Definitions

The most frequent definition used for severe injury was “requires admission to hospital” (Table 3.2, n=17). Other definitions of severe injury included: admitted to trauma center;[35, 36] admitted to hospital for head injury;[37] admitted to hospital for ≥3 days;[23] injury severity score (ISS) ≥ 9;[38, 39] ISS ≥ 10;[40] ISS ≥ 16;[41] brain injury with acute injury score ≥ 3;[34] and designated trauma alert status.[42] Few studies reported whether injury occurred during the weekend (n=2) or at night (n=2), and no study included in this review reported on inclement weather or occurrence in urban vs. rural areas.

The terminology used to define the mechanisms of injury was not consistent. Most frequently, mechanisms were loosely defined by involvement of a motor vehicle, collision with an object other than a motor vehicle (i.e., collision with the ground, collision with another bicycle, collision with a pedestrian, etc.), or fall from the bicycle. Examples of other mechanism categories that were used included: loss of control; unsafe riding practices; travelling at high speeds; fall during tricks/stunts; attempt to avoid person, animal or object; mechanical/equipment failure; “poor conditions”; etc. (Table 3.2). Ten studies did not describe the mechanisms of injury.

Age category definitions varied among studies and are presented in Table 3.2. The median cut-off age between children and adults was ≥17 years old (IQR 14-19, range: 14-20). The adolescent age group was identified in nine studies, two of which reported zero fatalities in the adolescent age group.[32, 43] The age boundaries for the adolescent age group varied widely by study, but generally referred to teenaged cyclists between the ages of 15 and 19 (Table 3.2). Data on cycling injuries in older adults was available from six studies, which defined “older adults” as cyclists ≥60 (n=1), ≥65 (n=3), ≥66 (n=2), or ≥71 (n=1) years old (Table 3.2).

3.3.4 Quality of included studies

Included studies were generally of low quality. No included studies received a “strong” global rating using the EPHPP quality assessment tool, and two thirds of the included studies were rated as “weak” (n=18; Table 3.5). The majority of studies were at either low (n=14) or moderate (n=12) risk of selection bias. Most studies (n=23) were rated “strong” for blinding because they were retrospective studies the included patients or clinicians would not have been aware of the study hypothesis and the assessors’ knowledge of a patient’s exposure or outcome status would not likely bias the results of a descriptive study. The presence and control of confounding was generally poorly reported, and 16 studies scored “weak” in that section of the EPHPP quality assessment tool. Similarly, 19 studies were not able to show that their data collection tools were valid. Twenty-three of 27 received a “moderate rating” for reporting of their withdrawal/dropout rates.

Severe and Fatal Bicycle Injuries by Age Group

The weighted proportions of fatalities among severely injured cyclists by age group are presented in Table 3.3. The weight proportion among children was 3.01% (95% CI: 2.27 - 3.76; I^2 = 98.2). Data on adolescents were available from nine studies, two of which reported there were no fatalities during their respective study periods. From the remaining seven studies, the proportion of fatalities among adolescents was 2.5% (95% CI: 1.1-3.9; I^2 = 95.6). Mean ISS was reported by three pediatric studies and was estimated for two others; the weighted mean ISS for these five studies was 11.04 (95% CI: 10.99-11.09).

Fourteen studies reported on adult injuries and fatalities. The weighted proportion of fatalities among severely injured adult cyclists was 7.1% (95% CI: 5.6-8.7; I^2=98.8). Data on older adults were available from seven studies; the weighted proportion of fatalities among these studies was 14.2% (95% CI: 9.4-19.0; I^2 = 95.7). Mean ISS was reported for adults by studies and was estimated for one other study; the weighted mean ISS for adults was 15.49 (95% CI: 15.48 – 15.51). One study reported median ISS among adults to be 17 (IQR 16-25).[18] The high level of heterogeneity precluded further pooling, except to identify sources of the heterogeneity.

3.3.5 Factors Associated with Severe and Fatal Bicycle Injuries

The median proportions and number of studies (by age group) reporting on factors indicted in cycling injuries are listed in Table 3.4. Most included cyclists were male, there was low reported helmet usage, and generally large proportions of both children and adults suffered head injury. The median proportion of adult cycling injuries with motor vehicle involvement was substantially higher than children. Alcohol use and crash during darkness were reported by more studies for adults than for children. None of the included studies reported occurrence of cycling crash location (urban vs. rural, on-street vs. off-street) by age group.

To confirm these findings, data from mixed population studies were compared in a sensitivity analysis to determine the weighted odds ratio of death among severely injured cyclists in children compared to adults using a random effects model. Children were at significantly lower odds of death compared to adults (OR = 0.54, 95% CI: 0.41-0.72; Figure 2). Due to an insufficient number of comparative studies, a funnel plot was not produced.[44]

3.3.6 Potential Sources of Heterogeneity

The overwhelming heterogeneity led to a *post hoc* exploratory analysis to attempt to identify some of the factors contributing to the differences in studies. Several potential sources of heterogeneity were considered, including: composition of study population (pediatric vs adult vs mixed); study design (etiologic vs. descriptive); study quality; data source for determining deaths (medical examiner/vital statistics vs. hospital-based trauma registry or enrolment); national vs. regional studies; geographic region; and year of publication.

Heterogeneity was notably reduced by stratifying by country of the study population, with lower heterogeneity observed in studies using Canadian samples for children (I^2=26.5). Presence of MHL during all or part of the study period eliminated heterogeneity among studies conducted on populations subject to MHL and using pediatric data (I^2=0). No included studies had MHL in place for adults during their study period; although previous studies have shown that the presence of MHL for children may also increase adult helmet use,[45] stratifying adult studies by presence of MHL did not reduce the I^2 among included studies. Pediatric studies with MHL present during the study period had a significantly lower weighted proportion of fatalities (1.47% vs. 3.0%), compared to all pediatric studies.

3.4 DISCUSSION

The present study is the first systematic review of severe and fatal cycling injuries in North America including children and adults. Although a large number of studies met the inclusion criteria, only two-thirds were able to be included in the analysis due to lack of available data. Of the 29 studies included in the analysis, most were descriptive studies. Generally, adults had a higher proportion of fatalities than children. Reporting of associated factors was inconsistent, and reporting of factors other than sex and occurrence of head injury was rare. Overall, the quality of included studies was low, and heterogeneity precluded pooled analysis for secondary outcomes.

To-date, only one other systematic review on cycling injuries and no reviews on cycling fatalities have been published. Macpherson *et al.* focused their review on the effectiveness of MHL at increasing helmet use and reducing head injuries.[46] Additionally, few studies have examined differences in cycling injuries between adults and children as their primary focus,[47] and none in North America. In fact, many studies of cycling injuries appear to be conducted on one specific age group. The age-specificity of cycling injury studies implies that there are differences among age groups; however, few studies have examined these differences directly.[39, 47]

High levels of heterogeneity were observed in the current review; however, that the 95% CI for the pooled weight proportions for children and adults do not overlap suggests that severely-injured adults suffer a higher proportion of fatalities than children or adolescents. Additionally, the 95% CI for the estimate for adults and older adults also did not overlap, suggesting that older adults who sustain severe injuries while cycling are at the highest risk of a fatal outcome compared to all other ages. The lack of studies providing “strong” evidence is unsurprising and is related to both the EPHPP quality assessment tool, for which only randomized trials can receive a “strong” rating for study design, and the variables of interest in this review (age and proportion of fatalities), neither of which can be randomized.

Although the level of heterogeneity present among studies precluded pooling of data, when the proportions of deceased children vs. adults reported by mixed population studies were compared, children had significantly lower odds of dying compared with adults. Two studies had a higher proportion of pediatric fatalities compared with adults; both were regional studies with a comparatively small sample and the odds ratio for fatalities in children compared with adults was not statistically significant. In all of the studies for which the odds ratios were statistically significantly, adults were at greater odds of dying. The reports of zero pediatric cycling fatalities by several included studies also indicates that children may be less likely than adults to sustain fatal cycling injuries, and suggests that the estimate for the proportion of pediatric cycling fatalities reported here may be biased upwards, as studies without occurrence of the event were not able to be included in the pooled analyses. While children may be at more risk of a cycling injury of any severity due to lack of coordination and cycling experience,[48] previous studies have shown that adults typically suffer from more severe injuries[25] and may be exposed to more factors associated with increased severity such as exposure to motor vehicle traffic (i.e., cycling on the road), consumption of alcohol prior to cycling, and cycling in the dark.[15, 16, 35]

An additional observation from this systematic review is the high proportion of fatality among severely injured older adult cyclists. There is recent evidence that the burden of injury may be shifting to older cyclists.[49] Older cyclists may be more physically susceptible to serious injury than younger cyclists and thus more likely to succumb to their injuries if they are involved in a serious cycling collision or they may be involved in serious cycling collisions more frequently than cyclists in other age groups due to reduced vision, hearing, and reflexes.[50]

High heterogeneity precluded pooling of data for more concrete results; however high heterogeneity is in itself is an important finding. Potential sources of heterogeneity included: study design (etiologic vs. descriptive); study population (pediatric vs adult vs mixed); injury focus (head injury vs. non-head injury); geographic region; and year of publication. Geographic region and year of publication of included studies may be linked to helmet use, as regions where MHL has been implemented may have had higher rates of helmet use.[46] Unfortunately, helmet use was not always documented by studies included in this review, but has been shown to decrease severe head injuries.[51] It is well documented that cycling culture differs significantly between North America and Europe, but it may be that cycling culture and environment also differ among cities/regions across North America. Cycling injury prevention strategies may need to be tailored to the specific cycling market in which they are being implemented in order to be successful.

3.3.1 Limitations

A large proportion of studies which met the inclusion criteria for this review were unable to be included due to a lack of available data (19/48). Poor reporting in the individual manuscripts was common and problematic. In addition, the broad scope of the review resulted in few inclusion criteria. The high levels of heterogeneity present in this study have been discussed at some length; the heterogeneity makes drawing conclusions about the point estimates for the proportion of fatal injuries potentially biased, but analyses provided other evidence to support the primary conclusion of this review: that adults bear a higher burden of injury from cycling fatalities than children, based on the proportion of fatalities among severely injured cyclists. Finally, the quality of included studies was generally low; however, the majority of included studies used the same definition for severe injury, and death is not likely to be over-reported.

3.5 CONCLUSIONS

Despite high economic and social costs of cycling fatalities,[10, 11] studies of severe and fatal cycling injury events provide only weak evidence and have inconsistent reporting of results. In cases of severe injury, adults appear to have a higher burden of fatality than children, and older adults (≥60 years old) had the highest fatality burden. Future studies should standardize definitions and reporting. Study of cycling injuries and fatalities at a regional level may provide stronger evidence for policy- and decision-makers, as injury interventions can then be tailored to fit the local cycling culture (e.g. focus on recreational vs. utilitarian cyclists) and environment.

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TABLE 3.1 DESCRIPTIVE CHARACTERISTICS OF STUDIES INCLUDED IN A SYSTEMATIC REVIEW OF SEVERE AND FATAL CYCLING INJURIES IN ADULTS AND CHILDREN.

First Author, Year	Region	Country	Study period	Population	Study design	Data source(s)	Age and year of mandatory helmet legislation
Brown, 2002	OH	USA	1991 – 2000	Children	Retrospective Cohort	Hospital trauma registry	Not applicable (No current state law)
Cheng, 2000	DC	USA	1995 – 1998	Children	Retrospective Descriptive	Medical records, District of Columbia adolescent injury surveillance program	Not applicable (<16, implemented 2000)
Durkin, 1999	NY	USA	1983 – 1995	Children	Retrospective Descriptive	Northern Manhattan Injury surveillance system	<14, 1994
Frank, 1995	OR	USA	1989	Mixed	Retrospective Descriptive	Oregon injury registry	Not applicable (<16, implemented 1994)
Haider, 2008	-	USA	2001 – 2005	Adults	Retrospective Cohort	National trauma databank	-
Hamann, 2013	-	USA	2002 – 2009	Mixed	Retrospective Descriptive	HCUP-NIS*	-
Hu, 1995	ON	Canada	1989 – 1991	Children	Prospective Descriptive	Hospital discharge records	Not applicable (<18, implemented 1995)
Konkin, 2006	BC	Canada	1993 - 2003	Mixed	Retrospective Cohort	British Columbia Trauma Registry	All ages, 1996
Li, 1995	-	Canada and USA	1989 – 1992	Children	Retrospective Descriptive	National pediatric trauma registry	-
Li, 1996	ME	USA	1987 - 1994	Mixed	Retrospective case-control	Coroner's records, hospital medical records	Not applicable (<16, implemented 1996)
Linn, 1998	BC	Canada	1991 – 1995	Children	Retrospective Descriptive	Canadian Hospitals Injury Reporting and Prevention Program	Not applicable (All ages, Implemented 1996)
Lopez, 2012	CA	USA	2000 - 2009	Adults	Retrospective cohort	Hospital medical records	<18, 1994
Lustenberger, 2010	-	USA	2002 – 2006	Mixed	Retrospective Descriptive	National trauma databank	-
Macpherson, 2002	-	Canada	1994 - 1998	Children	Retrospective Ecologic trend	Canadian Institute for Health Information	-

Mehan, 2008	-	USA	1990 - 2005	Children	Retrospective Descriptive	National Electronic Injury Surveillance System	-
Miller, 2004	-	USA	2000	Mixed	Retrospective Cohort	FARS[†], HCUP-NIS, NVSS[‡]	-
Naumann, 2010	-	USA	2005	Mixed	Descriptive cost analysis	NVSS, FARS, HCUP-NIS	-
Powell, 1997	-	USA	1986 – 1996	Children	Retrospective Descriptive	National pediatric trauma registry	-
Puranik, 1998	FL	USA	1992 – 1996	Children	Retrospective Descriptive	Trauma service records, emergency medical services reports, autopsy reports	Not applicable (<16, implemented 1997)
Rivara, 1997	WA	USA	1992 – 1994	Mixed	Prospective case-control	Hospital medical records	Not applicable (No current state law)
Roberts, 2013	AB	Canada	1995 – 2009	Adults	Retrospective cohort	Southern Alberta trauma Database	<18, 2002
Rosenkranz, 2003	MA	USA	1993 – 2000	Adults	Retrospective Descriptive	Massachusetts Discharge Dataset	<12, 1994 (<17, implemented 2004)
Teisch, 2015	FL	USA	2000 – 2012	Children	Retrospective cohort	Hospital medical records	<16, 1997
Thompson, 1989	WA	USA	1989 - 1987	Mixed	Prospective case-control	Medical records, corner's records	Not applicable (No current state law)
Wesson, 2000	ON	Canada	1989 - 1996	Children	Prospective Cohort	Ontario trauma registry, coroner's reports	<18, 1995
Winston, 2002	-	USA	1997	Children	Retrospective Descriptive	19-state hospital discharge data set	-
Zavoski, 1995	CT	USA	1987 - 1992	Mixed	Retrospective Descriptive	Death certificates, Connecticut health information management and exchange	Not applicable (<16, implemented 1993)

[*]HCUP-NIS – Healthcare Cost and Utilization Project National Inpatient Survey
[†]FARS = Fatality Analysis and Reporting System
[‡]NVSS = National Vital Statistics System

TABLE 3.2 AGE CATEGORIES OF STUDIES INCLUDED IN A SYSTEMATIC REVIEW OF SEVERE AND FATAL CYCLING INJURIES IN ADULTS AND CHILDREN.

First Author, year	Mechanism coding	Definition of "Severe Injury"	Children	Adolescents	Adults	Older adults
Brown, 2002	Fall from bicycle; collision with moving object; collision with stationary object	Admitted to hospital	≤17	-	-	-
Cheng, 2000	Collision with motor vehicle; collision involving other people; equipment related; poor conditions	Admitted to hospital	≤19	10-19	-	-
Durkin, 1999	Traffic-related bicycle injury	Admitted to hospital	≤17	-	-	-
Frank, 1995	Not reported	Admitted to hospital	≤20	-	≥21	-
Haider, 2008	Not reported	ISS[‡]≥9	-	-	≥15	-
Hamann, 2013	Motor vehicle collision; non-motor vehicle collision	Admitted to hospital	≤17	11-17	≥18	≥71
Hu, 1995	Not reported	Admitted to hospital	≤17	-	-	-
Konkin, 2006	Alone; vs. motor vehicle; vs other	Hospital admission ≥3 days	≤14	15-24[†]	≥15	≥65
Li, 1995	Collided with motor vehicle; collided with bike; collided with other	ISS≥10	≤14	-	-	-
Li, 1996	Not reported	Admitted to trauma center	≤19	10-19	≥20	≥60
Linn, 1998	Loss of control; fall, collision; traffic accident	Admitted to hospital	≤19	15-19	-	-
Lopez, 2012[*]	Auto-vs.-bicycle; cyclist-only	Admitted to hospital	-	-	-	-
Lustenberger, 2010	Cyclist injured by motor vehicle	ISS≥16	≤14	-	≥15	≥66
Macpherson, 2002	Struck by motor vehicle	Admitted to hospital	≤19	-	-	-
Mehan, 2008	Not reported	Admitted to hospital	≤17	-	-	-
Miller, 2004	Not reported	Admitted to hospital	≤19	10-19	≥20	≥66
Naumann, 2010	Not reported	Admitted to hospital	≤19	15-19	≥20	≥65
Powell, 1997	Motor vehicle involved; fall from bicycle	Admitted to hospital	≤14	-	-	-
Puranik, 1998	Bicycle-motor vehicle collision; lost control; hit object other than motor vehicle	Designated trauma alert status	≤15	-	-	-

Rivara, 1997	Motor vehicle involvement; lost control and hit ground; lost control and hit obstacle	ISS>8	≤19	13-19	≥20	-
Roberts, 2013	Fell off bike; attempted to avoid person, animal or object; rode downhill at speed; high speed bump, lost balance (speed-related or other); fell during trick, veered off cliff or roadside; collided with object other than motor vehicle; collided with parked vehicle, hit by motor vehicle while moving; hit by commuter train	Admitted to hospital	-	-	≥16	-
Rosenkranz, 2003	Fall from bike; bike vs bike; bike vs. motor vehicle	Admitted to hospital	-	-	≥16	-
Teisch, 2015	Not reported	Admitted to trauma center	≤17	-	-	-
Thompson, 1989	Not reported	"Serious facial injury"	≤14	15-24†	≥15	-
Wesson, 2000	Not reported	Admitted to hospital for head injury	≤14	-	-	-
Winston, 2002	Non-motor vehicle collision; bicycle crashes and falls	Admitted to hospital	≤19	-	-	-
Zavoski, 1995	Motor vehicle-related collision; non-motor vehicle collision	Admitted to hospital	≤19	15-19	≥20	≥65

[*] Patients enrolled in Lopez 2012 ranged from 1 – 90 years old; study was treated as "adult only" after correspondence with authors indicated the proportion of children that was included was "exceedingly low".
[†] Included as adult age group in binary age-group analyses
[‡] ISS = Injury Severity Score

TABLE 3.3 WEIGHTED PROPORTIONS OF FATAL CYCLING INJURIES REPORTED BY STUDIES OF SEVERE AND FATAL CYCLING INJURIES IN ADULTS AND CHILDREN, BY AGE GROUP.

	No. Studies	Weighted proportion of fatal over severe cycling injuries (%)	95 % Confidence Interval	I^2 Statistic
All Pediatric	21	3.02	2.27-3.76	98%
Children	13	2.56	1.73 - 3.40	96%
Adolescents	7	2.53	1.13 - 3.93	96%
All Adults	14	7.15	5.62 - 8.68	99%
Younger adults	7	6.58	4.46 - 8.70	99%
Older Adults	7	14.16	9.36 - 18.97	96%

TABLE 3.4 FACTORS FREQUENTLY REPORTED BY STUDIES INCLUDED IN A SYSTEMATIC REVIEW OF SEVERE AND FATAL CYCLING INJURY IN ADULTS AND CHILDREN. PROPORTIONS USED WERE THOSE REPORTED FOR ALL CYCLISTS IN EACH AGE GROUP IN EACH STUDY, REGARDLESS OF INJURY SEVERITY.

	Children (n = 19)			**Adults (n = 14)**		
	No. Studies (n)	Median (IQR*) (%)	Range (%)	No. Studies (n)	Median (IQR) (%)	Range (%)
Sex	11	76 (72, 81)	70 - 100	5	80 (77, 84)	74 - 86
Head injury	10	33 (21, 46)	1.3 - 61	5	28 (26, 41)	16 - 70
Motor vehicle involvement	8	24% (21, 46)	4.3 - 82	3	28 (28, 35)	28 - 35
Helmet use	6	2.4 (1.4, 5.8)	1.1 - 12	3	20 (7.4, 42)	7.4 - 42
On-Road	4	74 (59, 79)	24 - 79	0	-	-
Alcohol use	2	2.3, 2.4	2.3 - 2.4	4	16 (9.0, 21)	2.4 - 25
Weekend	1	54	-	1	45 (45, 45)	-
Darkness	0	-	-	2	20 (16, 24)	16 - 24

*IQR = Interquartile Range

TABLE 3.5 QUALITY ASSESSMENT OF 27 STUDIES OF SEVERE AND FATAL CYCLING INJURIES IN ADULTS AND CHILDREN.

Author, Year	Selection Bias	Study Design	Confounding	Blinding	Data Quality	Withdrawals/ Dropouts	Global Rating
Brown, 2002	Moderate	Moderate	Weak	Weak	Weak	Moderate	Weak
Cheng, 2000	Strong	Moderate	Weak	Strong	Weak	Moderate	Weak
Durkin, 1999	Strong	Moderate	Moderate	Strong	Moderate	Moderate	Moderate
Frank, 1995	Moderate	Weak	Weak	Strong	Weak	Moderate	Weak
Haider, 2009	Moderate	Moderate	Moderate	Strong	Weak	Moderate	Moderate
Hamann, 2013	Strong	Moderate	Moderate	Strong	Moderate	Moderate	Moderate
Hu, 1995	Strong	Weak	Weak	Moderate	Weak	Strong	Weak
Konkin, 2006	Moderate	Moderate	Weak	Strong	Weak	Moderate	Weak
Li, 1996	Strong	Weak	Moderate	Strong	Weak	Strong	Weak
Li, 1995	Strong	Weak	Moderate	Strong	Weak	Moderate	Weak
Linn, 1998	Moderate	Moderate	Weak	Strong	Weak	Moderate	Weak
Lopez, 2012	Strong	Moderate	Weak	Strong	Weak	Moderate	Weak
Lustenberger, 2010	Moderate	Moderate	Moderate	Strong	Weak	Moderate	Moderate
Macpherson, 2002	Moderate	Moderate	Strong	Strong	Moderate	Moderate	Moderate
Mehan, 2009	Strong	Weak	Weak	Strong	Moderate	Moderate	Weak
Miller, 2004	Strong	Weak	Weak	Strong	Moderate	Moderate	Weak
Naumann, 2010	Strong	Weak	Moderate	Strong	Moderate	Moderate	Moderate
Powell, 1997	Strong	Weak	Weak	Strong	Weak	Moderate	Weak
Puranik, 1985	Strong	Weak	Weak	Strong	Weak	Moderate	Weak
Rivara, 1997	Strong	Moderate	Moderate	Moderate	Weak	Strong	Moderate
Roberts, 2013	Strong	Moderate	Weak	Strong	Weak	Moderate	Weak
Rosenkranz, 2003	Weak	Moderate	Weak	Strong	Weak	Moderate	Weak
Teisch, 2015	Moderate	Moderate	Weak	Strong	Weak	Moderate	Weak
Thompson, 1989	Moderate	Moderate	Moderate	Weak	Strong	Strong	Moderate
Wesson, 2000	Moderate	Moderate	Weak	Strong	Moderate	Moderate	Moderate
Winston, 2002	Moderate	Weak	Weak	Strong	Weak	Moderate	Weak
Zavoski 1995	Moderate	Weak	Moderate	Strong	Weak	Moderate	Weak

FIGURE 3.1 PRISMA FLOW-CHART OF SYSTEMATIC SEARCH RESULTS FOR A SYSTEMATIC REVIEW OF SEVERE AND FATAL CYCLING INJURIES IN CHILDREN AND ADULTS.

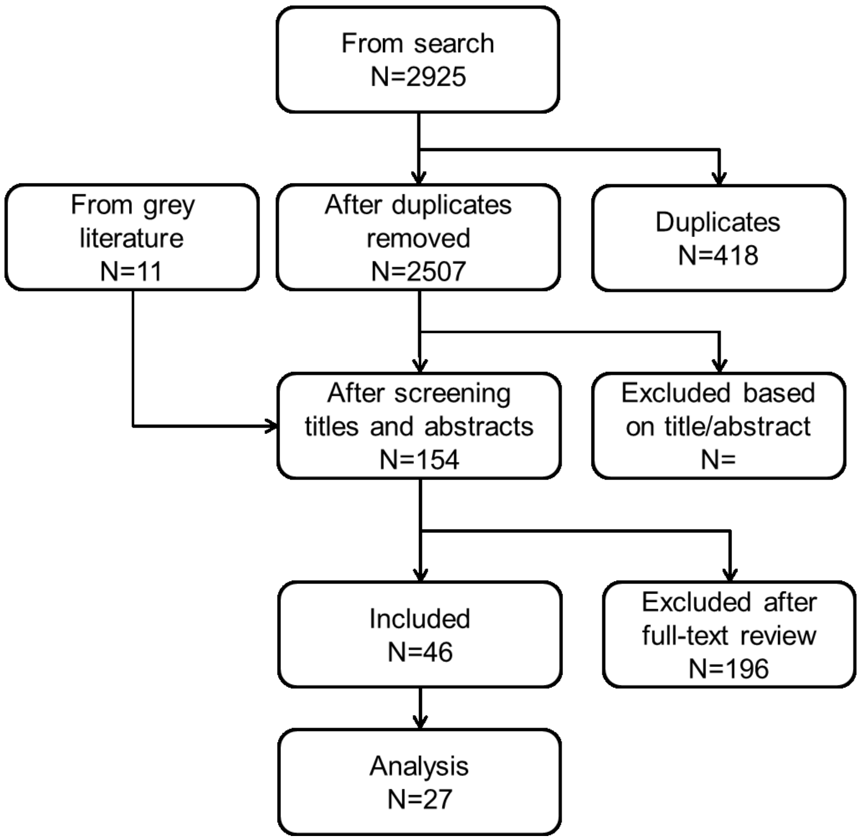
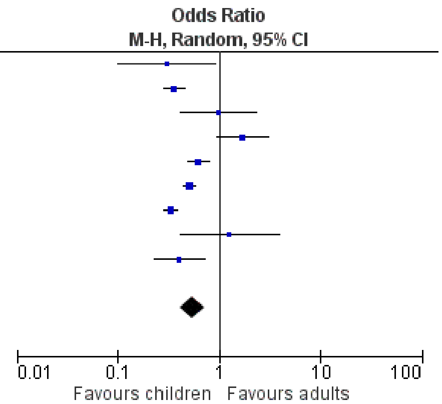


FIGURE 3.2 FOREST PLOT OF ODDS RATIOS COMPARING THE PROPORTION OF FATAL OVER SEVERE-CYCLING INJURIES BETWEEN ADULTS AND CHILDREN IN MIXED-POPULATION STUDIES INCLUDED IN A SYSTEMATIC REVIEW.

	Children		Adults			Odds Ratio
Study or Subgroup	Events	Total	Events	Total	Weight	M-H, Random, 95% CI
Frank 1995	5	189	10	122	4.9%	0.30 [0.10, 0.91]
Hamann 2013	77	13644	431	27575	15.3%	0.36 [0.28, 0.46]
Konkin 2006	6	225	34	1251	6.6%	0.98 [0.41, 2.36]
LI 1996	23	87	40	228	10.0%	1.69 [0.94, 3.04]
Lustenberger 2010	99	817	358	1979	15.4%	0.62 [0.49, 0.79]
Miller 2004	264	11869	602	14067	16.5%	0.51 [0.44, 0.59]
Naumann 2010	206	10183	799	13726	16.4%	0.33 [0.29, 0.39]
Rivara 1997	9	137	5	95	4.7%	1.27 [0.41, 3.90]
Zavoski 1995	23	1005	26	473	10.2%	0.40 [0.23, 0.71]
Total (95% CI)		**38156**		**59516**	**100.0%**	**0.54 [0.41, 0.72]**
Total events	712		2305			

Heterogeneity: Tau² = 0.12; Chi² = 54.07, df = 8 (P < 0.00001); I² = 85%

Test for overall effect: Z = 4.18 (P < 0.0001)



Chapter 4 Cycling Fatalities over a 14-year period in Alberta, Canada

4.1 INTRODUCTION

Cycling is a popular recreational activity that has both health and environmental benefits.[1] Despite the benefits, cycling can be dangerous, and cycling crashes can be fatal. While cycling fatalities are rare events, cyclists are killed at higher rates than other road users.[2] Cycling fatalities also have higher per-event medical costs than nonfatal injuries.[3]

Previous studies of bicycle fatalities conducted in the United States have found that fatally injured cyclists are usually male, often adult, and rarely wearing a helmet when they crash.[4-6] The relationships of cyclist and environmental factors to the mechanisms of cycling-related deaths among Canadian cyclists have not been thoroughly investigated; however, several recent studies evaluated helmet effectiveness for prevention of cycling-related fatalities and found decreased occurrence of head injury among severely and fatally injured cyclists.[7-10] In addition, the prevalence of cycling fatality risk factors may vary with age,[11] but these differences remain relatively unstudied. Many governments are making efforts to increase cycling among residents; however, the primary barrier is the perception that cycling is dangerous.[12] Understanding the factors that contribute to fatal cycling crashes and their difference between age groups will assist decision-makers to develop tailored interventions for prevention of cycling fatalities, a decrease in which may mitigate the perceived danger of cycling and thereby encourage more people to cycle.

Canada is a large, geographically diverse country with both dense urban and sparse rural areas, and a wide range of climates ranging from warm oceanic to sub-arctic. Most studies of Canadian cycling fatalities have used data from regions that are more densely populated and with warmer, wetter climates than Alberta, namely the province of Ontario and urban centers in southern British

Columbia.[7, 9, 13-16] This is the first study to examine the mechanisms and epidemiological factors (e.g., environmental and demographic) contributing to cycling fatalities in Alberta, a sparsely populated, mostly rural region with a cold northern climate.

4.2 METHODS

4.2.1 Study Design

This is a retrospective chart review. Ethical approval to conduct the study was received from the University of Alberta Health Research Ethics Board.

4.2.2 Data Collection

Case files from Alberta's Office of the Chief Medical Examiner (OCME) were used. Approximately 20% of all deaths in Alberta are investigated by the OCME, including those that are "the result of violence, accident or suicide".[17] Case files for the years 1998 to 2011, inclusive, coded with any of "MV bicycle", "fall", "sporting", or "other" were manually reviewed by OCME staff to identify bicycle-related deaths. Relevant cases were abstracted by two trained research staff onto standardized forms. Information about demographics, environmental (e.g., location, date and time, lighting) and cyclist (e.g., clothing, helmet use, alcohol or drug use) factors, as well as injury data, were collected and entered into a purpose-built Microsoft Excel database.

4.2.3 Data Sources

All available records within OCME case files were used to complete the form. Event circumstances, including action of involved parties and details on the deceased cyclist, the bicycle, and the scene of the crash, were determined from incident summaries within emergency department (ED) charts, Emergency Medical System (EMS) patient care reports (PCRs) and local police or Royal Canadian Mounted Police (RCMP) reports, including scene photographs (n=6). Previous studies have reported that helmet use by fatally injured cyclists is rare,[4, 7, 16] and helmet use in Alberta during the study period was generally low;[18] therefore, deceased cyclists were assumed not to have been wearing a helmet unless specifically stated. Injury details were collected from the medical examiner (ME) reports, nursing notes, medical consultant reports, ED charts, and EMS PCRs. Evidence of alcohol and prescription and illicit drug use was collected from OCME and police toxicology reports or witness statements.

In Alberta, all traffic collisions involving a death must be reported to police. Therefore, information about actions of motorist(s) involved in a fatal motor vehicle-cyclist collision (MVCC) was obtained from RCMP or local police reports. MVCCs were categorized according to the mechanisms defined by others: mid-block ride-out, cyclist inattention, motorist inattention, other, or unknown/unclear.[16]

4.2.4 Case Mapping and Event Rate Calculations

Fatal crashes were mapped into one of six regions (Edmonton region, Calgary region, Northern Alberta, Central Alberta, Southern Alberta, and Alberta Rockies) based on location of the crash using the open-source OpenJUMP geographical information software package (Vivid Solutions, Victoria, BC) and 2006 census sub-division digital boundary data (Figure 4.1).[19] Regional and age-specific cycling fatality rates per million population were calculated by dividing the number of events per region by person-years during the study period, estimated by multiplying the population of each region from the 2006 Statistics Canada census data (the census data closest to the mid-point of the study) by the study duration (14 years).

4.2.5 Statistical Analysis

The numbers of fatally injured cyclists with injuries to each anatomical area (head, neck/spine, trunk, extremities) are reported; some deceased cyclists sustained injury to more than one area of the body. MVCC events were compared to all non-MVCC events on cyclist demographics (% male, age), location (urban vs. rural, road vs. non-road), reported helmet use, alcohol/drug use, light condition, weather conditions, and injuries. An event was classified as “urban” if it occurred within the legal limits of a city or town; all other settings were considered rural. Urban events were compared to rural events on cyclist demographics (% male, age), reported helmet use, alcohol/drug use, light condition, weather conditions, and injuries. Deceased cyclists were grouped into five age categories: <10 years, 10-19 years, 20-44 years, 45 – 64 years, and ≥65 years. Age groups were compared on reported helmet, alcohol, and illicit drug use, and injuries.

Statistical analyses were performed using STATA Statistical Software Release 12.0 (Stata Corporation; College Station, TX, USA). Numerical data are reported as medians and interquartile ranges (IQR). Proportions were calculated for categorical variables. Differences in sub-groups were tested using Fisher’s exact test; $p \leq 0.05$ was considered statistically significant.

4.3 RESULTS

4.3.1 Included Cases

The OCME identified 106 cycling-related fatalities that occurred between February 1998 and October 2011. Five files were excluded because they did not describe the event, leaving 101 cases for analysis.

Deceased cyclists were mostly male (87%) and mainly adult (81%) (Table 4.1). Cyclists most often died at the scene (40%) or after hospital admission (40%) (Table 4.1). Helmet use was reported in 25 (25%) and alcohol use in 26 (26%) cases (Table 4.1).

4.3.2 Environmental Factors of Fatal Cycling Crashes

The number of fatal cycling crashes varied between years from a low of three events in 1998 to a high of 12 events in 2007; no trend in events per year was detected by a non-parametric test for trend (p=0.4). Fatal crashes mainly occurred between May and September, and peaked in September (21 [21%]). Most crashes occurred during the day, and crashes mainly occurred on a weekday (Table 4.2).

Nine (9%) events occurred during peak traffic (6:30 AM to 8:30 AM and 4:00 PM to 6:00 PM, Monday to Friday). The majority of crashes occurred on a road, and poor lighting and inclement weather were infrequent (Table 4.2). The majority of fatal crashes were MVCCs (Table 4.2); “other” mechanisms included a collision with a train and three collisions with urban rail transit. Of the 67 MVCC-related deaths, eight (12%) were midblock ride-outs, 23 (34%) were due to cyclist inattention, 25 (37%) were due to motorist inattention, and 11 (16%) were categorized as other/unknown. MVCCs occurred more frequently than non-MVCC crashes on roads (p<0.001; Table 4.3) and more often in poor lighting (p=0.029; Table 4.3). Incidence of trunk injury was higher among cyclists killed in MVCCs than non-MVCC crashes (Table 4.3). Reported helmet use did not differ with crash mechanism; however, evident cyclist alcohol use was present more often in MVCCs than in non-MVCC crashes (p<0.001; Table 4.3).

4.3.3 Cycling Fatalities in Urban and Rural regions

Table 4.4 presents the number of events and rate per million population in each region. Rural regions generally had higher rates of events compared with urban regions (Table 4.4); the event rate was highest in the Alberta Rockies. Table 4.4 also presents the population-based rates of events by age-group, which increased with age.

While the majority of crashes occurred in an urban location (Table 4.5), the proportion of fatalities due to MVCCs was higher in rural areas than in urban areas (84% vs. 58%; p=0.03). Alcohol use was more frequent among cyclists killed in urban compared with rural crashes (Table 4.5; p=0.048). While the frequency of reported helmet use was similar (Table 4.5; p=0.22), head injuries occurred more frequently among cyclists killed in urban crashes compared with rural crashes (Table 4.5; p<0.001)

4.3.4 Cyclist factors of cyclists killed while cycling

Reported helmet use increased with age; deceased children and adolescents were rarely reported to be wearing a helmet and elderly deceased cyclists were most often reported to be wearing a helmet (Table 4.6; *p*=0.077). Detected alcohol use was highest among deceased adolescents (Table 4.6). Most (18/25) deceased cyclists with indication of alcohol were intoxicated (BAC>0.08 g/dL); the median BAC was 0.17g/dL (IQR: 0.13, 0.23). All deceased cyclists 20-44 years old with evident alcohol use (n=9) were intoxicated (Table 4.6). Incidence of MVCC compared to non-MVCC crashes was higher among deceased cyclists <20 years old than ≥20 years old, but was not significant (*p*=0.101). Motorist inattention was involved in the deaths of most children and a notable fraction of adults 20-64 years old (Table 4.6). All cyclists who were killed after collision with a stationary object were ≥20 years old (Table 4.6).

Fatally-injured cyclists who had evidence of alcohol consumption were less frequently reported to be wearing a helmet than deceased cyclists without documented alcohol use (4% vs. 33%; p=0.003). More deceased cyclists who crashed in the dark had consumed alcohol compared with those who crashed in daylight (15/25 vs 8/67; *p*<0.001).

4.4 DISCUSSION

This is the first report of cycling fatalities in Alberta, a province with two large urban areas, five regional centers, and a large number of small towns across sparsely populated rural areas. Fatally injured cyclists were most often adult males and commonly sustained their injuries following a collision with a motor vehicle**.** Reported helmet use was infrequent, and 76% of fatally injured cyclists suffered a head or brain injury. Fatal cycling collisions most often occurred in urban locations, on roads, and during times of good light and fair weather (i.e., when cycling is most frequent).

Notable differences were observed in deceased cyclists and crash circumstances between urban and rural areas. Although most fatal cycling crashes in Alberta occurred in urban areas, the rates of cycling deaths per 1,000,000 inhabitants per year were noticeably higher in rural regions where cyclists may ride more often on highways due to lack of other available routes. Additionally, health resources are typically more limited in rural regions which may result in a longer delay between crash occurrence and receiving advanced trauma care than in urban areas. [20] The fatality rate was especially high in the Alberta Rockies, which has a very small population and is popular with cycle-tourists. Future research should examine the burden on local health systems due to injuries occurring in non-residents, as this could have implications for where to target injury prevention strategies. Cyclists killed in urban areas more frequently had evidence of alcohol use than cyclists killed in rural areas. Cycling may be viewed by urban cyclists as a safe transportation alternative to driving after planned drinking; on the other hand, cycling after drinking is not as feasible in rural areas due to the often large distances.

Canadian cycling fatalities have been previously examined in British Columbia and Ontario. In British Columbia, cyclists were at higher risk of being struck by a motor vehicle and fatal injury than in-line skaters and skateboarders.[13] In Ontario, young (<10 years old) and older (≥45 years old) cyclists who died after a cycling crash more frequently made cycling errors that contributed to the crash than adolescents and younger adults, while 19-44 year olds were more frequently killed while cycling at night.[16] The most recent Ontario inquiry, which had similar findings to the current study, resulted in a Coroner's Report and recommendations for safer cycling.[7, 21]

Despite the provincial differences, these results from Alberta mainly agree with previous studies of Canadian cycling fatalities in that the majority of cyclist deaths involved males and were the result of collisions with motor vehicles.[7, 16] However, while previous reports from Ontario and the United States indicated that one-third of cycling fatalities occurred in children,[16, 22] only 19% of deceased cyclists in the current report were under the age of 20. In our study, all children and most of adolescents died after a collision with a motor vehicle, which is consistent with other reports of pediatric cycling fatalities.[15, 16] It is possible that recently implemented interventions aimed to reduce distracted driving may also help to reduce cycling fatalities; however, this level of granularity was not available in these reports.

Cycling fatalities among children and adolescents have been decreasing nationally, which may result from improvements in the built environment and/or mandatory helmet legislation (MHL), which was introduced first in Canada in Ontario in 1998, in 2002 in Alberta (for cyclists <18 years only), and has since been introduced in other provinces. Although reported helmet use was low in this study, a larger proportion of fatally injured cyclists were wearing a helmet compared with older reports.[4, 15, 16] This increase is likely due to the influence of MHL, which (although targeted at under-age cyclists) has been shown to increase helmet use among all ages.[18]

It is interesting to note that the population-based rate of fatal cycling events increased with age, but this observation must be interpreted with caution. Older cyclists may be less coordinated and more frail than younger cyclists and subsequently more likely to be involved in a cycling crash and sustain more serious injuries;[23] however, data on cycling exposure including distance traveled, number of trips, and number of cyclists, are not readily available for Alberta, and it is possible (although unlikely) that older cyclists have a higher level of exposure to cycling which may bias the population-based rate upwards.

Alcohol use prior to fatal cycling events was particularly concerning. The correlation of alcohol consumption with non-use of protective devices such as helmets and seatbelts has been previously documented and is also indicated by our data, as deceased cyclists with evident alcohol use were less frequently reported to have been wearing a helmet than deceased cyclists without evident alcohol use.[24] The legal BAC limit for motorists in Alberta during the study period was 0.08 g/dL (17mmol/L). Twenty-three of the 26 deceased cyclists with evident alcohol consumption, and all of those between 20 and 44 years old, were over the legal limit. Similar to a previous report,[25] in this study a larger proportion of deceased cyclists involved in non-MVCC collisions were intoxicated. Compared with the widespread knowledge of the effects and penalties of consuming alcohol before driving a motor vehicle,[26] cyclists may not recognize the danger of impairment while cycling and may use cycling as an alternative mode of transportation after social drinking, which is suggested by the high proportion of younger adult (20-44 years old) cyclists with evident alcohol use who were over the legal limit for operation of a motor vehicle. Additionally, drivers who lose their license due to impaired driving convictions are likely turn to cycling as an alternative mode of transportation.[27] Drinking and biking has been identified as a potential issue elsewhere;[28] further study on the attitudes around drinking and cycling is needed to develop successful strategies to reduce injuries resulting from drinking and biking.

Cycling fatalities account for a disproportionate 3.2% of Canadian road fatalities, though cyclists only make up 1.2% of regular road users.[12, 29] Reports of cyclist crashes contribute to a lack of safety perceived by both cyclists and non-cyclists.[12] While the results presented here represent only one province, there are few other studies of cycling fatalities in regions with similar demographic and climactic characteristics, and the results presented here may be of interest to policy- and decision-makers in other regions with a low population densities and cold climates in Canada, such as Saskatchewan, Manitoba, and the Territories, and around the world (e.g., Northern mid-west US states, eastern Russia, etc.)

Future efforts to reduce cycling fatalities will require attention to interactions between motorists and cyclists. Prevention strategies that target risk-taking behaviors among cyclists, including education for cyclists on the potential dangers of drinking and cycling and encouraging all cyclists to wear a helmet should be explored. In addition, educational initiatives to instruct safe interactions between all types of road users should be implemented in Alberta, and other similar regions, to inform all road users on how to safely interact with each other.[30] These safety initiatives could help to reduce the public's perception of cycling as a dangerous activity, and therefore help to decrease injuries, increase physical activity, and promote the uptake of active transportation.

4.4.1 Limitations

The results of this exploratory study should be interpreted with caution, due to the lack of a control group. The retrospective methods employed in this study present several limitations. Relevant cases may have been missed due to miscoding, and OCME files are not available for cases in which an investigation, litigation or criminal proceedings are ongoing; however, given the small number of fatalities that occurred in the late fall and winter in other years, it is unlikely that a significant number of cases from 2011 were missed. The level of detail and missing data in the OCME files varied; thus the proportions listed here should be interpreted conservatively, as they may be underestimates. The rates calculated for the whole study period may over-estimate the annual cycling fatality rates prior to 2006 and under-estimate the annual rates after 2006 due to variation in the annual number of events and the change in Alberta's population over the study period. Finally, the use of population as the denominator for the fatality rates here does not reflect the risk of death due to exposure to cycling.

4.5 CONCLUSIONS

Cycling fatalities in Alberta are rare events that usually involve adults and are largely the result of a motor vehicle-cyclist encounter. Strategies to prevent cycling-related fatalities should consider the physical separation of and promotion of safe interactions between motor vehicles and cyclists, strategies to increase helmet use by all ages, and education about the potentially devastating effect of alcohol use on the operation of a bicycle. Reducing fatalities will increase the perceived safety of cycling and should help increase cycling activity in both frequency of cycling and distance travelled.

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TABLE 4.1 DEMOGRAPHIC DETAILS OF FATALLY INJURED CYCLISTS IN ALBERTA, CANADA.

Characteristic	n (%) N= 101
Male	88 (87)
Age (years)	
<10	7 (7)
10 – 19	12 (12)
20 – 44	31 (31)
45 - 64	31 (31)
≥65	20 (20)
Helmet use	26 (26)
Alcohol use	25 (25)
BAC* >0.08g/L	18 (18)
Unknown	3 (3)
Unknown	10 (10)
Illicit drug use	14 (14)
Unknown	33 (33)
Prescription drug use	7 (7)
Unknown	35 (35)
Time of death	
Dead at scene	41 (41)
Transport but DOA†	7 (7)
Transport but died in ED‡	13 (13)
Died after admission to hospital	40 (40)

*BAC - blood alcohol concentration
†DOA - dead on arrival
‡ED - emergency department.
Note: Percentages may not sum to 100 due to rounding.

TABLE 4.2 DESCRIPTIVE CHARACTERISTICS OF 101 FATAL BICYCLE CRASHES IN ALBERTA, CANADA.

Characteristic	n (%) N = 101
Time of Crash	
0601 – 1200	20 (20)
1201 – 1800	38 (38)
1801 – 0000	28 (28)
0001 – 0600	9 (9)
Unknown	6 (6)
Day of the Week	
Monday	13 (13)
Tuesday	14 (14)
Wednesday	11 (11)
Thursday	14 (14)
Friday	16 (16)
Saturday	19 (19)
Sunday	14 (14)
Location	
Urban	64 (63)
Rural	31 (31)
Undetermined	6 (6)
Route type	
Road	77 (76)
Sidewalk/Pathway	6 (6)
Trail/off-road	10 (10)
Other	4 (4)
Unknown	4 (4)
Surface Type	
Pavement	80 (80)
Gravel	7 (7)
Dirt/grass	4 (4)
Unable to determine	10 (10)
Mechanism	
MVCC*	67 (66)
Fell or thrown from bicycle	15 (15)
Collision with stationary object	7 (7)
Other	12 (12)

*MVCC = motor vehicle-cyclist collision
Note: Percentages may not sum to 100 due to rounding.

TABLE 4.3 CYCLISTS AND CRASH CHARACTERISTICS BY MECHANISM FOR 101 FATAL BICYCLE CRASHES IN ALBERTA, CANADA.

	Non-MVCC* (N=34)	**MVCC (N=67)**	**Fischer's Exact *p*-value**
	n (%)	n (%)	
Location			
Urban	27 (79)	37 (55)	0.030
Rural	5 (15)	26 (39)	
Undetermined	2 (6)	4 (6)	
Environment			
On road	14 (41)	63 (94)	<0.001
Poor lighting	6 (18)	20 (30)	0.029
Cyclist			
Helmet use	8 (24)	18 (27)	0.812
Alcohol use	13 (38)	12 (18)	0.031
BAC† >0.08g/dL (17 mmol/ L)	8 (24)	10 (15)	0.378
Drug use	4 (12)	10 (15)	0.448
Type of Injury			
Head Injury	28 (82)	48 (72)	0.330
Trunk Injury	10 (29)	47 (70)	<0.001
Spine Injury	11 (32)	15 (22)	0.337
Limb Injury	17 (50)	51 (76)	0.013

*MVCC = motor vehicle-cyclist collision
†BAC = blood alcohol content
Note: Percentages may not sum to 100 due to rounding.

TABLE 4.4 REGIONAL AND AGE-BASED RATES OF FATAL BICYCLE INJURIES. RATES WERE CALCULATED BY DIVIDING THE NUMBER OF EVENTS PER REGION BY PERSON-YEARS DURING THE STUDY PERIOD, WHICH WERE ESTIMATED BY MULTIPLYING THE POPULATION OF EACH REGION BY THE STUDY DURATION (14 YEARS).

	No. Events (%)	Population*	Events per 1,000,000 inhabitants per year
Region			
Edmonton	30 (30)	1,034,945	2.1
Calgary	26 (26)	1,079,310	1.7
Northern Alberta	13 (13)	328,073	2.8
Central Alberta	11 (11)	240,368	3.3
Southern Alberta	13 (13)	272,017	3.4
Alberta Rockies	8 (8)	35,983	15.9
Age Category			
< 10	7 (7)	406,705	1.2
10 to 19	12 (12)	462,705	1.9
20 to 44	31 (31)	1,232,350	1.8
45 to 64	31 (31)	835,170	2.7
≥65	20 (20)	353,410	4.0

*Population data taken from the Statistics Canada 2006 Census
Note: Percentages may not sum to 100 due to rounding.

TABLE 4.5 CYCLISTS AND CRASH CHARACTERISTICS BY LOCATION OF THE CRASH EVENT FOR 101 FATAL BICYCLE CRASHES IN ALBERTA, CANADA.

	Urban (N=64)	**Rural (N=31)**	**Undetermined (N=6)**	**Fischer's Exact *p*-value**
	n (%)	n (%)	n (%)	
Environment				
On road	46 (72)	26 (84)	5 (83)	0.500
Poor lighting	21 (33)	5 (16)	2 (33)	0.322
Cyclist				
Helmet use	14 (22)	9 (29)	3 (50)	0.222
Alcohol use	20 (31)	3 (10)	2 (33)	0.048
BAC* >0.08g/L	14 (22)	2 (6)	2 (33)	1.00
Drug use				0.171
Age				
<10	4 (6)	3 (10)	0	0.980
10-19	7 (11)	4 (13)	1 (17)	
20-44	22 (34)	8 (26)	1 (17)	
45-64	18 (28)	10 (32)	3 (50)	
≥65	13 (20)	6 (20)	1 (17)	
Type of Injury				
Head Injury	56 (88)	15 (48)	5 (83)	<0.001
Trunk Injury	31 (48)	23 (74)	3 (50)	0.053
Spine Injury	14 (22)	11 (35)	1 (17)	0.362
Limb Injury	45 (70)	20 (65)	3 (50)	0.491

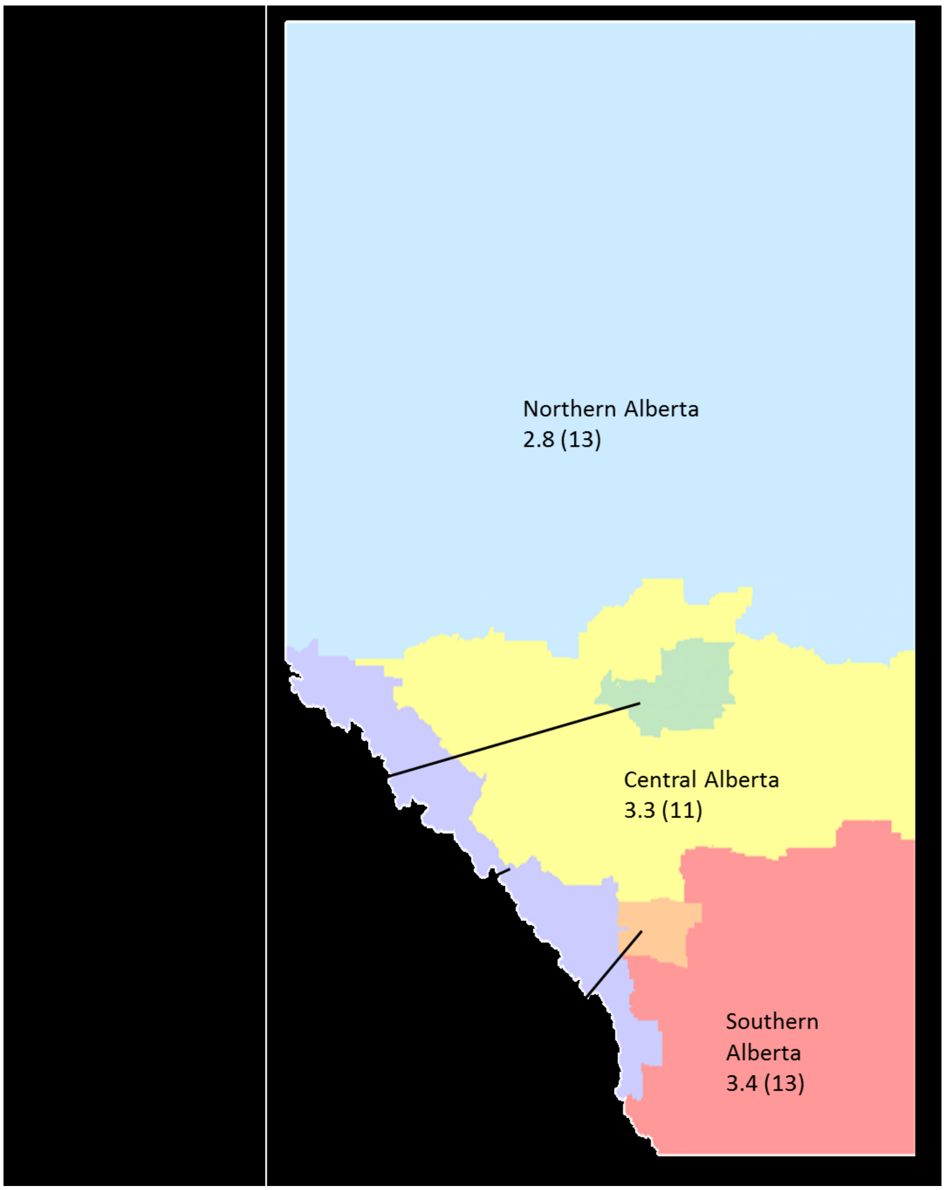
*BAC = blood alcohol content
Note: Percentages may not sum to 100 due to rounding.

TABLE 4.6 CYCLIST CHARACTERISTICS AND CRASH CHARACTERISTICS FOR 101 FATAL BICYCLE CRASHES IN ALBERTA, CANADA BY AGE.

	<10 (N=7)	**10 – 19 (N=12)**	**20-44 (N=31)**	**45 - 64 (N=31)**	**≥65 (N=20)**	**Fisher's Exact *p*-value**
	n (%)	n (%)	n (%)	n (%)	n (%)	
Male	4 (57)	12 (100)	27 (87)	27 (87)	18 (90)	0.161
Alcohol use	0	5 (42)	9 (29)	10 (32)	1 (5)	0.035
BAC* >0.08g/L	0	4 (33)	9 (100)	5 (50)	0	0.029
Illicit Drug use	0	3 (25)	9 (29)	2 (6)	0	0.0984
Helmet	1 (14)	1 (8)	8 (26)	6 (19)	10 (50)	0.077
Location						
Urban	4 (57)	7 (58)	22 (71)	18 (58)	13 (65)	0.955
Rural	3 (43)	4 (33)	8 (26)	10 (32)	6 (30)	
Unknown	0 (0)	1 (8)	1 (3)	3 (10)	1 (5)	
Environment						
On Road	6 (86)	11 (92)	21 (68)	23 (74)	16 (80)	0.575
Darkness	1 (14)	5 (42)	12 (39)	9 (29)	1(5)	0.044
Mechanism						
Cyclist fall	0	0	6 (19)	6 (19)	3 (15)	0.390
MVCC†	7 (100)	9 (75)	20 (65)	19 (61)	12 (60)	
Midblock ride-out	1 (14)	2 (17)	3 (15)	1 (5)	1 (5)	0.545
Cyclist inattention	2 (29)	4 (44)	4 (20)	6 (32)	7 (35)	
Motorist inattention	4 (57)	1 (8)	9 (45)	7 (37)	4 (20)	
Unclear/Unknown	0	2 (17)	4 (20)	5 (26)	0	
Struck object	0	0	4 (13)	2 (6)	1 (5)	
Other	0	3 (25)	1 (3)	4 (13)	4 (20)	
Injury						
Head Injury	5 (71)	10 (83)	24 (77)	23 (74)	14 (70)	0.929
Trunk Injury	4 (57)	9 (75)	18 (58)	15 (48)	11 (55)	0.655
Spine Injury	1 (14)	1 (8)	11 (35)	8 (26)	5 (25)	0.475
Limb Injury	5 (71)	9 (75)	22 (71)	20 (65)	12 (60)	0.895

*BAC = blood alcohol concentration
†MVCC = motor vehicle-cyclist collision
Note: percentages may not sum to 100% due to rounding

FIGURE 4.1 POPULATION-BASED RATES PER 1,000,000 POPULATION PER YEAR OF FATAL CYCLING CRASHES IN ALBERTA FROM 1998 TO 2011 BY REGION. NUMBERS OF EVENTS ARE IN PARENTHESES. RATES WERE CALCULATED BY DIVIDING THE NUMBER OF EVENTS PER REGION BY PERSON-YEARS DURING THE STUDY PERIOD, WHICH WERE ESTIMATED BY MULTIPLYING THE POPULATION OF EACH REGION BY THE STUDY DURATION (14 YEARS)



Chapter 5 Relevance, Conclusions, and Future Directions for Research

5.1 RELEVANCE

Cycling is a popular form of recreation and transportation with health and environmental benefits that is being encouraged by many jurisdictions in North America as an alternative mode of transportation to motorized vehicles. Crashes while cycling can lead to injuries ranging in severity from minor to severe or fatal, and these injuries can significantly impact both the short- and long-term health of cyclists. As a result, lack of safety is frequently cited by Canadians as a reason for not cycling on a regular basis.[1] While severe and fatal cycling injuries are a small proportion of total cycling-related injury events (the top of the so-called "injury pyramid"),[2] they account for a large proportion of cycling injury-related health spending.[3] Although cycling fatalities are rare, cyclists have higher per-trip and per-distance fatality rates than motorists.[4, 5] Cycling fatalities also have larger per-event costs compared to other cycling injury events.[6, 7]

Research on cycling fatalities and their causes is sparse and generally of poor quality (due in part to the inherent difficulties of studying fatal events). In order to develop effective injury prevention interventions for bicycle injuries, the factors associated with their occurrence and mechanisms of action need to be identified. Similar to other types of sports and recreation injuries, the mechanisms of cycling injuries may vary with the age of the cyclist.[8, 9] The aims of this thesis were to investigate the state of the literature on severe and fatal cycling injuries; examine differences in their occurrence between children and adults; and describe their epidemiology in a northern and mostly rural province. This thesis is comprised of: a scoping review to compile the state of the literature on cycling fatalities; a systematic review examining the difference in the ratio of severe to fatal cycling injuries between different age groups; and a descriptive study using chart review methods to examine cycling fatalities in the province of Alberta, Canada – a mostly rural province with a cold, northern climate - over a 14-year period.

5.2 OVERVIEW OF THESIS RESULTS

5.2.1 Cycling Fatalities in North America: A Scoping Review

A scoping review was conducted to identify and describe the current state of the research on cycling fatalities, factors commonly associated with them, and potential gaps in knowledge. The search strategy resulted in 25 unique studies that reported on cycling fatalities in North America. Few etiological studies examined cycling fatalities; most studies reporting on cycling fatalities were retrospective descriptive studies. Eight of the 25 included studies were published in the last five years using data collected from 1996-2011, and cycling fatality studies were most commonly conducted using data from US samples (n=21). Reporting of potential risk factors was inconsistent; studies reported the proportions of fatally injured cyclists who had evidence of alcohol use (n=10), sustained a head injury (n=9), or were wearing a helmet (n=5). The low number of studies reporting on helmet use likely relates to the time period during which most studies were conducted (i.e., prior to the introduction of helmet legislation in many parts of North America), and the data sources used, as most studies obtained data from trauma registries and medical records which often do not accurately record helmet use. Studies also reported on crash-specific factors such as motor vehicle involvement (n=12), occurrence at night (n=12), in urban locations (n=7), or during the weekend (n=6).

Data on cycling fatalities in Canada remains uncommon and focuses on the role of helmet-use. Comparative studies of cycling fatalities examined helmet use and alcohol use; other factors frequently reported as factors associated with bicycle crashes have not been thoroughly examined. Studies of motor vehicle involvement, time and location of crash (urban or rural setting, on-street, etc.), and actions of involved parties (i.e., cyclists and motorists) using etiologic methods are necessary to confirm their roles in cycling fatalities and identify feasible behavioral and environmental targets for injury prevention interventions.

5.2.2 Systematic Review of Severe and Fatal Cycling Injuries in Children and Adults in North America

Previous studies have indicated that age may be related to the types of cycling crashes that occur,[8] so a systematic review was conducted with the aims of comparing the occurrence of fatal cycling injuries to non-fatal severe injury in children compared to adults and the factors associated with each. Twenty-nine studies reported on the occurrence of cycling fatalities, including 15 studies on children, four studies on adults, and ten mixed-population studies. Reporting of associated factors among studies was inconsistent. Proportion of cyclists involved in a collision with a motor vehicle (n=12 for children and n=5 for adults), and the proportions of cyclists who were male (n=12 for children and n=5 for adults) were most common factors reported by age group. Studies were generally of low quality, likely due to the difficulties associated with studying fatal events. While high levels of heterogeneity tempered the strength of conclusions drawn from pooled data, there was no evidence that children experience higher proportions of fatality than adults. In fact, the data indicates that the opposite is true; in both the weighted proportion and the sensitivity analysis using data from studies that included both pediatric and adult populations, adults had a significantly higher proportion of fatalities. Additionally, older adults (≥60 years old) had the highest proportion of fatality, at over 14%. In the *post hoc* analyses to identify potential sources of heterogeneity, only groups of pediatric studies conducted in Canada or in regions with mandatory helmet legislation (MHL) during any part of the study period had reduced heterogeneity and lower proportions of cycling fatalities.

Overall, this review suggests that studies of severe and fatal cycling injury events rarely compare differences in severe and fatal cycling injury occurrence between children and adults, provide weak evidence, and have inconsistent reporting of results. Adults have a higher burden of cycling fatality than children, and older adults (≥60 years old) have the highest fatality burden of all. Cycling fatalities are less frequent in Canada. Studying cycling injuries and fatalities at the regional level may provide stronger evidence for policy- and decision-makers so that injury interventions can be tailored to the local social and physical environments.

5.2.3 Cycling Fatalities in Alberta Canada over a 14-year period

Finally, a descriptive study of cycling fatalities in Alberta from 1998 to 2011 (inclusive) was undertaken. There are few studies of cycling fatalities in Canada and none in a region as sparsely populated as Alberta, as most other Canadian cycling fatality studies have been conducted in Ontario or in the urban centers of British Columbia.[9-12] In the present study, chart review methods were used to collect data on personal characteristics and crash circumstances from the Office of the Chief Medical Examiner of Alberta case files with listed bicycle involvement, and Canadian census data were used to calculate region-specific and provincial age-specific cycling fatality rates.

Overall, this fatality review concluded that cycling fatalities are rare events in Alberta and usually involved adult male cyclists. Crash events mainly occurred during the summer and in urban settings. Collisions with motor vehicles accounted for 68% of fatal crashes. Among fatally injured cyclists in Alberta, helmet use was low and the proportion of head injuries was high; however, the proportion of torso injuries was also high, likely due to the large proportion of crashes that involved collision with a motor vehicle. Alcohol was reported in a quarter of fatalities, frequently in fatal crashes occurring at night and involving younger adults aged 20-44 and 45-64. The population-based fatality rate over the study period was highest in the Alberta Rockies, which has a relatively low population and where cycle-touring is popular, and among cyclists ≥65 years old.

5.3 IMPLICATIONS FOR CYCLISTS

Overall, these results suggest several ways in which cyclists can protect themselves from severe injury and death while cycling. First, the most obvious action cyclists can take to protect themselves from severe injury or death while cycling is to avoid interaction with motor vehicles as often as possible by riding on separated bicycle infrastructure whenever possible, being aware of their surroundings, and cycling courteously when using shared routes. Additionally, where the interconnectedness of cyclist and motorist transportation networks where cycling paths and roads cross is unavoidable, cyclists should take care when coming to an intersection between off-road cycling paths and roads to ensure that motor vehicles have time to see the cyclist and/or the cyclist is able to safely stop, if necessary.

Properly fitted bicycle helmets have been shown repeatedly to decrease rates of cycling-related head injury.[13] Using a properly fitted helmet is one of the simplest things cyclists can do to protect themselves from severe injury and death; however, the cyclist must be wearing the helmet at the time of a crash and the helmet must be properly fitted to obtain full benefit from its use.[14] One intervention that has successfully increased helmet use is MHL. There is some controversy about whether MHL may have other consequences that overshadow the public health benefits associated with increasing helmet use among cyclists.[15, 16] Opponents have raised multiple concerns about MHL including its potential to reduce cycling rates due to cyclists considering wearing a bicycle helmet uncomfortable, inconvenient or unstylish.[17] Fortunately, helmets in a variety of shapes and styles have become available in the past few years, making it increasingly easy for cyclists to find a comfortable helmet.

Although not addressed by results presented here, in part due to lack of reporting of visibility data by severe and fatal cycling injury studies, the use of visibility aids is an easy step that cyclists can take in order to make motor vehicles aware of their presence when riding in darkness. Wearing brightly coloured or reflective clothing, attaching lights to their bicycle or helmet, or applying reflective coatings to the entire bicycle will allow motorists to more easily identify cyclists riding in low-light or at night, especially at intersections between roads and separated bicycle paths. Additionally, using reflective markers around the knees and ankles highlights the biomechanical motion of a cyclist pedaling which may increase the ability of motorists to see the lighted object (cyclist) in front of them and also to more readily identify it as a cyclist.[18] Earlier identification of a lit or reflective object, such as a cyclist, may enable motorists to better avoid cyclists as they approach.[18] This may be especially helpful in preventing collisions in areas with lower rates of cycling, where motorists may not be used to seeing cyclists at night.[19]

Finally, it is clear that “drinking and cycling” leads to an increased risk of bicycle-related injury and death.[20-22] There has been little research into the reasons why cyclists choose to cycle after drinking; regardless, cyclists need to be aware of the potential dangers and the role of alcohol in severe and fatal cycling crashes.

5.4 IMPLICATIONS FOR FUTURE RESEARCH

The quality of the available evidence regarding cycling fatalities is sparse and of generally of low quality. Few reports of controlled or comparative studies on bicycle fatalities in North America exist, and most intervention-based studies reported in our reviews focused on the effectiveness of helmets at preventing head injury and/or interventions to increase their use. While helmets do not mitigate crash incidence or the occurrence of non-head injuries, there are more factors involved in cycling injuries and fatality than helmet use and head injury occurrence, and these additional factors need to be studied in more detail, using etiological and/or comparative methodologies, in order to identify best practice for reduction of severe cycling-related injuries and fatalities. Case-control methods, which compare a risk factor or exposure in people with an outcome of interest to those without the outcome to identify significant differences, are particularly suited to studying rare fatal cycling events in a resource-efficient manner.[23] Additional and higher quality evidence is required surrounding cycling fatalities in order to tailor effective injury prevention strategies and guide policy decisions.

Adult cyclists, especially those >60 years of age, bear the largest injury burden due to severe cycling-related injuries and deaths; therefore, to reduce individual and health system costs due to cycling fatalities, interventions targeting older adult cyclists are needed. Additionally, physical activity has been promoted as especially important for older adults and has been shown to be associated with increased physical resilience,[24] protection against mobility disability,[25] protection against dementia,[26] and promotion of mental health and overall quality of life.[27] Cycling is a common activity among older adults who are physically active,[28] yet these and other results indicate that older adult cyclists may be at greatest risk of fatal injury in the event of a cycling crash compared to cyclists in other age groups.[29] There have been few studies to identify the concurrent factors that may be responsible, which is especially imperative as recent evidence suggests that the burden of injury from cycling may be shifting onto older cyclists.[29] Determining whether older cyclists are more likely to be killed by a cycling injury due to their decreased physical resilience against a traumatic injury, their involvement in collisions at a greater rate due to sensory (e.g., hearing and/or visual) impairment or are involved in different types of collisions than other age groups will be important steps in identifying the course of action most likely to promote safe cycling among older adults.

Another important issue in the field of severe and fatal injury research is the lack of standardized reporting. This issue can be divided into two components: i) non-standardized reporting of concurrent variables, especially by age; and ii) unstable definitions of variables including age categories and crash mechanisms. In the systematic review examining age and its relationship to severe and fatal cycling injuries, it was surprising that even among single age-group (i.e., pediatric only or adult only) studies, not all included studies reported the proportion of cyclists sub-grouped by sex. Multiplicitous definitions of age categories make it difficult to accurately compare results across studies, especially given that many studies did not provide any reasoning for their age cut-offs. This issue is especially applicable to the “adolescent” age category, as patients 12-18 years old are often studied as “children”, although there is evidence that suggest adolescent injuries (ages 12-19) are more similar to adults than to children.[30] In the context of the descriptive study in this thesis, the age-groups were based on previously published reports of Canadian cycling fatalities for ease of comparisons.[9]

Finally, given the importance of mechanism of crash to the potential severity of an injury subsequent to a crash, discrete and standardized definitions for types cycling crashes need to be developed and used within the literature. Despite the importance of mechanism of a cycling crash to injury severity and prevention interventions and differences in mechanism among age groups,[8] the mechanism of crash was infrequently reported. Cycling crashes are often divided into motor-vehicle and cyclist only; however, there may be nuances within those two categories that could be specific targets for injury prevention interventions or strategies. For example, cyclists riding off a path onto a road and subsequently being struck by a motor vehicle may be reduced by installing bicycle-specific traffic signals, barriers and signage to signal to drivers to watch for cyclists where cycling routes intersect roads. Clarity and standardization within the literature will increase the quality of the available evidence and make it easier for public health practitioners and policy-makers to identify specific areas of concern and tailor prevention strategies to meet their specific needs.

5.5 IMPLICATIONS FOR POLICY

A variety of interventions are used around the world to reduce the occurrence of cycling injures. These interventions, which are often part of an overarching road-safety strategy, include education for all road users on how to safely interact with other road users of all types, both during motorist driver training and for children in schools, infrastructure designed to accommodate the needs and safety of vulnerable travelers, and promoting use of visibility equipment, and legislation to support road-user education, safer infrastructure, and use of protective equipment.[31] While cycling injury prevention strategies affect the safety of cycling, they also affect the public's perception of cycling as a viable alternative to traveling by motor vehicle.

North America has been built upon a motorist culture and the subsequent motorist-centric public perspective may foster a negative view of cyclists by motorists. Although only a minority of cyclists regularly flaunt the law, these few negatively influence motorist perceptions of cyclists which has been characterized as unlawful, careless, risk-takers.[32] This may cause significant resistance by motorists (who are the vast majority of road users in all North American markets) to strategies promoting the safety of cyclists and pedestrians, which could be perceived to be anti-motorist. Although the majority of severe and fatal cycling injuries are the result of cyclist-motor vehicle interactions, traditional cycling injury prevention interventions have relied on fear to change the behavior of cyclists, rather than teaching motorists to look out for the more vulnerable cyclists, or separating cyclists and road users. These fear tactics, however, imply that cycling is a dangerous activity and as a result have decreased pediatric cycling injuries by decreasing the number of pediatric cyclists, which is counter-productive to current health promotion approaches.[33] Organizations aiming to increase cycling and increase cycling safety should instead focus on encouraging motorists to watch for cyclists and on interventions that increase cyclist safety passively, such as by implementing changes in city design and infrastructure planning.

Ultimately, a shift needs to occur in urban design from focusing on the needs of motor vehicles to focus on the needs of people.[34] Creating a safer built-environment is possible and can be accomplished. For example, building cycling lanes and multi-use paths along routes that cyclists already use, creating residential dead-ends and other barriers for motor vehicles while allowing shortcuts for cyclists and pedestrians, implementing traffic calming measures in residential neighbourhoods, locating commercial spaces close to residential areas so they are accessible by walking and cycling, and installing pedestrian routes through large parking lots will help support a shift away from motorist-centric cities.

Additionally, cycling environment and/or culture may differ significantly among cities or regions in North America, and injury prevention strategies that are successful in one area may not be effective elsewhere. For example, while mandatory helmet legislation for cyclists under the age of 18 in Alberta increased helmet use among both adults and children,[35] similar legislation in California showed no effect on helmet use.[36] Alternatively, cyclists avoid cycling routes that are hilly;[32] in hilled regions efforts should be made to increase bicycle-accessible public transportation, such as ensuring bicycles are easily transportable by public transit or ensuring transit centers have adequate (in both amount and level of protection) bicycle parking facilities. Implementing strategies to improve the safety of cycling will help to increase cycling participation, but will require careful planning and marketing of the benefits of safer cycling to all road users, coupled with evidence to support the proposed strategy which should be tailored to the region.

Finally, it has also been suggested by legal experts that the current state of traffic laws in North America are suboptimal for increasing road safety of both cyclists and motorists and it has been proposed that governments review/revise their current laws to more accurately reflect the danger proposed both to and from cyclists and motorists. For example, allowing the “Idaho stop”, which allows cyclists to treat stop signs as a yield, and redefining right-of-way for areas where cyclists and motor vehicles are often at conflict, such as crossings between cycling infrastructure and motor vehicle traffic, should be encouraged.[37]

In addition to encouraging safe cycling habits among cyclists, for the safety of cycling in North America to truly increase, some of the responsibility for the safety of non-motorized road users (i.e., cyclists and pedestrians) needs to shift back onto motorists. Strategies to increase the safety and convenience of cycling should be marketed in a manner that highlights the benefits to all road users, such as the convenience of walking/cycling over short trips and the potential reduction of traffic congestion with greater participation in cycling. Implementation of cycling safety strategies also needs to be carried out with sufficient evidence to support their potential effectiveness and concordant evaluation programs to ensure limited resources are not squandered on interventions with limited effectiveness.

5.6 CONCLUSION

Many factors contribute to the occurrence of severe and fatal cycling injuries. Identifying these factors and how they relate to the severity of injury is important for the development of injury prevention strategies. Considering that the perceived lack of safety is consistently cited as one of the main reasons for not cycling, identifying the factors associated with cycling injuries in regional contexts will help decision-makers to implement appropriate interventions to increase the perceived and actual safety of cycling in order to promote it as a healthy and “green” mode of transportation.

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Appendix A

Full systematic search strategy used to search Medline database for Chapters 2 and 3.

1. exp Bicycling/
2. (bicycl* or cyclist* or bike* or biking or pedalcycl*).mp.
3. exp Bicycling/in [Injuries]
4. 1 or 2 or 3
5. (injur* or trauma or wound* or fatal* or mortality or death*).mp.
6. exp "Wounds and Injuries"/
7. 5 or 6
8. 4 and 7
9. ((bicycl* or cyclist* or bike* or biking or pedalcycl*) adj3 (trauma or wound* or fatal* or injur* or fracture* or lacerat* or mortality or death*)).ti,ab.
10. 8 or 9
11. exp canada/ or exp "united states"/ or "north america"/
12. ("north america*" or canad* or "british columbia" or alberta or saskatchewan or manitoba or ontario or quebec or "new brunswick" or "nova scotia" or "prince edward island" or newfoundland or labrador or yukon or nunavut or "northwest territories" or nwt or "united states").af.
13. 11 or 12
14. 10 and 13
15. exp africa/ or exp "caribbean region"/ or exp "central america"/ or exp "latin america"/ or exp "south america"/ or exp "antarctic regions"/ or exp "arctic regions"/ or exp asia/ or exp australia/ or exp europe/ or exp oceania/ or exp "oceans and seas"/ or mexico/
16. 10 and 15
17. 13 or 16
18. 10 not 17
19. 14 or 18

Appendix B

Inclusion/Exclusion Form for Cycling Fatality Scoping Review

CRITERIA for INCLUSION	Yes	No	Unclear
Publication Type			
a. Report of primary research (circle one: Journal Article or Abstract)	☐	☐	☐
Study Design			
a. Report provides any description of methods used	☐	☐	☐
b. Observational design (circle one: case-series, cross-sectional, cohort, case-control, other descriptive study)	☐	☐	☐
c. Includes information about cyclist injury that was obtained from medical charts, trauma registry, or coroner's report	☐	☐	☐
Study population includes:			
a. Study conducted in USA or Canada	☐	☐	☐
b. Cyclists with acute/traumatic injury	☐	☐	☐
c. Study includes <u>at least one</u> of the following: Cyclists with an Injury Severity Score (ISS) ≥12 OR Cyclists who were hospitalized OR Cyclists who died as a result of injury sustained while cycling	☐	☐	☐
<u>Answering "No" or "Unclear"</u> to any of the above <u>excludes</u> the study from this review.			

Article is not a primary report of research. (e.g. editorial, letters, opinion pieces, non-systematic literature reviews, etc.)	☐	☐	☐
Article or report does not provide any description of the methods.	☐	☐	☐
Study only uses anecdotal evidence (i.e. surveys) for injury data.	☐	☐	☐
Study conducted outside North America (circle one: USA or Canada)	☐	☐	☐
Study reporting only on cyclists with overuse injuries	☐	☐	☐
Study reports only on BMX or "trick" cyclists, mountain or other off-road cyclists or professional/elite/competitive cyclists (including "recreational" bicycle tours)	☐	☐	☐
Answering "Yes" or "Unclear" to any of the above <u>excludes</u> the study from this review.			
Please state the primary reason for Exclusion:			

Appendix C

Inclusion/Exclusion Form for Systematic Review of Severe and fatal bicycle injuries in North America

Reviewer: Date: dd / mm / yyyy Record ID:

CRITERIA for INCLUSION	Yes	No	Unclear
Publication Type			
b. Report of primary research (circle one: Journal Article or Abstract)	☐	☐	☐
Study Design			
d. Medical records used for injury data (i.e., hospital charts, ED enrolment, trauma database, etc.)	☐	☐	☐
Study population includes:			
d. Study conducted on North American population (USA or Canada)	☐	☐	☐
e. Cyclists with acute/traumatic injury	☐	☐	☐
f. One or more of the following (please circle): Cyclists with an Injury Severity Score ≥12 OR Cyclists requiring hospitalization	☐	☐	☐
AND (please circle) Cyclists Who died OR No cyclists who died but states that fatality records (Medical Examiner, Vital Statistics System, etc.) were searched	☐	☐	☐

CRITERIA for EXCLUSIONS			
Publication Type			
EXCLUDE: Articles that are not primary research reports: editorials, letters, opinion pieces, non-systematic literature reviews, etc.			
Study Design			
EXCLUDE: Studies using non-medical sources for injury data (e.g., police reports, patient surveys)			
Population			
EXCLUDE: g. Study conducted outside North America	☐	☐	☐
h. Cyclists with overuse injuries	☐	☐	☐
i. Only mountain, BMX, off-road or professional cyclists.	☐	☐	☐
j. Only cyclists involved in a mass cycling event (i.e., road cycling tour)	☐	☐	☐

Appendix D

Data Extraction Form For Cycling Fatality Scoping Review

Article ID:____________

Title: ____

First Author:____ Publication Year:________________

Country of first author:__________________________________

Methodology

Type of study: 1 Case-control 2 Cohort 3 Descriptive 4 Other:________________________

Study period: _____/___________ to ______/__________

Country where study was conducted: 1 Canada 2 USA 3 Both

Nation-wide □ or Specify province(s)/state(s):____

Author-defined definition of a severe injury:

If Authors did not define severity, which definition will be used:

1 ISS ≥ 12 **2 Admission to hospital** **3 Admission to ICU** **4 Death**

Age of included cyclists (Mean/Median and SD/IQR): ____

Injuries

Severity	**Adults**		**Children**	
	N	**%**	**N**	**%**

Injuries

Type of injury □ **Not reported**	**Children**		**Adults**	
	N severely injured	*%*	*N severely injured*	*%*
Fracture/Dislocation				
Abrasion/Laceration/Contusion				
Head injury/TBI				
Other				

Body part □ **Not reported**	**Children**		**Adults**	
	N severely injured	*%*	*severely injured*	*%*
Head/Neck				
Upper Extremity				
Lower Extremity				
Torso				

Mechanism (e.g. MVC, cyclist-only, etc.)	**Children**		**Adults**	
	N severely injured	*% of total*	*N severely injured*	*% of total*

Factor	**Children**		**Adults**		**N/A**
Cyclists	*N severely injured*	*% of total*	*N severely injured*	*% of total*	
Male					
Helmet use					
Alcohol use					
Drug use					
Use of visibility aids (e.g. reflective clothing or lights)					
Environment					
Poor lighting/darkness					
Poor weather					
Location					
Rural					
Urban					
Surface					
Road					
Sidewalk					
Other:					

Appendix E

Data Extraction Form For Systematic Review of Severe and fatal bicycle injuries in North America

Collector's Initials: ______________UID: _______________Author:________________________________

Year: _________________________

Publication Type(s) (Please list all):____

Region(s), Country:______________________________Study Period:________________________________

Population: Adults □ Children □ Mixed □

Study Design:____

Data Source(s):____

____

Mechanism Coding – please write the categories and subcategories of mechanism that were used

Term	Definition
Severe Injury	
Weekend	
Darkness	
"Poor" Weather	
Urban	

Cyclist Characteristics

	N	Age Range	No. Male	No. Severe injury	No. Fatal	Helmet use n/N	EtOH n/N
Children							
Adolescent							
Adult							
Elderly							
Total							

Injury Characteristics

	Head Injury N	Spine Inj. N	Thorax/ Torso n	Abdom n	Upper Extrem n	Lower Extrem n	Median or Mean ISS	Median or Mean AIS	Median or Mean GCS
Children									
Adolescent									
Adult									
Elderly									
Total									

Crash Characteristics

	# MVCC	# Urban	# Road	# Poor weather	# Night	# Weekend
Children						
Adolescent						
Adult						
Elderly						
Total						

Comments/Notes: