Outcomes and Processes of Care Among Trauma Centres Caring for Injured Children

By

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A thesis submitted in conformity with the requirements for the degree of Master’s of Science in Clinical Epidemiology

Institute of Health Policy, Management, and Evaluation

University of Toronto

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ABSTRACT

Introduction: We evaluated the association between mortality and trauma centre type to elucidate the optimal care environment for injured children. Secondly, we assessed whether centres that perform well in one domain of quality perform similarly in other domains.

Methods: Hierarchical regression was used to evaluate the association between centre type and in-hospital mortality. Kappa statistics were used to evaluate the consistency of centre-level performance across quality metrics.

Results: Children had higher odds of death when treated at adult (OR 1.57 (1.15-2.14)) or mixed (1.45 (1.05-2.01)) trauma centres versus pediatric trauma centres. Kappa statistics showed no significant agreement of centre performance across quality indicators (-0.01 (-0.07, 0.06)).

Conclusions: Efforts to determine what processes of care result in lower mortality among injured children treated at pediatric trauma centres are required. Furthermore, the inconsistency in centre-level performance across quality indicators should be considered as strategies for measuring hospital quality are developed.
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# TABLE OF CONTENTS

ABSTRACT .................................................................................................................. II

ACKNOWLEDGEMENTS .......................................................................................... IV

TABLE OF CONTENTS ........................................................................................... V

LIST OF FIGURES ..................................................................................................... VIII

LIST OF TABLES ...................................................................................................... XI

CHAPTER 1: Introduction to Pediatric Trauma ......................................................... 1

1.1 Definition of Injury ............................................................................................. 1

   1.1.1 Unique Considerations of Injuries in Children .......................................... 1

   1.1.2 Global Childhood Injury ........................................................................... 3

   1.1.3 Childhood Injury in the United States ...................................................... 7

1.2 Public Health Approach to Injury ....................................................................... 11

1.3 Organized Systems of Trauma Care ................................................................. 12

   1.3.1 History of Trauma Systems ...................................................................... 12

   1.3.2 Trauma Centres ....................................................................................... 14

   1.3.3 Impact of Trauma Systems ..................................................................... 17

   1.3.4 Pediatric Trauma Centres ....................................................................... 19

   1.3.5 Access to Pediatric Trauma Centres ....................................................... 21
1.3.6 Impact of Trauma Systems on Injured Children ................................. 23

1.3.7 Mortality Among Children Treated at Different Trauma Centre Types ...... 24

1.3.8 Processes of Care Among Children Treated at Different Trauma Centre Types
..................................................................................................................................................... 27

1.3.9 The Canadian Perspective .................................................................................. 31

1.4 Quality of Care and Benchmarking ........................................................................ 32

1.4.1 Quality Indicators ............................................................................................. 33

1.4.2 Quality Indicators of Pediatric Trauma Care .................................................... 34

1.5 Summary of Background and Gaps in Knowledge .............................................. 37

CHAPTER 2: Thesis Overview ....................................................................................... 39

2.1 Research Aims .................................................................................................... 39

2.2 Hypotheses ......................................................................................................... 39

2.3 Data Sources ...................................................................................................... 40

2.4 Patient Selection ................................................................................................. 41

2.5 Data Validity and Quality .................................................................................... 44

2.6 Ethics .................................................................................................................... 46

CHAPTER 3: Mortality Among Injured Children Treated At Different Trauma Centre
Types ............................................................................................................................. 47

3.1 Summary ............................................................................................................. 47

3.2 Introduction ......................................................................................................... 48
3.3 Methods ............................................................................................................ 50

  3.3.1 Hierarchical Data And Multi-Level Modeling ............................................. 54

3.4 Results ............................................................................................................. 57

3.5 Discussion ....................................................................................................... 65

CHAPTER 4: Concordance Of Performance Metrics Among U.S. Trauma Centres

Caring For Injured Children .................................................................................. 70

4.1 Summary ......................................................................................................... 70

4.2 Introduction ..................................................................................................... 71

4.3 Methods ......................................................................................................... 74

4.4 Results ............................................................................................................ 79

4.5 Discussion ..................................................................................................... 88

CHAPTER 5: Discussion And Conclusions ............................................................. 92

5.1 Summary of Findings ..................................................................................... 92

5.2 Limitations .................................................................................................... 93

5.3 Implications ................................................................................................... 96

5.4 Directions for Future Research ..................................................................... 98

REFERENCES ..................................................................................................... 102
LIST OF FIGURES

Figure 1.1: Main causes of death among children, World, 2014 ................................. 4

Figure 1.2: Leading causes of death in children, both sexes, World, 2004 ........................ 5

Figure 1.3: Rate of unintentional injuries per 100,000 children, by WHO region and country income level, World, 2004 ......................................................................................................................... 7

Figure 1.4: Reduction in death rates for persons 1-24 years of age, by cause and year, United States, 1910-2000 ......................................................................................................................... 8

Figure 1.5: The five leading causes and number of child deaths, by age group, United States, 2009 ................................................................................................................................. 9

Figure 1.6: Age-adjusted unintentional injury death rate per 100,000 population-all races, all ethnicities, both sexes, ages 0-19 years, United States, 2000-2006 ........................................... 10

Figure 1.7: Geographic representation of access within 60 minutes to a verified pediatric trauma centre (PTC) ......................................................................................................................... 22

Figure 3.1: Association between centre type and mortality ............................................. 61

Figure 3.2: Association between centre type and mortality (ISS ≥ 25) ......................... 63

Figure 4.1: Centre-specific adjusted odds of splenectomy vs. death .............................. 83

Figure 4.2: Centre-specific adjusted odds of ICP monitor placement vs. death ............. 84

Figure 4.3: Centre-specific adjusted odds of craniotomy vs. death .............................. 85

Figure 4.4: Heat map of hospital performance quartile by quality indicator ............... 87
LIST OF TABLES

Table 3.1: Patient characteristics ............................................................... 58

Table 3.2: Hospital characteristics ........................................................... 59

Table 3.3: Adjusted analyses with and without trauma centre volume ............... 60

Table 4.1: Patient characteristics ............................................................... 81
CHAPTER 1: Introduction to Pediatric Trauma

1.1 Definition of Injury

Injury is defined as bodily harm resulting from acute exposure to physical agents, such as mechanical energy, heat, electricity, chemicals, or radiation.¹ In some instances, injury results from a lack of vital physiological elements (drowning, strangulation, freezing). Injuries can be either non-intentional (e.g. motor-vehicle collisions, falls, drownings) or intentional (e.g. homicide, suicide).² Injury severity ranges from minor cuts and bruises to limb or life threatening.

Injuries are typically classified by severity, the setting in which it took place (e.g. home, school, road), activity during which it occurred (e.g. sport, work), mechanism (e.g. fall, motor-vehicle collision, burn, gunshot), intent (e.g. unintentional, intentional), and the nature of injury (e.g. fracture, bleeding). ² Injuries are also often subdivided into blunt (e.g. fall, motorcycle) and penetrating (gunshot, knife-wound).

1.1.1 Unique Considerations of Injuries in Children

The United Nations defines children as “every human being under the age of 18.” Although children are susceptible to the same injury mechanisms as adults, their size, growth, development, and behavioral characteristics make them particularly prone to injury. As children grow older they move through a variety of developmental stages, each of which carry different levels of cognitive ability, independence, and risky behavior. ¹² As a result, young children may not fully understand the level of risk associated with certain activities and may not appropriately respond to danger. Alternatively, teenagers have their own set of
unique behavioral characteristics that make them more likely to engage in high-risk behaviors and sustain more severe injuries.²

The majority of injuries in children are blunt in nature. Among these, traumatic brain injuries are the most common and usually the most severe injuries sustained. They account for the majority of injury-related mortality in children. With regards to intra-abdominal trauma, the spleen is the most commonly injured abdominal organ. When evaluating unintentional injuries that require hospitalization in children under the age of 15, limb fractures tend to be the most common type of injury.²

In order to understand a child’s unique response to injury, one must consider differences in the physical and physiological characteristics of children compared to an adult. For example, because of a child’s small body size, force from injury is distributed over a large surface area, often resulting in multi-system trauma.³ During road traffic situations, small stature increases risk of injury by making children less visible than adults if a vehicle hits them and by increasing their risk of head and neck injuries. Children also have a very large head size in relation to their body (large head-to-body ratio), which increases the risk of traumatic brain injury and cervical spine injuries during falls. Furthermore, the organs of a child are more susceptible to traumatic forces because of decreased protective muscle and surrounding fat. During resuscitation as well, special anatomical considerations, such as a child’s small trachea, must be taken into consideration during airway management and can lead to an increased aspiration risk.³ In addition, children have large body surface areas that make them particularly vulnerable to heat loss and hypothermia.³

As children progress through developmental stages, the patterns and types of injury they sustain vary. Infants (birth to 12 months), toddlers (1-3 years), and preschoolers (3-5 years) are at particular risk for falls. As a result of the aforementioned large head-to-body ratio,
children in these age groups have a high proportion of trauma brain injury.\textsuperscript{4} School aged children (6-12 years) often get injured as a result of motor vehicle-related trauma and as a result, sustain a large number of traumatic brain injuries as well as associated injuries to the chest, abdomen, and axial skeleton.\textsuperscript{4} Adolescents (13-18 years) are a unique subpopulation that engages in multiple high-risk behaviors such as alcohol, drugs, distracted driving, suicide, and homicide. Expectedly, their injuries tend to be more severe and life threatening. Adolescents represent a complex subpopulation of children that are transitioning from childhood to adulthood and care plans that combine the psychosocial needs of a child with the physical needs of an adult are often required. \textsuperscript{4}

These anatomical, psychological, and emotional characteristics of children give them unique injury profiles. Knowledge of these intricacies is crucial toward understanding childhood injury epidemiology and the specialized trauma care that is required for pediatric patients.

\section*{1.1.2 Global Childhood Injury}

Childhood injury is a growing public health concern and remains a major cause of death and disability in children worldwide (Figure 1.1). The United Nations Convention on the Rights of the Child states that all children across the world have the right to a safe environment and to protection from injury and violence. The convention has been adopted by nearly every country in the world and underscores the seriousness of childhood injury. However, despite the convention, meaningful political action toward implementing proven strategies that prevent injury and reduce severity are lacking in most parts of the world. \textsuperscript{2}
Injury is responsible for 950,000 deaths in children under the age of 18 worldwide per year.\(^2\) Approximately 90% of these injury-related deaths are due to unintentional injuries. Globally, injury is the leading cause of death for children aged 10-19.\(^2\) Roughly 60% of children with fatal injuries are injured as a result of road traffic injuries, burns, drowning, falls, or poisoning. After 1 year of age, road-traffic accidents contribute to most injury-related deaths in children. Road-traffic accidents alone are the leading cause of death in children aged 15-18 years and the second leading cause of death in children aged 5-14 (Figure 1.2).\(^2\)
In addition to death, children suffer equally important morbidity as well.\textsuperscript{2} Hospital admissions, emergency department visits, long-term disability, and days lost from school are other measures of the impact of disease states like injury. Experts often use the “child-injury” pyramid to describe the epidemiology of childhood injuries,\textsuperscript{2} in which death represents the smallest group at the top of the pyramid, hospitalized injury is in the middle, and non-hospitalized injury is the largest group at the base. According to UNICEF, for each injury-related childhood death, there are 12 children admitted to hospital or permanently disabled.
from injury, and another 34 children required medical care or missed school or work as a result of injury. ²

Globally, upward of 10 million children require hospitalization for non-fatal injuries every year. The leading cause of non-fatal childhood injuries is falls. Subsequent disability from these non-fatal injuries is a major concern. Both road traffic accidents and falls are in the top 15 causes of disability-adjusted life years (DALY) lost in children aged 0-14. The Global Childhood Unintentional Injury Surveillance ⁵ showed that almost 50% of children under the age of 12 who sustained an unintentional injury warranting presentation to the emergency department were left with some form of disability. In many children, ongoing mental or psychological problems are encountered, resulting in social withdrawal and inability to attend school. ⁵

The burden of childhood injury globally falls unequally on children in low and middle-income countries (Figure 1.3). ² The rate of injury-related death in children is 3.4 times higher in low and middle-income countries than in high-income countries. More than 95% of all childhood injuries occur in poorer countries. ² Furthermore, children of lower socioeconomic status, regardless of the income status of their country, carry the bulk of injury-related disease burden within each country. ² However, even in high-income countries injury is still responsible for over 40% of child deaths, making it a principle public health concern regardless of Gross Domestic Product. ²
1.1.3 Childhood Injury in the United States

Rates of unintentional injury-related deaths among children in the United States have declined in the last 90 years. However, the magnitude of reduction in injury-related childhood death is significantly less than reductions in death due to other preventable causes such as influenza and other infectious disease (Figure 1.4). As such, childhood injury continues to be a significant, yet underappreciated, public health concern in the U.S. 6
Unintentional injury remains the leading cause of mortality and morbidity among children in the United States. Approximately 12,000 children die every year as a result of injury.

Unintentional injury is responsible for 44% of all child deaths after infancy (Figure 1.5). Road-traffic accidents are the leading cause of fatal injuries and falls are the leading case of non-fatal injuries among children in the U.S.\textsuperscript{6,7} For children under the age of 1, however, suffocation is the leading cause of fatal injury and for children under 5 years of age, drowning is the major cause of fatal injury. Unintentional injuries were responsible for 42% of all Years Of Potential Life Lost (YPLL) among U.S children. The rate of YPLL as a result of injury is five times higher than the rate for cancer, 13 times higher than the rate for heart disease, and 31 times higher than the rate for respiratory illness.\textsuperscript{6,7}
In addition, non-fatal injuries result in a significant burden on the U.S healthcare system. Every year, roughly 9.2 million children are treated for injuries in emergency departments and 225,00 require hospitalization. Many of these children end up with permanent disability, depression, and chronic pain. The Child Safety Network used the “child injury-pyramid” to estimate that for every one child who dies from injury in the U.S., 45 children require hospitalization and another 1300 are seen emergency departments. 6,7

Specific populations of children are more vulnerable to injury than others. 7 Males are twice as likely as females to die from injury and males aged 15-19 have the highest rates of emergency department visits, hospitalizations, and deaths. Injury-related deaths are highest
among American Indians and Alaskan Natives and lowest in Asians and Pacific Islanders. Similar to global statistics, children who are of lower socioeconomic in the U.S. carry the bulk of the injury disease burden. Injury death rates also vary significantly from state to state, with the lowest death rates in the northeast states. In contrast, the highest number of traffic-related injuries occurs in southern states (Figure 1.6).  

Figure 1.6
Total societal and medical costs related to both fatal and non-fatal childhood injury amount to an astounding $87 billion USD annually. When the additional cost of reduced quality of life and decreased productivity on the part of injured children and their families is factored in, economic burden from injury surpasses $200 billion USD a year. 

1.2 Public Health Approach To Injury

In the past, injuries were considered as random “accidents” that were largely unpreventable. However, William Haddon changed this fundamental ideology by adapting the epidemiological approach used for communicable disease to injury. The epidemiological approach to disease helps to identify modifiable risk factors by evaluating the interaction between host, agent, and environment. In the case of communicable disease, a human host interacts with an infectious agent in an environment that promotes exposure. Haddon extended this approach to injury, whereby the host would be the person at risk, the agent would be the vehicle or product, and the environment would be the setting in which host and agent interact. The concept of environment was extended to include physical and socio-economic factors. By doing so, Haddon was able to build a framework to help understand causes and consequences of injury and identify injury prevention strategies. As a result, injury is no longer considered as an accident but rather a preventable and predicable disease state with modifiable risk factors.

In addition to this pioneering work, Haddon developed a matrix that evaluated host, agent, and environment with respect to three different injury time points: pre-event, event, and post-event. The application of this matrix to injury forms the framework for primary (pre-event), secondary (event), and tertiary (post-event) injury prevention efforts. Primary prevention refers to strategies aimed at stopping injury events before they even take place, in the pre-event phase (e.g. accident prevention education). Secondary prevention includes strategies
aimed at minimizing harm that occur during the injury, or in the event phase (e.g. seat belts).

Tertiary prevention refers to interventions aimed at treating people after an injury has occurred in the post-event phase (e.g. prompt medical treatment at trauma centre, rehabilitation).

Effective injury prevention strategies aimed at reducing mortality and morbidity utilize a combination of primary, secondary, and tertiary prevention strategies. Primary or secondary prevention of injuries, whenever possible, is ideal. However, this isn’t always feasible. When injuries do occur, appropriate tertiary prevention is critical. This includes timely and efficient transport of injured patients to hospitals, optimal injury care at the receiving hospital, and post-injury rehabilitation. These elements of tertiary prevention form the backbone of organized systems of trauma care in the United States.

**1.3 Organized Systems of Trauma Care**

Organized systems of trauma care, also known as trauma systems, encompasses all the components required to provide optimal care to injured patients. This includes pre-hospital care (e.g. EMS services, medical care en route to hospitals, communication between field responders and receiving hospital staff), hospital care (e.g. trauma care, resuscitation, operating room capabilities), rehabilitation, and dedicated trauma research. Trauma systems were developed to organize the way in which injured patients are cared for and to optimize their treatment by ensuring timely and efficient care.4

**1.3.1 History of Trauma Systems**

Throughout the 20th century military trauma systems aimed at providing better injury care to soldiers began to evolve.9 Rapid transport of injured soldiers to hospitals, field triage based on injury severity, the use of paramedic personnel, and specialized injury treatment centres
became integral parts of military injury care during the Vietnam War. As a result, mortality was reduced from 4.5% in World War II to 1.9% in the Vietnam War. The effectiveness of these early military trauma systems led to the implementation of similar trauma systems in civilian populations, with particular emphasis on identifying severely injured patients who require immediate care, reducing transport times, and transfer to hospitals that specialize in trauma care when possible.

The concept of using trauma systems for civilians in the U.S. was pushed forward in part by a report published by the National Academy of Sciences of the National Research Council in 1996 titled “Accidental Death and Disability: The Neglected Disease of Modern Society.” In the landmark report, Howard et al. drew on experiences from the Korea war to make recommendations to improve trauma care in the United States. The report emphasized that injury-related deaths were preventable while also evaluating the current state of injury care in the U.S. By highlighting deficiencies in U.S. trauma care, Howard et al. made a convincing argument for the implementation of protocols pertaining to ambulance design, pre-hospital care, better integration of first responders and hospitals, and the development of specialized trauma centres.

In 1976, the American College of Surgeons (ACS) created the Committee on Trauma (COT) to lead the development and organization of trauma systems in the United States. In the same year, the ACS-COT published a pivotal report titled “Resources for the Optimal Care of the Injured Patient,” which provided guidelines and criteria for the organization of state and regional trauma systems. Most notably, the ACS initiated an external review process aimed at producing “centres of excellence” in injury care, which are now widely referred to as trauma centres. The ACS developed a three-tier verification system whereby hospitals could attain a particular “trauma centre” status depending on the extent of injury care-related resources
available. The three levels of trauma centre verification will be discussed in chapter 1.3.2. By the 1990’s, the ACS-COT had fully developed the verification program. In addition, a number of states had developed their own trauma centre criteria, which were used to designate certain hospitals as state trauma centres.\textsuperscript{12}

The effectiveness of initial trauma systems was proven by a number of studies demonstrating that a large number of “excess” deaths could have been prevented if optimal trauma systems had been in place.\textsuperscript{12} As a result of these studies, trauma systems throughout the U.S. were rapidly implemented.\textsuperscript{12} In 1988, for example, only 2 states had regional trauma systems in place and 29 states had no system. Whereas in 1999, 43 states had local, regional, or state trauma systems in place, 23 states had statewide coverage, and 5 states met all ACS criteria.\textsuperscript{12} Over the last decade, this drastic increase in the adoption of trauma systems has continued and has resulted in all states, apart from Arkansas, having access to a trauma centre.\textsuperscript{13} In 2002, there were 1154 trauma centres in the U.S, including 190 level 1 trauma centres and 263 level 2 trauma centres.\textsuperscript{14} Despite this, trauma systems still have a long way to go before all patients have adequate and timely access to trauma centres.\textsuperscript{15} Another study in 2005 estimated that roughly 700 regional trauma centres in the U.S serve 281,423,231 people over 3,794,083 square miles.\textsuperscript{13,15}

Although trauma systems encompass elements of pre-hospital care, hospital care, and post-hospital care, trauma centres are undoubtedly the foundation of organized trauma systems. Without specialized trauma centres, which effectively coordinate all aspects of a trauma system, optimal injury care would be nearly impossible to provide.

\textbf{1.3.2. Trauma Centres}
The cornerstone of any trauma system is a specialized trauma centre. These large hospitals act as lead points for statewide trauma systems and have the resources and staffing required to optimally care for injured patients. Hospitals in the United States can be designated and/or verified as trauma centres. Designation is a state-level government responsibility whereby hospitals are designated as state trauma centres. Verification, however, is a voluntary process under the guise of the American College of Surgeons and involves externally evaluating the level of resources that are available at hospitals caring for injured patients.

In order to become verified as a trauma centre, hospitals must meet certain criteria as outlined by the ACS-COT “Resources for the Optimal Care of the Injured Patient.” The three-level verification system mentioned earlier allows hospitals to be verified at different levels of “excellence” depending on available resources. As an overview, level 1 and 2 trauma centres provide definitive care for injured patients without having to transfer the patient elsewhere, whereas level 3 and 4 centres typically provide initial injury care and resuscitation until patients are stable enough for transfer. Level 3 and 4 centres are usually found in rural environments where initial transport to higher-level centres is not feasible.

Level 1 trauma centres provide the highest level of injury care. They are often located in large densely populated cities and in very large cities, more than one level 1 centre may be available. These centres act as lead hospitals for regional trauma systems and work alongside other level 1 centres to form the backbone of statewide trauma systems. In order to be verified as a level 1 trauma centre, hospitals must admit at least 1,200 injured patients per year or have 240 admissions with a Injury Severity Score (ISS) greater than 15. Level 1 centres are required to have 24-hour in-house availability of staff trauma surgeons. This ensures that surgeons are involved in the care of all seriously injured patients, present in the emergency department during major resuscitations, and present for all operative procedures.
Surgeons must also be present within 15 minutes of arrival of injured patients. For patients in stable condition, an emergency physician can initiate management according to trauma team protocols. Level 1 trauma centres are also required to have timely access to neurosurgeons, orthopedic surgeons, anesthesia, and life support equipment. A number of other resources, such as intensive care units led by trained intensivists, are commonly found in level 1 centres and provide a mortality benefit.

Some features that distinguish level 1 from level 2 trauma centres are their requirements to have a certain patient volume, maintain a critical care service directed by surgeons, participate in the training of residents, be a leader in education, and conduct trauma research.

Level 2 centres, however, are otherwise quite similar to level 1 trauma centres. They have the same requirements with respect to 24-hour in-house availability of surgeons. Level 2 centres can operate in two distinct environments. Firstly, these centres may be located in densely populated large cities, in which case level 2 centres often supplement clinical care provided at level 1 centres. In these instances, both the level 1 and 2 trauma centres work together to extend optimal injury care to patients in their region. Secondly, a level 2 trauma centre may be located in a less populated area without a nearby level 1 centre. In these cases, the level 2 centre must act as the lead hospital for that regional trauma system, providing support to smaller surrounding institutions.

Both level 3 and 4 trauma centres provide lower tiers of trauma care. Level 3 centres must be able to provide initial injury care to the majority of severely injured patients. As such, continuous coverage by a general surgeon is required. The maximum acceptable response time for a surgeon is 30 minutes. Since level 3 centres will frequently treat patients requiring transfer to higher level centres, well-defined inter-hospital transfer guidelines are required. Trauma surgeons are required to be involved in the evaluation of patients regardless of
whether a transfer decision is already made. Level 4 centres are usually located in rural settings and often supplement care within a larger trauma system. These centres are capable of initially evaluating and assessing injured patients, but most patients require transfer. Although continuous surgical coverage is not required, 24-hour coverage by a physician or mid-level provider is necessary. Level 4 centres allow for expansion of trauma systems to sparsely populated and often underserved communities.4

1.3.3 Impact of Trauma Systems

Trauma systems have resulted in a significant reduction in mortality and morbidity among injured patients in the United States.12 In 1998, a symposium was held in Washington State to review the literature on trauma system effectiveness. The review found that the implementation of trauma systems had resulted in a 15 to 20% reduction in trauma-related mortality.19 A more recent meta-analysis also determined that the presence of trauma systems reduced mortality by 15%.20

A number of studies in particular are worth discussing. Nathens et al. performed a nationwide study in 1995 comparing mortality among states with and without trauma systems.21 At the time, 22 states had trauma centres. After adjusting for population density, speed limit laws, income status, and average number of miles driven, states with trauma systems had a 9% reduction in mortality. An even greater mortality reduction of 17% was observed when evaluating children aged one to 14 years old. Prior to this study, the majority of research on trauma system effectiveness had been at the county or city level and had demonstrated little to no benefit.21

Nathens and colleagues went on to perform a multi-year study from 1979 to 1995 22 evaluating the effect of trauma systems on motor vehicle crash mortality across all states in
the United States. Time series analysis was used to compare death rates before and after the implementation of trauma systems. During the study time period, states that had implemented a trauma system had an 8% reduction in mortality. Among the 22 states with trauma systems, 18 had statistically significant reductions in mortality after adopting an organized trauma system. Interestingly, mortality reductions only became evident 10 years after trauma system implementation, likely a reflection of the time required to develop and establish trauma centre protocols, triage guidelines, and transfer policies.22

To assess the effect of trauma systems on other processes of care, in addition to mortality, Sampalis et al. evaluated 12,208 injured patients in the Quebec Trauma Registry over the 6-year four-phase implementation of a regional trauma system.23 Authors found a decrease in mortality, pre-hospital time, and time to operative intervention, and increased triage of severely injured patients to designated trauma centres with every stage of trauma system implementation.23 Sampalis and colleagues conducted another study in 2005 to determine what components of trauma systems were associated with mortality.24 They found that pre-hospital notification, the presence of a performance improvement program in that hospital, increased patient volume, and care at a tertiary trauma centre conferred a survival benefit.24

Given the pivotal role of trauma centres within trauma systems, a number of studies have focused on the impact of trauma centres themselves. Early evidence of the benefit of trauma centre care came from preventable death studies. In a landmark study by West et al., the “excess” death rate among patients injured in motor-vehicle collisions was compared between two counties in California.25 In one county, patients were transported to the nearest 39 hospitals, whereas in the other county, all injured patients were sent to one centrally located trauma centre. The study found that the preventable death rate was 43% in the county
without a designated trauma centre compared to only 1% in the country with a trauma centre.\textsuperscript{25}

Multiple large cohort and population-based studies have further demonstrated the survival benefit of trauma centre care.\textsuperscript{21,26,27} One of the most notable is the National Study of the Costs and Outcomes of Trauma by Mackenzie et al., which compared mortality among severely injured adults treated at trauma centres versus non-trauma centres with similar resources.\textsuperscript{26} After propensity-score adjustment, in-hospital mortality was significant lower among injured patients treated at trauma centres versus non-trauma centres. Furthermore, Mackenzie and colleagues also demonstrated that long-term functional outcomes (one-year post injury) in patients with lower extremity injuries were better among those treated at trauma centres versus non-trauma centres.\textsuperscript{28,29} It is important to note that both studies by Mackenzie et al. only evaluated level 1 trauma centres. However, other studies have demonstrated a clear survival benefit for patients treated at lower level trauma centres compared to non-trauma centres.\textsuperscript{20} When comparing level 1 and 2 trauma centres, some studies have demonstrated a superior survival benefit for patients treated at level 1 centres,\textsuperscript{30-32} while others have shown no difference in survival between the two centre types.\textsuperscript{33}

Organized systems of trauma care undoubtedly have a major impact on injury-related mortality and morbidity. However, even higher-level care is required for children because of their unique injury characteristics. Pediatric-specific expertise and resources are often lacking at adult trauma centres, and as a result, specialized pediatric trauma centres are needed to provide optimal pediatric injury care.

**1.3.4 Pediatric Trauma Centres**
In the U.S., 25% of traumatic injuries occur in children. However, there has been a documented lack of specialized pediatric personnel, expertise, and equipment at adult trauma centres.\textsuperscript{34,35} According to the ACS, care for injured children “may be optimally provided in the environment of a children’s hospital with demonstrated commitment to trauma care.”\textsuperscript{4} As a result, pediatric trauma centres became a necessity after the development and establishment of adult trauma systems. The first pediatric trauma centres evolved in the 1970s in Boston, Baltimore, Ann Arbor, and Washington DC.\textsuperscript{12}

In 2006, the ACS-COT began verifying pediatric trauma centres using an external review process akin to the verification of adult trauma centres. Hospitals can be verified as either level 1 or 2 pediatric trauma centres depending on the availability of pediatric-specific resources. At the state-level, hospitals can be designated as pediatric trauma centres as well.\textsuperscript{12}

Hospitals seeking ACS verification as pediatric trauma centres must meet the same verification criteria as adult trauma centres, in addition to a set of pediatric criteria. Level 1 pediatric trauma centres must admit at least 200 injured children under the age of 15 every year, whereas level 2 pediatric trauma centres are required to admit 100 injured children yearly. Both level 1 and 2 pediatric trauma centres must have a pediatric trauma program manager and participate in pediatric trauma research at an equivalent level to their adult counterparts.

Level 1 pediatric trauma centres must have at least two surgeons who are board certified in pediatric surgery. These centres must also have pediatric specialists in orthopedics, neurosurgery, emergency medicine, and critical care medicine along with a pediatric intensive care unit. Level 2 pediatric trauma centres require only one board certified pediatric surgeon, but have many of the same requirements when it comes to other pediatric specialists. Both levels of pediatric trauma centres require an established pediatric trauma service with
surgeon presence in the pediatric emergency department for all injured children who require major resuscitation.\(^4\)

Adult trauma centres can also obtain added pediatric qualifications. ACS verified adult trauma centres that admit more than 100 children per year are required to fulfill additional pediatric criteria, including the availability of specialized pediatric personnel and equipment, and the presence of a pediatric emergency department and intensive care unit. However, hospitals wishing to provide optimal injury care to both adults and children can be dually verified. A trauma centre can be verified as a level 1 adult trauma centre and a level 2 pediatric trauma centre, or vice versa, if they meet the verification criteria required for both types. These centres are often referred to as adult trauma centres with added pediatric qualifications, or mixed trauma centres.\(^4\)

Accreditation standards ensure that pediatric trauma centres offer high-level trauma care to injured children. However, access to pediatric trauma centres is variable across the U.S.

### 1.3.5 Access to Pediatric Trauma Centres

According to estimates, 34 designated level 1 pediatric trauma centres existed in 1997.\(^{12}\) This number has grown to over 170 ACS verified or state designated pediatric trauma centres across 41 states in 2009.\(^{36}\) However, the distribution of ACS verified pediatric trauma centres is quite heterogeneous. A recent study showed that 36% of states have a verified pediatric trauma centre and 24% of states have a verified level 1 pediatric trauma centre.\(^{37}\) The same study showed that 32 states were without verified pediatric trauma centres, but 22 of these states did have verified adult trauma centres.\(^{37}\)

As a result of the geographical scarcity of pediatric trauma centres, access to specialized pediatric injury care is limited for most children in the U.S.\(^{36}\) Nance et al. evaluated the
percentage of children who had access (within 60 minutes by ground or air) to pediatric trauma centres in the U.S. They found that an estimated 17.4 million children did not have access to a pediatric trauma centre. Access to pediatric trauma centres ranged from 22.9% in rural areas to 93.5% in urban areas (Figure 1.6).

Figure 1.6

Limited access results in the majority of children being treated by adult specialists at adult trauma centres or non-trauma centres. In fact, only 10% of children receive care at pediatric trauma centres. Segui-Gomez et al. showed that 43% of children get treated at non-trauma centres and only 13% get treated at pediatric trauma centres. These findings were corroborated by another study, which showed that 89% of children get treated outside of children’s hospitals.
These findings highlight the need for improved access to specialized pediatric trauma care. Despite this, access to trauma systems as a whole, whether adult or pediatric, have demonstrated a considerable impact on reducing injury-related mortality in children.

1.3.6 Impact of Trauma Systems on Injured Children

The advent of trauma systems in the U.S has had a significant impact on outcomes among injured children. One of the earliest studies by Hulka et al. compared mortality rates among injured children treated in Oregon, where a trauma system had been implemented, to children treated in Washington State, where no such system existed. Severely injured children (Injury Severity Score >15) treated in Oregon had a significantly lower risk-adjusted odds of death.\textsuperscript{41} Authors concluded that the trauma system was responsible for this mortality reduction.\textsuperscript{41} Further evidence of the impact of trauma systems on injured children was evidenced in the study by Nathens et al., which showed that the mortality reduction associated with state trauma system implementation was most profound in children aged 1-14 years.\textsuperscript{21}

Ample evidence supports the notion that treating injured children at trauma centres, regardless of whether or not they have pediatric expertise, is advantageous compared to treatment at non-trauma centres.\textsuperscript{42-45} Osler et al. performed a study using the National Pediatric Trauma Registry and demonstrated improved survival (OR 0.75 (0.58-0.97)) among children treated at trauma centres versus non-trauma centres.\textsuperscript{42} More recently, Wang et al. compared mortality rates among injured children treated at trauma versus non-trauma centres in California from 1991 to 2001. Adjusted analysis demonstrated a significantly lower mortality when children were treated at a trauma centres.\textsuperscript{43}

In addition, care in pediatric trauma centres has been associated with lower mortality in injured children. Notrica et al. recently conducted a large population-based study that
evaluated pediatric injury mortality rates across the U.S.\textsuperscript{37} They found that the presence of a verified pediatric trauma centre in a given state correlated with lower pediatric injury-related mortality. Furthermore, pediatric injury mortality was 37% lower in states that had level 1 pediatric trauma centres and was inversely correlated with the number of level 1 pediatric trauma centres per state, suggesting that pediatric trauma centres provided injured children with a significant survival benefit.\textsuperscript{37}

There is little doubt that trauma systems, regardless of whether they have pediatric expertise, have significantly improved outcomes for injured children. There is also evidence to suggest that pediatric trauma centres are associated with lower rates of pediatric injury-related mortality. However, given that many injured children receive care at adult or mixed trauma centres, determining whether or not pediatric trauma centres confer a survival benefit over these other centre types is an area of great interest.

1.3.7 Mortality Among Children Treated at Different Trauma Centre Types

It is controversial as to whether or not injured children treated at pediatric trauma centres have improved outcomes compared to those treated at adult or mixed trauma centres. Mortality, though a crude outcome measure, has been the focus of a number of studies attempting to compare different trauma centre types.\textsuperscript{46,47}

One of the earliest studies was a large retrospective analysis of 13,351 injured children in the Pennsylvania Trauma Outcome Study from 1993 to 1997.\textsuperscript{48} Potoka et al. compared mortality among children treated at pediatric, mixed, and adult trauma centres. Analyses were stratified by mechanism of injury, injury severity, specific organ injury, and type of trauma centre. Authors found that severely injured children (ISS\textgreater15) had significantly better survival rates when treated at pediatric (11.9%) or mixed (12.4%) trauma centres compared to level 1
(21.6%) or 2 (16.2%) adult trauma centres. Survival among children with head, spleen and liver injuries was significantly better at pediatric trauma centres compared to adult or mixed trauma centres. Authors concluded that severely injured children with head, liver, or spleen injuries benefited the most from treatment at pediatric trauma centres. This study has, however, been widely criticized for a lack of appropriate injury severity and case mix adjustment.

Subsequent studies have also evaluated data from the Pennsylvania Trauma Outcome Study, but have used different methodologies and have reached conflicting conclusions. Sherman et al. measured the “unexpectedness of survival” or “excess death rate” among injured children treated at adult and pediatric trauma centres, rather than mortality. Authors used TRISS methodology to compare the predicted probability of survival for a given injury to the actual survival rate in their study cohort. Survival probabilities used in TRISS are derived from the Major Trauma Outcome Study (MTOS) database that was generated in the 1980s based on injury data from adults. Sherman and colleagues found that the unexpected survival rate among injured children was in fact higher at adult or mixed trauma centres compared to pediatric trauma centres. Authors concluded that severely injured children had an improved chance of survival when treated at adult trauma centres. Another study similarly evaluated children in the same dataset using TRISS methods, however, they found no significant difference in mortality among children treated at pediatric versus adult trauma centres.

The majority of studies that suggest adult trauma centres have equal or better outcomes than pediatric trauma centres use TRISS methodology. Authors of these studies argue that the unexpected survival rate derived using TRISS is a better outcome measure than mortality, since injury-related death is rare in pediatrics and severely injured children tend to be unequally distributed across different trauma centre types. However, TRISS has been
widely criticized for its lack or validity in the pediatric population.\textsuperscript{14,46,47} Critics argue that the probabilities of survival generated from MTOS are outdated and heavily skewed toward the adult population, resulting in an overestimation of mortality risk when using TRISS.\textsuperscript{12} Furthermore, studies show that injured children treated at pediatric trauma centres have better outcomes than predicted by TRISS.\textsuperscript{12} Concerns with TRISS have limited the use of this approach.

A number of other studies have attempted to evaluate differences in mortality among children treated at different centre types. Of particular importance is the study by Osler et al., in which 53,100 injured children in the National Pediatric Trauma Registry were evaluated.\textsuperscript{42} A total of 22 pediatric and 31 adult trauma centres were represented in the study. The crude mortality rate among injured children was lower at pediatric trauma centres (1.8\%) versus adult trauma centres (3.9\%). However, after adjusting for Injury Severity Score, Pediatric Trauma Score, injury mechanism, gender, age, and ACS verification status, there was no difference in mortality rate between adult and pediatric trauma centres (OR 1.02 (0.83-1.26)).\textsuperscript{42} Densmore et al. compared mortality among 79,673 children treated at adult versus pediatric trauma centres using the 2000 Kids’ Inpatient Database. After adjusting for injury severity, they found a significantly higher mortality and length of stay among children treated at adult and mixed trauma centres compared to pediatric trauma centres.\textsuperscript{40}

More recent studies also demonstrate conflicting findings. Pracht et al. reviewed hospital discharge records from 1995 to 2004 in Florida to compare mortality among injured children treated at pediatric versus adult trauma centres versus non-trauma centres and at pediatric versus adult trauma centres.\textsuperscript{44} Authors used an instrumental variable analysis and adjusted for injury severity using the International Classification Injury Severity Score (ICISS), which uses the product of ICD-9 derived survival risk ratios. They found that treatment at
pediatric hospitals was associated with a 4.84% reduction in mortality when compared to adult trauma centres. A similar study from California also used instrumental variable analysis, but found no survival benefit for children treated at pediatric versus adult trauma centres.

There also appears to be a gradient effect across trauma centre types, with mixed trauma centres offering an intermediate survival benefit between that of pediatric and adult trauma centres. Some studies have shown that injured children treated at mixed trauma centres have higher survival than those treated at adult trauma centres, suggesting that added pediatric qualifications make a difference, whereas others show no difference between mixed and adult trauma centres. However, studies have consistently shown that mixed trauma centres do not offer the same survival benefit as pediatric trauma centres.

Many of the aforementioned studies suffer from shortcomings in injury severity risk adjustment, sample size at the patient or centre level, and a failure to compare adult, mixed, and pediatric trauma centres in the same analysis. Furthermore, most of these studies use regional or local, making generalizability an issue. As a result, the current body of evidence makes it difficult to ascertain which care environment offers a survival benefit to injured children. However, in addition to mortality, processes of care related to other elements of pediatric trauma have also been compared across different trauma centre types.

### 1.3.8 Processes of Care Among Children Treated at Different Trauma Centre Types

There is considerable variability in processes of care among pediatric, mixed, and adult trauma centres. The management of intra-abdominal injury in children, namely blunt splenic
injury (BSI), has been the focus of many studies comparing practice patterns in adult and pediatric trauma centres. Among children, the spleen is the most commonly injured intra-abdominal organ and thus, represents a large proportion of intra-abdominal injuries. With the first reports of successful non-operative treatment of pediatric blunt splenic injury in the 1960s, management shifted from being primarily operative to non-operative. In instances where operative treatment is required, such as hemodynamic instability or rapidly falling hemoglobin, splenorrhaphy with splenic preservation is preferred. Splenic preservation in children has been shown to be safe and superior with regards to faster recovery, shorter hospital length of stay, no wound infections, and decreased chance of overwhelming post-splenectomy sepsis. The current success rate for non-operative management of pediatric blunt splenic injury without blood transfusion is greater than 90%. In adults, however, splenectomy is associated with favorable outcomes and splenic preservation is not as critical. As a result, the threshold for operative intervention in adults with splenic injury is much lower.

There is significant variability in splenectomy rates depending on whether injured children are treated at adult or pediatric trauma centres. Potoka et al. showed that children had a significantly higher rate of non-operative treatment for spleen (91% vs 61.1%) and liver injury (96.6% vs. 84.1%) when treated at pediatric versus adult trauma centres, despite similar injury severity. Mooney et al. evaluated 126 children with splenic injury using the New Hampshire Uniform Hospital Discharge Sets and found that adjusted operative rates were 41% at adult hospitals compared to only 10% at children’s hospitals. Authors stated that most splenectomy cases were avoidable if adult hospitals adopted similar non-operative strategies as children’s hospitals. In a subsequent study, Mooney et al. found that children
treated by non-pediatric surgeons had an increased odds of laparotomy (OR 3.1 (2.3-4.4)) versus those treated by pediatric surgeons.\textsuperscript{57}

Of particular importance is a study by the American Pediatric Surgical Association (APSA) Centre on Outcomes, which compared splenectomy rates among children with splenic injury treated at different hospitals types.\textsuperscript{58} They found an increased odds of laparotomy for children treated at non-trauma hospitals (OR 2.1 (1.4-3.1)) versus trauma hospitals. Despite this, splenectomy rates at both trauma and non-trauma centres exceeded APSA national benchmarks for children with splenic injury, suggesting that further dissemination of pediatric guidelines was necessary to reduce operative rates in these centres to a level consistent with children’s hospitals.\textsuperscript{58}

Recent data suggests that increasing education about pediatric splenic injury management among adult specialists has led to a decline in operative rates at adult trauma centres. Davis et al. used discharge data to evaluate splenectomy rates in children with splenic injury treated during a 9-year period.\textsuperscript{59} They found a progressively declining frequency of operative intervention across all trauma centre types, without an increase in mortality. Authors suggested that a resurgence of literature on the efficacy of non-operative splenic injury management might have served to educate adult surgeons and result in this decline.\textsuperscript{59} Similarly, children in Washington who were hospitalized with splenic injury were evaluated before and after the implementation of a statewide quality improvement program aimed at educating trauma surgeons about pediatric splenic injury management.\textsuperscript{60} Children with splenic injury who were treated at adult trauma centres had a decreased odds of splenectomy after the implementation of the quality improvement program.\textsuperscript{60}
Many of the outcomes disparities at pediatric versus adult trauma centres may be due, in part, to differing management of traumatic brain injury in children.\textsuperscript{47,61} Traumatic brain injury is the most common severe injury sustained by children. In the U.S. traumatic brain injury is the leading cause of death and disability among children. From 2002 to 2006, over 700,000 U.S. children sustained traumatic brain injuries. The majority of these injuries are mild (Glasgow Coma Scale (GCS) score 13-15), however, almost a quarter are moderate to severe and carry a high-risk of mortality and morbidity among children.\textsuperscript{47} Studies have demonstrated a survival benefit among children with traumatic brain injury who are treated at pediatric trauma centres.\textsuperscript{47} Potoka et al. showed that children with severe traumatic brain injury (GCS<8) had lower mortality when treated at pediatric (21.1%) or mixed (20.5%) trauma centres versus level 1 (31.3%) or level 2 (27.5%) adult trauma centres.\textsuperscript{48} Authors also found an increased likelihood of neurosurgical interventions, such as craniotomy, among children treated at pediatric trauma centres. Furthermore, the mortality rate among children with traumatic brain injury who required operative intervention was lower at pediatric and mixed trauma centres. These findings are consistent with reports suggesting that aggressive use of craniotomy results in surprisingly good outcomes in children. A number of other studies have also demonstrated improved survival and higher surgical intervention rates among brain-injured children treated at pediatric trauma centres.\textsuperscript{47}

Considerable variability in hospital care and outcomes exist between pediatric, mixed, and adult trauma centres. Further dissemination of practice guidelines is required to reduce heterogeneity in care. In addition, reliable measures of quality of care and benchmarks must be incorporated into quality improvement programs to help identify areas of weakness across hospitals and offer targeted support where needed.
1.3.9 The Canadian Perspective

The bulk of this thesis will focus on U.S. trauma care given the nature of our analyses. However, we wanted to briefly highlight important similarities between U.S. and Canadian trauma systems. First and foremost, the burden of childhood injury is very similar between the two countries. In Canada, injury is also the leading cause of death for children. Roughly 390 Canadian children age 14 and under die from unintentional injury and another 25,500 are hospitalized yearly. In 2004, unintentional childhood injury resulted in nearly $3 billion CDN in health care costs and lost productivity. Similar to the U.S., the leading cause of injury-related deaths among Canadian children is motor-vehicle collision and falls are the leading cause of hospitalization.

As we previously described, trauma systems in North America first evolved in the U.S. However, Canada has adopted similar trauma system organization and works through many of the same mechanisms. As of 2010, 32 level I and II trauma centres existed in Canada. Furthermore, the majority of Canadians (77.5%) live within 1 hour of these specialized trauma centres. With respect to pediatric injury care, 5 accredited pediatric trauma centres currently exist in Canada. High quality analyses evaluating access to specialized pediatric injury care in Canada have not yet been done.

Trauma system organization in Canada is overseen by Accreditation Canada and the Trauma Association of Canada that designate and verify trauma centres based on the criteria outlined by the American College of Surgeons Committee on Trauma. Hence, the structure of trauma systems in Canada does not differ significantly from the U.S.


1.4 Quality of Care and Hospital Benchmarking

As evidenced earlier in this chapter, there is considerable variation in patterns of care and outcomes across different trauma centre types, despite the presence of best practice guidelines. As a result, there is an increasing push to measure the quality of care provided at hospitals to ensure that optimal care is consistently provided. The concept of hospital quality assurance was first introduced by Ernest Amory Codman, an American surgeon, who promoted the idea that every hospital should be responsible for following their own patients, deciding if treatment was effective, and determining what caused any errors that occurred.

With the growing use of evidence-based practice in surgery, significant variation in patterns of care across hospitals raises concerns about efficacy and cost. In order to reduce variation, benchmarking, which involves comparing a hospital’s performance to the performance of a hospital that exemplifies best practices, has become an increasing priority. The process of inter-hospital comparison allows for benchmarks to be inferred using real-world clinical data. The goals of benchmarking are to identify areas of weakness among hospitals, allow for targeted quality improvement initiatives, and improve overall care for patients. A number of national and state-level quality improvement programs have been developed in the United States. These programs provide hospitals with risk-adjusted data pertaining to their performance, which allows hospitals to compare their performance with each other. As a consequence, high and low performing centres can be identified and targeted quality improvement initiatives can be implemented. However, in order for these programs to function, appropriate measures of hospital “quality,” also known as quality indicators, must first be developed. These indicators must be reliable markers of quality in order to truly identify areas for improvement among hospitals.
1.4.1 Quality Indicators

“Before assessment can begin we must decide how quality is to be defined,” said Avedis Donabedian in 1988. Donabedian’s work was pivotal in defining how quality indicators could be used to measure quality of care. Quality indicators provide a quantitative metric by which clinicians and organizations can measure quality and improve care where required. Indicators make it possible to quantify quality of care, make comparisons between hospitals (benchmarking), set priorities, and support accountability, accreditation, and quality improvement. Indicators are based on standards of care, which are either derived from evidence based sources or expert consensus. However, quality is a multidimensional entity and a variety of different indicators are required to measure overall quality of care.

Donabedian pushed forth the concept that indicators could be related to three categories of healthcare: structure, process, or outcome. Structure refers to qualities of the setting in which care is given, or in other words, infrastructure. These include hospital facilities, equipment, personnel, medical staff, and the organizational structure of the hospital itself. Process refers to the components involved in providing patient care, such as diagnostic and treatment activities. Outcome measures describe the effect of care on the health status of patients. Common outcome measures are mortality, morbidity, and quality of life. Indicators related to process are only valid if they have been shown to produce a better outcome. Similarly, structure indicators must have demonstrated an association with a good outcome or with a process that is associated with better outcomes.

Process indicators are particularly useful when trying to determine why certain providers achieve particular outcomes and when evaluating performance of low volume providers.
Outcome measures are more useful when assessing the performance of whole systems, if a high volume of cases is available, and for detecting problems with the application of processes of care. In most cases, indicators are chosen based on the needs of the condition or treatment being assessed. In the case of pediatric trauma, indicators that are specific to injury care in children are required to help identify areas of weakness.

1.4.2 Quality Indicators of Pediatric Trauma Care

Indicators related to structure, process, and outcome are integral elements of quality and form the basis of the American College of Surgeons trauma centre verification process. In recent years, the ACS-COT developed a quality improvement program called the Trauma Quality Improvement Program (TQIP). The program provides trauma centres in the U.S. with performance data, allowing them to compare their performance to peer centres. Furthermore, a pediatric TQIP has been developed to provide benchmarking data to pediatric trauma centres in the U.S.

As the management of pediatric trauma differs significantly from that of adults, specific pediatric quality indicators are required to evaluate the performance status of trauma centres caring for injured children. Since the majority of injured children receive care at adult trauma centres, pediatric indicators can be used across all trauma centre types to determine the quality of pediatric care provided.

A recent systematic review found over 120 known quality indicators of pediatric trauma care. The majority of these indicators were measures of pre-hospital and hospital processes and outcomes. No structure or post-hospital indicators were found. Authors could not,
however, develop a core group of pediatric trauma quality indicators given the poor quality of most studies included in the review. In addition, authors pointed out that many of the indicators were derived from the adult population and had simply been applied to children. As a result, many of the indicators being used may not have been pertinent to pediatric patients, which can significantly affect indicator validity. 65

However, a number of unique pediatric trauma quality indicators, or performance metrics, have been proposed. 65 Trauma-related mortality is a commonly cited outcome indicator that is used to assess quality at hospitals caring for injured children. Studies have used mortality as a measure of performance when comparing adult versus pediatric trauma centres or trauma versus non-trauma centres. 73 As with any outcome indicator, mortality is best used when attempting to evaluate the quality of systems as a whole. However, it is not as useful for detecting quality differences in smaller sample sizes as it tends to be a relatively rare outcome. 70

As mentioned earlier, the management of blunt splenic injury in children differs considerably from that of adults. Non-operative management is the standard of care in pediatrics and tends to be more closely adhered to among pediatric specialists. As a result, there is significant variation in splenectomy rates across regions and hospitals depending on the acceptance of pediatric treatment strategies. 47 For this reason, splenectomy rates are often used as a process of care quality indicators among hospitals caring for children with blunt splenic injury. 73 Hospitals that perform a lower number of splenectomies are considered high performing centres given their adherence to the standard of care. Furthermore, non-operative treatment of splenic injuries in children has been associated with better outcomes, such as decreased hospital stay, fewer complications, and decreased risk of
post-splenectomy sepsis.\textsuperscript{59} This ensures that splenectomy rate is “outcome-validated” as a process quality indicator.\textsuperscript{70}

Similarly, the management of traumatic brain injury differs significantly in children and adults. As discussed earlier, children treated at pediatric hospitals have an increased likelihood of neurosurgical intervention (craniotomy) and a higher survival rate.\textsuperscript{46} This is consistent with reports suggesting that more aggressive treatment of traumatic brain injury may have benefits in children that would not otherwise be observed in adults.\textsuperscript{46} To this affect, the Brain Trauma Foundation released a set of evidence-based guidelines pertaining to the treatment of traumatic brain injury in children\textsuperscript{74} The guidelines suggest that intracranial pressure (ICP) monitors be placed in all children with severe traumatic brain injury (GCS<9) to accurately measure intra-cranial pressure.\textsuperscript{74} They also suggest decompressive craniotomy be performed in all children with severe traumatic brain injury and an associated subdural or epidural hematoma.\textsuperscript{74} Furthermore, increased utilization of ICP monitors in children with severe traumatic brain injury\textsuperscript{75} and craniotomy in select children with epidural or subdural hematomas\textsuperscript{76} has been associated with favorable outcomes, such as improved survival and functional outcome.\textsuperscript{46} For these reasons, ICP monitor utilization and craniotomy rates across trauma centres caring for children with severe traumatic brain injury are often used as process indicators.\textsuperscript{65,73} Hospitals that do not place ICP monitors in children with severe traumatic brain injury or perform craniotomy in children with epidural or subdural hematomas may be performing below the standard of care and could benefit from added quality improvement.

Well-developed and valid indicators of quality pediatric trauma care allow for accurate measurements of quality at hospitals caring for injured children. Since injured children are
treated at a variety of different trauma centre types in the U.S, benchmarking is critical toward identifying low performing centres and implementing appropriate quality improvement.

1.5 Summary of Background and Gaps in Knowledge

Thus far, we have reviewed the epidemiology of childhood injury and the development of pediatric trauma systems in the U.S. Furthermore, we have highlighted how limited access to specialized pediatric trauma centres in the U.S. results in the majority of injured children being treated by adult specialists at trauma centres or non-designated hospitals. Many of these centres lack the pediatric resources required to optimally care for injured children or have been slow to adopt pediatric trauma care guidelines. As a result, there are significant variations in practice patterns and outcomes depending on where children receive injury care. In order to improve pediatric trauma care across the U.S., pediatric trauma quality improvement initiatives are being developed. These programs benchmark centres based on risk-adjusted performance data, allowing centres to compare performance relative to their peers. In order to measure the quality of pediatric trauma care at hospitals, a number of quality indicators, or performance metrics, have been developed. These indicators are well defined and are standardized for measurement across centres. Consequently, areas for improvement can be identified and interventions can be implemented.

However, several notable gaps in the literature exist. Firstly, it is unknown as to whether treatment at pediatric trauma centres offers a survival advantage for injured children compared to treatment at adult or mixed trauma centres. There is little doubt that adherence to particular pediatric trauma standards of care, such as the non-operative management of
blunt splenic injury, is superior at pediatric trauma centres.\textsuperscript{47} However, as indicated, studies comparing mortality among pediatric, mixed, and adult trauma centres have produced conflicting results.\textsuperscript{47} For these reasons, one of our objectives was to evaluate differences in mortality among injured children treated at different trauma centre types. By doing so, our hope was to identify the optimal environment for care of injured children, leading to opportunities to explore differences in practice in this ideal environment that might lead to better outcomes across all centres.

As indicator development for pediatric trauma care evolves, it will become critical to understand how quality in one domain relates to others. This knowledge will create efficiencies in measurement and reporting so that quality can be measured with limited data collection and relatively few metrics. At present, there is limited evaluation of how indicators of quality relate to one another within the same centre. In prior work, quality of care has been measured using a single indicator,\textsuperscript{73} yet there is no reason to believe that performance in one area of quality, such as in-hospital mortality, predicts similar performance in another domain of quality. This is particularly important because a number of non-mortality pediatric trauma quality indicators also exist.\textsuperscript{65,73} To better this understanding, our second objective was to evaluate whether centres that perform well in one area of quality perform similarly in other domains. This work will provide valuable insight into how to accurately measure hospital quality of care that will better inform pediatric trauma quality improvement initiatives and benchmarking strategies.
CHAPTER 2 – Thesis Overview

As part of this thesis, we sought to address the knowledge gaps that were outlined at the end of chapter 1. To do so, we studied a large cohort of injured children who were treated at trauma centres in the United States. The U.S. is an ideal setting in which to compare variation in practice patterns and outcomes across trauma centres since injured children are treated at many different trauma centre types (pediatric, adult, mixed). As such, practice patterns and outcomes across hospitals are likely not homogenous, making quality improvement initiatives in this population of even greater importance.

2.1 Research Aims

As an overarching theme of this thesis, we sought to evaluate how processes of care and outcomes vary across U.S. trauma centres caring for injured children. The first half of this thesis will focus on evaluating the optimal care environment for injured children. The second half of the thesis will take a broader look at a number of quality indicators and will elucidate whether centre-level performance in one area of quality, such as in-hospital mortality, predicts similar performance in other areas of quality. With these concepts in mind, we identified two specific research aims for this thesis.

1. To evaluate differences in mortality among injured children treated pediatric, mixed, and adult trauma centres.

2. To evaluate the consistency of centre-level performance across pediatric trauma quality indicators.

2.2 Hypotheses
In regards to research aim 1, we postulated that there would be significant differences in in-hospital mortality among injured children treated at different centres types, with pediatric trauma centres having the lowest rates of mortality, followed by mixed trauma centres, and then by adult trauma centres with the highest mortality rate.

With respect to research aim 2, we postulated that centres that perform well with respect to one pediatric trauma quality indicator, such as in-hospital mortality, would not necessarily perform similarly in other domains of quality, such as processes of care related to the management of blunt splenic injury and traumatic brain injury.

2.3 Data Sources

Our analyses focused on injured patients hospitalized at U.S trauma centres participating in the American College of Surgeons (ACS) Trauma Quality Improvement Program (TQIP).\textsuperscript{68,77,78} TQIP is a voluntary quality improvement program for ACS-verified Level I or II trauma centres in the United States.\textsuperscript{68} The program was initially piloted in 2008 and currently has over 255 participating trauma centres. TQIP provides centres with risk-adjusted quarterly benchmark data on trauma outcomes and processes of care. By doing so, centres can benchmark their performance relative to their peers and identify areas for improvement. Data pertaining to patients treated at TQIP participating centres is derived from a prospective trauma registry called the U.S. National Trauma Databank (NTDB), which is based on the National Trauma Data Standard.\textsuperscript{79} As a requirement of the ACS verification process, all level 1 and 2 trauma centres in the U.S. must submit data to NTDB. However, TQIP participating centres receive specialized training of their registrars in regards to NTDB data collection. As a result, the data generated from TQIP centres is considered higher quality.\textsuperscript{80} Furthermore, the reliability of the TQIP data is ensured through intensive training mechanisms for the data abstractors and by conducting inter-rater reliability audits of participating sites.\textsuperscript{80}
Within the TQIP dataset, more than 100 patient and institutional variables are recorded, including patient demographics, injury characteristics, pre-hospital and emergency department clinical data, laboratory values, procedures performed, and in-hospital morbidity and mortality. The richness of clinical data captured allows for comprehensive risk-adjustment during TQIP analyses.

TQIP was initially based solely on evaluating injured adults (age>18); however, a pediatric-specific (age≤18) pilot TQIP was initiated in 2012, which focused on assessing the quality of pediatric trauma care across trauma centres caring for injured children. This pilot program gave way to a formal pediatric TQIP, which began enrolling trauma centres in 2014. Currently, 45 trauma centres are enrolled in pediatric TQIP, the majority of which are dedicated pediatric trauma centres.

For the purposes of this thesis, we used data pertaining to centres that participated in the adult, pediatric pilot, or formal pediatric TQIP. Our analyses focused on injured children (age≤18) who were hospitalized at trauma centres participating in any of these TQIP programs. As a result, we were able to evaluate a diverse cohort of injured children who were treated at a variety of pediatric, mixed, and adult trauma centres.

### 2.4 Patient Selection

Inclusion into TQIP requires that patients are hospitalized with a diagnosis of injury and meet a minimum injury severity threshold. In order to select patients who have particular injury diagnosis, TQIP relies on the International Statistical Classification of Diseases, Ninth Revision (ICD-9CM). The ICD is a general classification system of diagnosis for all health conditions and includes diagnostic codes pertaining to the nature and external causes of injury. The ICD is widely used to classify disease in clinical, administration, and
research settings across North America and abroad. Patients included in TQIP must have an ICD-9CM diagnosis of injury (800–959), excluding late effects of trauma (905–909), superficial injuries (910-924), or foreign bodies (930-939). The ICD system does not, however, explicitly code for injury severity.

Instead, TQIP relies on a widely accepted anatomical-based injury severity scoring system known as the Abbreviated Injury Scale (AIS). The AIS is a consensus-driven scoring system that was developed by the Association for the Advancement of Automotive Medicine in 1971. The score was first developed to characterize injury type and severity among motor vehicle crash victims. Over the years, it has gained acceptance as the primary injury severity classification system for all types of injury. AIS classifies injury severity in every body region using a 6 point ordinal scale, with 1 representing a minor injury and 6 representing an injury with maximum severity that is often untreatable. As a result, multi-system trauma can be accurately characterized based on the severity of injury in different body regions. The AIS classifies body regions into head, neck, face, thorax, abdomen, spine, lower extremity, upper extremity, and unspecified. Each AIS injury is coded using 7-digits, which denote the body region, type of anatomical structure, specific anatomical structure, level, and severity. The AIS has been shown to reliability predict the probability of death after injury.

AIS, however, only denotes the severity of individual injuries. A number of composite measures of overall injury severity that rely on AIS scores have been developed. Of particular importance is the Injury Severity Score (ISS), which is widely utilized as a scoring system for overall injury severity. The ISS is calculated by squaring and then adding the AIS scores from the three most severely injured body regions. As a result, the ISS ranges from 0 to 75, with 1-9 representing mild, 9-15 as moderate, and >15 as severe. If any patient has an AIS of 6 in any body region, the ISS is automatically 75 as an injury of AIS=6 is considered
unsalvageable. Studies have demonstrated increased mortality among patients with increasing ISS, especially among those with severe injury severity (ISS>15). An ISS of 15 carries a mortality risk of approximately 15%.\textsuperscript{16}

Both AIS and the composite ISS score are available within the TQIP dataset.\textsuperscript{79} However, for the purposes of inclusion criteria, TQIP requires that patients have a minimum AIS score of 2 or greater in any body region. This serves to exclude patients with minor injuries.\textsuperscript{80} TQIP uses the 1998 version of AIS (AIS-98)\textsuperscript{82} for injury severity calculations.\textsuperscript{79,80} In cases where centres submit different versions of AIS, TQIP uses the AIS-98 crosswalk to convert codes into a format consistent with AIS-98 structure.\textsuperscript{80} Furthermore, in instances where centres do not submit AIS codes, TQIP uses the ICDMAP to derive AIS injury severity scores from ICD-9CM injury diagnosis codes.\textsuperscript{84} The ICDMAP has been well validated for this purpose.\textsuperscript{85}

Patients are also selected for inclusion into TQIP based on injury mechanism. Only patients with blunt or penetrating injury mechanisms are included.\textsuperscript{80} Patients with burns, drowning, asphyxiation or poisoning are excluded.\textsuperscript{68} In order to identify patients with these injury mechanisms, TQIP uses ICD-9CM external cause of injury codes (E-codes).\textsuperscript{79} External causes of injury are categorized into broader groups of injury mechanism using a standard categorization matrix developed by the CDC.\textsuperscript{86} As a result, TQIP categorizes injury mechanism into seven distinct groups: motor vehicle collision (MVC), motorcycle, pedestrian pedal (pedestrian, cyclist, struck by), fall, other blunt (transport, machinery), cut/pierce, and firearm.\textsuperscript{80}

Furthermore, patients with missing data pertaining to emergency department discharge disposition and hospital discharge disposition were excluded, as outcomes are not valuable.\textsuperscript{80} In addition, patients with an emergency discharge disposition of home were excluded, as these patients are believed to be not at risk for adverse outcomes given their identification for
discharge without inpatient care. Also, patients with an emergency department disposition of transfer to another centre were excluded, because limitations of the dataset precluded knowledge of the outcomes of these patients. Lastly, patients with advanced directives to withhold life-sustaining interventions were excluded.

The aforementioned inclusion and exclusion criteria form the basis of the TQIP dataset. All analyses presented in this thesis were performed using this dataset. However, for the purposes of this thesis, we only evaluated pediatric patients (age ≤ 18 years). Furthermore, we excluded patients who arrived to trauma centres without signs of life (pulse=0, blood pressure=0, emergency department motor GCS score=1), since their outcomes were likely independent of trauma centre care. The intricacies of cohort selection and the identification of subsets of children with particular injuries for each analysis will be discussed in subsequent relevant chapters.

2.5 Data Validity and Quality

The data within the National Trauma Databank (NTDB) is structured using a data dictionary called the National Trauma Data Standard (NTDS) that was introduced in 2007 to allow for consistent coding within NTDB across the country. This dictionary gives data abstractors exact definitions of how to code diseases and procedures. The enhanced consistency in coding across centres as a result of NTDS has improved the quality of NTDB data significantly. Regarding NTDB itself, internal validation occurs via range and logic checks and evaluation of improbable values. This occurs even prior to the data being extracted by TQIP and is commonplace for all NTDB data.

Data from NTDB pertaining to TQIP participating centres is considered higher quality for a variety of reasons. In particular, specialized training of TQIP registrars and frequent
internal/external validation checks assist in assessing and improving data quality. Training of registrars via quarterly conferences and focused training sessions are required prior to TQIP participation by any centre. Furthermore, external validation visits are performed where data quality issues are an identified concern. At these visits, submissions to TQIP are compared to a cohort of selected patient charts for assessment of case ascertainment and accuracy. Emergency department logs are also assessed to ensure all patients who meet TQIP inclusion criteria are captured in the dataset.

Although large-scale validation studies on the TQIP dataset have yet to be performed, as we have outlined, processes for assessing validity are currently underway and tackle several different data quality issues. An initial unpublished external validation study was discussed in a TQIP methodological paper in 2009. In the study, 50 charts from 10 randomly selected centres were re-abstracted. Concordance was excellent for data that was easily attainable, such as dates and gender; however, they found missing or incomplete data relating to Glasgow Coma Scale scores, systolic blood pressure and respiratory rate, and inconsistent recording of complications and co morbidities. On further analysis, these differences were not only from registrar error or differences in interpretation, but were often introduced as a result of mapping issues when data was submitted from centre specific registries to NTDB. Hence, authors of the study highlighted that the introduction of the NTDS will reduce errors related to using different sources of information and mapping to NTDB, in addition to dedicated TQIP registrar training and external validation as mentioned earlier. Authors also note that there was a high degree of inter-rater reliability among trained registrars in their validation study, further suggesting that education and mapping improvements will lead to improved data quality.

2.6 Ethics
Research ethics approval was obtained from Sunnybrook Health Sciences Centre for all analyses conducted herein. Furthermore, ethics approval was also obtained from the University of Toronto pertaining to the undertaking of these analyses for the purposes of graduate studies.
CHAPTER 3 – Mortality Among Injured Children Treated at Different Trauma Centre Types

Acknowledgment: Parts of this chapter are derived from material that is accepted for publication in JAMA Surgery. The exact reference cannot be provided as of yet, but all copyright permission requests for any material, tables, or figures presented in this chapter must be made to the primary copyright holder (JAMA Network). I would also like to acknowledge my co-authors: Aziz S Alali, Paul W Wales, Damon C Scales, Paul J Karanicolas, Randall S Burd, Michael L Nance, Wei Xiong, Avery B Nathens for granting permission to reproduce this material.

3.1 Summary

In this chapter, we address research aim 1 to determine the association between trauma centre type (pediatric (PTC), adult (ATC) or mixed (MTC) trauma centres) and in-hospital mortality among injured children. Furthermore, we explore how the association between trauma centre type and in-hospital mortality differs by clinically significant age strata.

We performed a retrospective cohort study using data derived from American trauma centres (n=252) participating in the American College of Surgeons (ACS) adult or pediatric Trauma Quality Improvement Program (TQIP). Patients’ aged ≤ 18 years with at least one injury of AIS ≥ 2 from 2010-2013 were included. Our primary outcome was in-hospital death. We used random-intercept multi-level modeling to evaluate the association between centre type and in-hospital mortality after adjusting for patient and hospital level confounders. Stratified analyses in young children (0-5 years), older children (6-11 years), and adolescents (12-18 years) were performed to determine if the association differed in each age group. All analyses were performed with and without hospital volume (patients per annum) as a hospital-level covariate,
to determine how volume influenced the effect of centre type on mortality. Secondary analyses limited to patients with severe injuries only (ISS ≥ 25) were performed to ensure our results were robust.

We identified 175,585 patients for analysis. Crude mortality rates were 2.3% for ATC, 1.8% for MTC, and 0.6% for PTC. After adjustment, children had higher odds of death when treated at ATC (OR 1.57 (1.15-2.14)) or MTC (1.45 (1.05-2.01)) versus PTC. Upon stratified analyses, younger children had higher odds of death when treated at ATC vs. PTC (OR 1.78 (1.05-3.04)) but no statistically significant difference between MTC and PTC (1.52 (0.92-2.52)). Among all other age groups there was no association between centre type and mortality. Results were robust and even more pronounced upon secondary analyses of severely injured children. Differences in hospital volume explained some of the effect of centre type on mortality among all children, but had no effect on the association in severely injured children.

Among injured children, we found that treatment at ATC and MTC was associated with a higher mortality when compared to treatment at PTC. The effect of centre type on mortality appears to be most relevant to younger children. Results were similar in a cohort of severely injured children.

3.2 Introduction

Trauma continues to be the leading cause of death and disability for children in North America. Every year, approximately 10 million children are treated for an injury and more than 9,000 children die in the United States alone. Furthermore, pediatric trauma results in substantial
burden on the U.S. economy, with a staggering estimated overall annual cost of more than $200 billion USD.\textsuperscript{7}

Pediatric hospitals have unique expertise in providing care to pediatric patients. This expertise addresses the unique disease states, physiology, and social needs of children and their families.\textsuperscript{12} Similarly, specialized trauma care for children is available at designated pediatric trauma centres (PTC).\textsuperscript{12} However, the priorities, number and geographic distribution of these centres require that either adult trauma centres (ATC) or adult trauma centres with added pediatric qualifications (mixed trauma centres – MTC), provide care to most injured children.\textsuperscript{36,38}

The precise care environment offering a survival advantage to severely injured children is not clear.\textsuperscript{46,47} On one hand, PTC provides children with specialized pediatric trauma care. On the contrary, ATC may have higher patient volumes than PTC, which could translate into improved outcomes. Some studies have shown lower mortality among children treated at PTC or MTC compared to ATC alone,\textsuperscript{47,48} while others have shown no difference.\textsuperscript{43,51} One study showed lower mortality among severely injured children treated at ATC.\textsuperscript{49} Many of these studies, however, are hampered by significant methodological limitations including insufficient injury severity risk adjustment and small sample sizes at the patient or centre level.\textsuperscript{47}

Also, it is plausible that the benefits of one centre type over another differ by patient age. For example, there is no reason to believe that the unique expertise available to care for an infant benefits an adult-size adolescent.\textsuperscript{49,88,89} The heterogeneity in the type and quality of care across different pediatric age groups may account for the variable findings observed in previous studies.
To fill this knowledge gap, we sought to evaluate the relationship between care environment and mortality among pediatric trauma patients. We hypothesized that the association between centre type and mortality differs across clinically relevant age strata. The purpose of identifying strengths and opportunities for improvement is not to redirect pediatric patients from one type of centre to another. Rather, it defines areas where centres might need additional support and quality improvement to provide the highest level care for children of all ages.

3.3 Methods

Study Design

This is a retrospective cohort study designed to evaluate the relationship between trauma centre type and in-hospital mortality among injured children. We used stratified analyses to evaluate whether the association differed across age strata. This work was approved by the Research Ethics Board at Sunnybrook Health Sciences Centre, Toronto, Ontario.

Data Sources and Participating Centres

Data were derived from American trauma centres (n=252) participating in the American College of Surgeons (ACS) adult or pediatric Trauma Quality Improvement Program (TQIP). TQIP is a voluntary performance improvement program that was created to provide level I and II trauma centres with feedback on risk-adjusted outcomes for quality-improvement purposes. Inclusion criteria for entry into TQIP require an International Statistical Classification of Diseases, Ninth Revision (ICD-9CM) diagnosis of 800–959 excluding late effects of trauma (905–909), superficial injuries (910-924), or foreign bodies (930-939). A number of institutional variables
are recorded in the dataset, including patient demographics, comorbid conditions, injury characteristics and severity, physiological variables, in-hospital procedures and complications, and outcomes including in-hospital mortality and discharge disposition. The authors of this study are solely responsible for the analysis and conclusions presented here.

**Study Cohort**

We identified all pediatric patients aged 18 years or younger who were admitted between January 2010 and December 2013 to a TQIP trauma centre. We included patients with either blunt or penetrating trauma with a minimum Abbreviated Injury Score (AIS) ≥ 2 in any body region. We excluded patients with superficial injuries, those who were transferred to another hospital or home directly from the emergency department, and those who were dead on arrival.

**Trauma Centre Classification**

Our exposure of interest was definitive care at a pediatric trauma centre (PTC), mixed trauma centre (MTC), or adult trauma centre (ATC). We defined an ATC as any centre having adult ACS verification or adult state designation and no pediatric qualifications. PTC was defined as any centre exclusively having either pediatric ACS verification or pediatric state designation. MTC was defined as any centre having both adult and pediatric ACS verifications or state designations. MTC was analyzed separately because it is unclear whether injured children at these centres were treated by adult or pediatric specialists. In some MTC, the pediatric trauma team may be only activated upon request by the adult team.

**Outcomes and Covariates**
The primary outcome was in-hospital death, which included patients who either died in the emergency department or during their hospital admission. As case mix varied significantly across centres, we used multivariable regression analyses to adjust for differences in mortality risk. The main effect in the model was centre type, with patient and injury characteristics considered as potential confounders. Clinically significant confounders were included in the model \textit{a priori} and confounders of uncertain significance were retained if they lead to a +/- 10\% change in the estimate of the exposure-outcome relationship.\textsuperscript{90}

Patient characteristics considered for inclusion into our model were: age, sex, co-morbidities, transfer status (transfer to centre or direct from scene), and insurance type (commercial vs. non-commercial). Injury characteristics considered were age-adjusted hypotension as defined by the American Heart Association,\textsuperscript{91} initial motor Glasgow Coma Scale score (mGCS), injury mechanism (motor vehicle collision (MVC), motorcycle, fall, pedestrian, other blunt, firearm, cut/pierce), and the presence of severe injury (AIS $\geq 3$) in any AIS body region (head, chest, abdomen, neck, face, spine, lower extremity, upper extremity).

In addition to the inclusion of potential confounders in our models, we used an ICD-9 derived injury severity score based on survival risk ratios (SRRs) given its superiority over other risk adjustment methods such as the Injury Severity Score (ISS).\textsuperscript{83,92,93} SRR is defined as the number of patients who survive a given ICD-9 coded injury divided by the total number of patients who sustain the injury. Independent SRRs were calculated from patients who have sustained an isolated injury only.\textsuperscript{94} Traditional SRRs were calculated from patients with multiple injuries and are typically only used when certain injuries did not occur in isolation in the study cohort. We primarily used independent SRRs and in cases where no independent SRRs existed, traditional
SRRs were used.\textsuperscript{94} Consistent with the approach used in other reports, we used the SRR from the single worst injury (SWI) for each patient.\textsuperscript{83,92,93,95} This approach has been well validated in the pediatric trauma population.\textsuperscript{93}

The following covariates were retained in the final model: age, gender, transfer status, single worst injury (SWI), age-adjusted hypotension, mGCS, injury mechanism, insurance type, and severe injury (AIS $\geq 3$) in body region of head, chest, and abdomen.

We also considered the possibility that centre volume (number of injured pediatric patients per annum with AIS $\geq 2$ in at least one body region) might account for observed differences in mortality between trauma centre types. Prior studies have shown a strong association between trauma centre volume and outcomes such as mortality.\textsuperscript{96} To further explore how centre volume influenced the association between centre type and mortality, we performed additional regression analyses with trauma centre volume as a hospital-level covariate (quartiles of injured pediatric patients per annum).

**Statistical Analysis**

Categorical variables were summarized as counts and continuous variables were presented as means (if normally distributed) or as medians (if non-normally distributed).

A random-intercept multi-level logistic regression model was developed to evaluate the association between trauma centre type and in-hospital death after adjusting for potential confounders. Results were reported as adjusted odds ratios (OR) and 95\% confidence intervals (CI). As patients cared for in the same centre are not independent, we accounted for clustering...
(correlation) within centres using hierarchical multi-level modeling.\textsuperscript{97} Model discrimination was estimated using the c-statistic and calibration was evaluated using observed-versus-predicted plots. The variance inflation factor was used to check for multicollinearity within the model.\textsuperscript{98} Data for age-adjusted hypotension, mGCS and insurance type was missing for less than 5% of patients. Rather than delete records with missing data, we used multiple imputation with 5 datasets to reduce the potential for introducing bias.\textsuperscript{99}

As a secondary analysis, we elected to examine the association between centre type and mortality in a cohort of children who were at highest risk of adverse outcomes (Injury Severity Score (ISS) $\geq 25$). All analyses were repeated in this cohort.

3.3.1 Hierarchical Data and Multi-Level Modeling

Data in health research are often hierarchical in nature, meaning that patients may be nested within physicians, which in turn may be nested in hospitals. If one is only interested in drawing inferences from characteristics at the lowest level of the hierarchy (i.e. patient-level), then simple logistic regression models are suitable.\textsuperscript{97} However, when one wants to incorporate characteristics from other levels of hierarchy (i.e. physician- or hospital-level), special statistical methods must be utilized to prevent false inferences.\textsuperscript{97} Given the hierarchical nature of our data, we elected to use hierarchical logistic regression for all analyses conducted in this thesis.

A traditional regression model assumes that all subjects are independent of one another. However, the model ignores the concept that patients may be clustered within a particular group (i.e. by physician or by hospital), and as a result, may not be independent of one another.\textsuperscript{97} In our dataset, it is highly likely that patients are clustered within trauma centres. In other words,
patients treated at a particular trauma centre are more likely to be similar to each other than
compared to patients treated at other centres. As such, one must consider that there may be a
significant correlation of outcomes among patients treated within one centre. For example, it is
possible that certain trauma centres are more likely to treat particular groups of patients (i.e.
sicker patients or patients from a specific cultural or socioeconomic group). This type of
clustering would result in greater homogeneity among patients treated within one trauma centre
than expected by chance alone.\textsuperscript{97} Therefore, a traditional regression model that does not account
for the hierarchical nature of data can often lead to inaccurate results and incorrect estimations of
the standard errors of coefficients.\textsuperscript{97} In addition, traditional regression does not allow for the
incorporation of physician- or centre-level characteristics into the model.\textsuperscript{97}

Multi-level modeling has been shown to produce more robust estimations of standard errors and
prevent false interferences during the analysis of hierarchical data.\textsuperscript{97} Furthermore, conventional
logistic regression may falsely increase the statistical significance for the effects of variables
measured at the hospital-level when compared to multi-level models.\textsuperscript{100}

We used random-intercept hierarchical logistic regression to address the hierarchical structure of
our data. By doing so, we were able to account for the clustering of patients within centres, in
addition to a number of patient-level and hospital-level confounders. This ensures that we were
able to account for unmeasured characteristics that resulted in the clustering of patients at the
centre-level. Furthermore, the multi-level nature of the model allowed us to incorporate hospital-
level characteristics, such as trauma centre type (pediatric, mixed, and adult trauma centre) and
hospital volume into our model.

\textbf{Age-Stratified Analyses}
In order to evaluate whether the effect of trauma centre environment on mortality differed across age strata, we developed separate multi-level regression models to examine the association in young children (0-5 years), older children (6-11 years), and adolescents (12-18 years).\textsuperscript{101} Stratum-specific odds ratios were generated within each age group to determine how the magnitude of the effect of centre type on mortality differed.\textsuperscript{102}

In addition, an alternate approach using an interaction term between centre type and age group was used to provide a test of statistical significance of the difference between stratified odds ratios. A statistically significant interaction term suggests that the effect of centre type on mortality is statistically different within one age group versus another.

All statistical analyses were performed using SAS, version 9.3, Cary, NC. All tests were two-sided with p-values <0.05 considered statistically significant.

3.4 Results

We identified a total of 175,585 injured children admitted to 252 level I and II trauma centres across the United States. Overall mortality in the study cohort was 1.6% (n=2892).

Patient and hospital level characteristics are presented (Table 3.1 and 3.2). Overall, 35.4% of patients received definitive care at ATC, 35.2% at MTC, and 29.4% at PTC. Relative to children treated at PTC, children treated at ATC and MTC were older, more severely injured, had higher rates of penetrating injury, and lower mGCS. At the hospital level, PTC were more likely to be level 1 trauma centres, university teaching hospitals, and have higher pediatric patient volumes.
Crude mortality rates were 2.3% for ATC, 1.8% for MTC, and 0.6% for PTC. When compared to PTC, the crude odds of death for children treated at ATC was 4.31 (3.31-5.62) and 3.29 (2.47-4.37) when treated at MTC.
### Table 3.1: Patient Characteristics

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>ATC</th>
<th>MTC</th>
<th>PTC</th>
</tr>
</thead>
<tbody>
<tr>
<td>N (%)</td>
<td>62119 (35.4)</td>
<td>61766 (35.2)</td>
<td>51700 (29.4)</td>
</tr>
<tr>
<td>Age (SD) *</td>
<td>12.4 (5.8)</td>
<td>10.1 (5.9)</td>
<td>8.0 (5.1)</td>
</tr>
<tr>
<td>Age Category (%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0-5</td>
<td>10774 (17.3)</td>
<td>17771 (28.8)</td>
<td>19551 (37.8)</td>
</tr>
<tr>
<td>6-12</td>
<td>11388 (18.3)</td>
<td>16848 (27.3)</td>
<td>19140 (37.0)</td>
</tr>
<tr>
<td>13-18</td>
<td>39913 (64.3)</td>
<td>27080 (43.8)</td>
<td>13009 (25.2)</td>
</tr>
<tr>
<td>Male Sex (%)</td>
<td>42470 (68.4)</td>
<td>41022 (66.4)</td>
<td>33406 (64.6)</td>
</tr>
<tr>
<td>Transfer Patient (%)</td>
<td>20386 (32.8)</td>
<td>26875 (43.5)</td>
<td>25944 (50.2)</td>
</tr>
<tr>
<td>Injury Mechanism (%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MVC</td>
<td>15662 (25.2)</td>
<td>12649 (20.5)</td>
<td>4871 (9.4)</td>
</tr>
<tr>
<td>Motorcycle</td>
<td>1302 (2.1)</td>
<td>873 (1.4)</td>
<td>233 (0.5)</td>
</tr>
<tr>
<td>Fall</td>
<td>18716 (30.1)</td>
<td>24284 (39.2)</td>
<td>28504 (55.1)</td>
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<tr>
<td>Pedestrian</td>
<td>14539 (23.4)</td>
<td>14651 (23.7)</td>
<td>13084 (25.3)</td>
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<tr>
<td>Other Blunt</td>
<td>6157 (9.9)</td>
<td>6079 (9.8)</td>
<td>3747 (7.3)</td>
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<td>Firearm</td>
<td>4054 (6.5)</td>
<td>1990 (3.2)</td>
<td>568 (1.1)</td>
</tr>
<tr>
<td>Cut/Pierce</td>
<td>1689 (2.7)</td>
<td>1238 (2.0)</td>
<td>693 (1.3)</td>
</tr>
<tr>
<td>ISS (%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4-8</td>
<td>26091 (42.0)</td>
<td>26627 (43.1)</td>
<td>26445 (51.2)</td>
</tr>
<tr>
<td>9-15</td>
<td>20431 (32.9)</td>
<td>20008 (32.4)</td>
<td>17119 (33.3)</td>
</tr>
<tr>
<td>16-24</td>
<td>9640 (15.5)</td>
<td>9908 (16.0)</td>
<td>5887 (11.4)</td>
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<tr>
<td>≥25</td>
<td>5957 (9.6)</td>
<td>5223 (8.5)</td>
<td>2169 (4.2)</td>
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<td>Age Adjusted Hypotension (%)</td>
<td>2038 (3.3)</td>
<td>2493 (4.0)</td>
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<td>GCS Motor Score (%)</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>1-2</td>
<td>4084 (6.6)</td>
<td>3709 (6.0)</td>
<td>1305 (2.5)</td>
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<td>3-4</td>
<td>1158 (1.9)</td>
<td>872 (1.4)</td>
<td>609 (1.2)</td>
</tr>
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<td>5-6</td>
<td>54148 (87.1)</td>
<td>54419 (88.1)</td>
<td>46507 (90.0)</td>
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<tr>
<td>Severe Injury AIS ≥ 3 (%)</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Head</td>
<td>13457 (21.7)</td>
<td>14660 (23.7)</td>
<td>9672 (18.7)</td>
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<tr>
<td>Chest</td>
<td>10251 (16.5)</td>
<td>8481 (13.7)</td>
<td>2881 (5.6)</td>
</tr>
<tr>
<td>Abdomen</td>
<td>4573 (7.4)</td>
<td>4064 (6.6)</td>
<td>2296 (4.4)</td>
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<tr>
<td>Upper Extremities</td>
<td>2942 (4.7)</td>
<td>2836 (4.6)</td>
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<td>Lower Extremities</td>
<td>8816 (14.2)</td>
<td>8853 (14.3)</td>
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<td>Spine</td>
<td>2230 (3.6)</td>
<td>1711 (2.8)</td>
<td>707 (1.4)</td>
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<td>Commercial Insurance Type (%)</td>
<td>28967 (46.6)</td>
<td>29020 (47.0)</td>
<td>24343 (47.1)</td>
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<tr>
<td>Mortality (%)</td>
<td>1451 (2.3)</td>
<td>1118 (1.8)</td>
<td>323 (0.6)</td>
</tr>
</tbody>
</table>

* The one continuous variable (Age) was normally distributed; hence the mean and standard deviation (SD) were presented.
Table 3.2: Hospital Characteristics

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>ATC</th>
<th>MTC</th>
<th>PTC</th>
</tr>
</thead>
<tbody>
<tr>
<td>N (%)</td>
<td>161 (63.9)</td>
<td>61 (24.2)</td>
<td>30 (11.9)</td>
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<tr>
<td>Trauma Level (%)</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>84 (52.2)</td>
<td>51 (83.6)</td>
<td>26 (86.7)</td>
</tr>
<tr>
<td>2</td>
<td>77 (47.8)</td>
<td>10 (16.4)</td>
<td>4 (13.3)</td>
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<tr>
<td>Region (%)</td>
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<tr>
<td>Midwest</td>
<td>54 (33.5)</td>
<td>13 (21.3)</td>
<td>13 (43.3)</td>
</tr>
<tr>
<td>Northeast</td>
<td>21 (13.0)</td>
<td>16 (26.2)</td>
<td>6 (20.0)</td>
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<tr>
<td>South</td>
<td>50 (31.1)</td>
<td>22 (36.1)</td>
<td>7 (23.3)</td>
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<tr>
<td>West</td>
<td>35 (21.7)</td>
<td>9 (14.8)</td>
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<td>Bedsize (%)</td>
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<td>201-400</td>
<td>62 (38.5)</td>
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<td>401-600</td>
<td>43 (26.7)</td>
<td>21 (34.4)</td>
<td>8 (26.7)</td>
</tr>
<tr>
<td>&lt;=200</td>
<td>8 (5.0)</td>
<td>0 (0)</td>
<td>5 (16.7)</td>
</tr>
<tr>
<td>&gt;600</td>
<td>48 (29.8)</td>
<td>34 (55.7)</td>
<td>2 (6.7)</td>
</tr>
<tr>
<td>Volume of Injured Pediatric Patients per Annum (%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1&lt;sup&gt;st&lt;/sup&gt; Quartile (&gt;237)</td>
<td>13 (8.1)</td>
<td>26 (42.6)</td>
<td>24 (80.0)</td>
</tr>
<tr>
<td>2&lt;sup&gt;nd&lt;/sup&gt; Quartile (114-237)</td>
<td>36 (22.4)</td>
<td>23 (37.7)</td>
<td>4 (13.3)</td>
</tr>
<tr>
<td>3&lt;sup&gt;rd&lt;/sup&gt; Quartile (50-113)</td>
<td>56 (34.8)</td>
<td>6 (9.8)</td>
<td>1 (3.3)</td>
</tr>
<tr>
<td>4&lt;sup&gt;th&lt;/sup&gt; Quartile (&lt;50)</td>
<td>56 (34.8)</td>
<td>6 (9.8)</td>
<td>1 (3.3)</td>
</tr>
<tr>
<td>Teaching Status (%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Community</td>
<td>75 (46.6)</td>
<td>17 (27.9)</td>
<td>8 (26.7)</td>
</tr>
<tr>
<td>Non-Teaching</td>
<td>25 (15.5)</td>
<td>2 (3.3)</td>
<td>1 (3.3)</td>
</tr>
<tr>
<td>University</td>
<td>61 (37.9)</td>
<td>42 (68.9)</td>
<td>21 (70.0)</td>
</tr>
<tr>
<td>For Profit (%)</td>
<td>20 (12.4)</td>
<td>4 (6.6)</td>
<td>2 (6.7)</td>
</tr>
</tbody>
</table>

Adjusted Analyses

After adjustment, injured children had higher odds of death when treated at ATC (OR 1.57 (1.15-2.14)) and MTC (OR 1.45 (1.05-2.01)) compared to PTC (Figure 3.1). All of the following were associated with higher odds of death: presence of hypotension, lower mGCS, MVC, pedestrian, and firearm injury mechanism, and severe head, chest, and abdominal injuries (Table 3.3). In contrast, having been transferred or having commercial insurance were associated with a lower odds of death (Table 3.3). The regression model had excellent discrimination (c-statistic = 0.96) and calibration (observed versus predicted plot not shown).
Upon secondary analyses of severely injured children (ISS ≥ 25), results were similar (Figure 3.2). Severely injured children treated at ATC and MTC had higher odds of death ((1.75 (1.25-2.44)) and (1.62 (1.15-2.29)), respectively) when compared to PTC.

Table 3.3: Adjusted Analyses With and Without Trauma Centre Volume

<table>
<thead>
<tr>
<th>Variable</th>
<th>Adjusted OR (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Without Volume</td>
</tr>
<tr>
<td>Trauma Centre Type</td>
<td>Ref</td>
</tr>
<tr>
<td>Pediatric</td>
<td>1.57 (1.15-2.14)</td>
</tr>
<tr>
<td>Adult</td>
<td>1.45 (1.05-2.02)</td>
</tr>
<tr>
<td>Mixed</td>
<td>0.99 (0.98-1.01)</td>
</tr>
<tr>
<td>Age</td>
<td>0.98 (0.85-1.12)</td>
</tr>
<tr>
<td>Male Sex</td>
<td>0.74 (0.64-0.85)</td>
</tr>
<tr>
<td>Transfer Patient</td>
<td>3.51 (4.71-6.44)</td>
</tr>
<tr>
<td>Age-Adjusted Hypotension</td>
<td>5.51 (4.71-6.44)</td>
</tr>
<tr>
<td>GCS Motor Score</td>
<td>Ref</td>
</tr>
<tr>
<td>1-2</td>
<td>48.7 (40.1-59.0)</td>
</tr>
<tr>
<td>2-6</td>
<td>9.85 (7.40-13.1)</td>
</tr>
<tr>
<td>5-6</td>
<td>Ref</td>
</tr>
<tr>
<td>Severe Injury AIS ≥ 3</td>
<td>Ref</td>
</tr>
<tr>
<td>Abdomen</td>
<td>2.22 (1.88-2.62)</td>
</tr>
<tr>
<td>Chest</td>
<td>1.62 (1.42-1.86)</td>
</tr>
<tr>
<td>Head</td>
<td>2.42 (2.05-2.86)</td>
</tr>
<tr>
<td>Injury Mechanism</td>
<td>Ref</td>
</tr>
<tr>
<td>MVC</td>
<td>1.34 (1.04-1.71)</td>
</tr>
<tr>
<td>Motorcycle</td>
<td>1.48 (0.92-2.38)</td>
</tr>
<tr>
<td>Fall</td>
<td>Ref</td>
</tr>
<tr>
<td>Pedestrian</td>
<td>1.39 (1.08-1.78)</td>
</tr>
<tr>
<td>Other Blunt</td>
<td>1.38 (1.02-1.85)</td>
</tr>
<tr>
<td>Firearm</td>
<td>6.35 (4.81-8.38)</td>
</tr>
<tr>
<td>Cut/Pierce</td>
<td>1.33 (0.76-2.31)</td>
</tr>
<tr>
<td>Commercial Insurance Type</td>
<td>Ref</td>
</tr>
<tr>
<td>0.73 (0.64-0.83)</td>
<td>0.73 (0.64-0.83)</td>
</tr>
<tr>
<td>Volume of Injured Pediatric Patients per Annum</td>
<td></td>
</tr>
<tr>
<td>1st Quartile (highest)</td>
<td>--</td>
</tr>
<tr>
<td>2nd Quartile</td>
<td>--</td>
</tr>
<tr>
<td>3rd Quartile</td>
<td>--</td>
</tr>
<tr>
<td>4th Quartile (lowest)</td>
<td>--</td>
</tr>
</tbody>
</table>
Figure 3.1. Association Between Centre Type and Mortality

Legend
PTC – Pediatric Trauma Center (reference group)
MTC – Mixed Trauma Center
ATC – Adult Trauma Center
**Figure 3.1.** Forrest plot displaying the association between trauma centre type and mortality in different subgroups. Hierarchical logistic regression was used to generate adjusted odds ratios (OR) and 95% CI. Pediatric Trauma Centres (PTC) were used as the reference group. ATC=Adult Trauma Centre. MTC=Mixed Trauma Centre.
Figure 3.2. Association Between Centre Type and Mortality (ISS ≥ 25)

Legend

PTC – Pediatric Trauma Center (reference group)
MTC – Mixed Trauma Center
ATC – Adult Trauma Center
**Figure 3.2.** Forrest plot displaying the association between trauma centre type and mortality in different subgroups of severely injured children (Injury Severity Score (ISS) ≥25).

Hierarchical logistic regression was used to generate adjusted odds ratios (OR) and 95% CI. Pediatric Trauma Centres (PTC) were used as the reference group. ATC=Adult Trauma Centre. MTC=Mixed Trauma Centre.

**Age-Stratified Analyses**

On stratified analyses (Figure 3.1), younger children had higher odds of death when treated at ATC compared to PTC (OR 1.78 (1.05-3.04)), but no significant difference in the odds of death when treated at MTC vs. PTC (1.52 (0.92-2.52)). There was no association between centre type and mortality in other age groups. In the secondary analyses of injured children with ISS ≥ 25, younger children had higher odds of death when treated at both ATC and MTC versus PTC (Figure 3.2). Similar to our primary analyses, no significant association between centre type and mortality in older children or adolescents was observed (Figure 3.2).

When the interaction term approach was used in both our primary and secondary analyses, the interaction term between centre type and age group was not significant, suggesting that the association between mortality and trauma centre type was not statistically different across age groups.

**Effect of Trauma Centre Volume**
In our analyses, volume of injured pediatric patients per annum was independently associated with mortality. The lowest volume centres had increased odds of death when compared to centres with higher volumes (Table 3.3).

To explore the extent to which volume explained the relationship between centre type and mortality, we added volume as a hospital level covariate into our models. The effect of volume on the association between centre type and mortality was limited with a diminution of the strength of the association (Figure 3.1). In our secondary analyses, however, volume had almost no effect on the association between centre type and volume (Figure 3.2).

3.5 Discussion

In a large population of injured children across the United States we have demonstrated that children treated at ATC and MTC have a higher odds of dying in hospital than those treated at PTC. The findings were robust after case mix adjustment and after sensitivity analyses limited to children with severe injuries only.

We also found that the effect of centre type on mortality is most apparent in younger children. Compared to older children and adolescents, younger children had higher odds of death when treated at ATC versus PTC. In our secondary analyses of severely injured children, younger children had higher odds of death when treated at both ATC and MTC versus PTC, whereas there was no such association in other age groups. However, our interaction terms were not significant, suggesting that the association between mortality and centre type may not significantly differ between age groups. It should be noted that our analyses were not powered to
test for this interaction, and as such, this does not exclude a statistically significant difference in the association across age groups.

Centre volume appeared to attenuate the strength of the association between centre type and mortality in all children. However, volume had no influence on the association in severely injured children. As such, the association between trauma centre type and mortality is not entirely explained by centre volume and remained evident even after accounting for differences in centre volume.

Previous studies evaluating the association between trauma centre type and mortality have produced conflicting results.\textsuperscript{47} A number of studies have shown higher mortality rates among injured children treated at ATC and MTC versus PTC.\textsuperscript{46,48} These studies used a variety of different methods of injury severity risk adjustment including the Injury Severity Score (ISS), Trauma and Injury Severity Score (TRISS), ICD-derived Injury Severity Score (ICISS) and Trauma Mortality Prediction Model (TMPM).\textsuperscript{42-44,46} However, similar studies using these same methods of injury severity risk adjustment have demonstrated no difference in mortality between trauma centre types.\textsuperscript{42} One study used TRISS methodology and demonstrated higher survival among injured children treated at ATC and MTC versus PTC.\textsuperscript{49} More recent studies have used instrumental variable analyses as strategies to account for unmeasured confounding, but results again have been conflicting. One Florida study showed that injured children had higher mortality when treated at ATC vs. PTC,\textsuperscript{44} whereas another study from California demonstrated no difference in mortality among injured children treated at different trauma centre types.\textsuperscript{43}

Our findings are consistent with studies demonstrating a survival benefit for injured children treated at PTC,\textsuperscript{44,47} but also contrast findings in other studies that show no difference in mortality
between trauma centre types. Many of these prior studies have used small sample sizes or state specific data, have not had the ability to compare a large number of PTC to MTC and ATC, have not sufficiently adjusted for important confounders and injury severity, or have not compared all three centre types in the same analysis. We were able to overcome all these methodological shortcomings in our study.

One major strength of our study includes the use of a large nationally representative sample to evaluate the association between trauma centre type and mortality. As a result, we were able to compare a large number of geographically diverse PTC, MTC, and ATC in the same analyses. In addition, by analyzing MTC separately we were able to examine this unique centre type independently as opposed to categorizing it as an ATC. Also, random-intercept multi-level regression was used to account for clustering of patient outcomes within centres, in addition to controlling for a number of confounders. Furthermore, the single worst injury (SWI) based on the lowest survival risk ratio was used as our main method for injury severity risk adjustment. SWI has been shown to be superior to ISS, TRISS, ICISS and other multiple injury scoring systems and has been validated in the pediatric population as highly predictive of mortality. To ensure our results were robust, we also performed secondary analyses in children with severe injuries only.

In addition, we performed stratified analyses geared at evaluating how the association between centre type and mortality varied across age groups, something reported in few other studies. Lastly, we explored centre volume within the context of the association between centre type and mortality to better understand how it might explain some of the differences in mortality between centre types.
However, there are limitations that should be considered when interpreting our findings. Our study used a voluntary trauma registry of only level I/II trauma centres, which may introduce an element of selection bias. Also, data on each patient in the registry only pertains to a single admission. Among transfer patients we have no information on where patients received treatment prior to being transported to a TQIP centre and where patients were transferred to once they left hospital. To address this potential limitation, we included inter-facility transfer status as a covariate and excluded patients who were transferred out of hospital. In addition, it was not possible to determine if children treated at MTC received care from adult or pediatric specialists. In a number of these centres, the pediatric team is only activated upon request from adult specialists. Hence, misclassification bias may be an issue. To limit this potential, we analyzed MTC as a separate centre type in an effort to account for the unique organizational structure of these centres. Lastly, residual confounding needs to be considered. Our dataset did not have pre-hospital, EMS or geographical data, limiting our ability account for these factors. Despite this, we were able to adjust for the majority of clinically important confounders.

Our results support the argument that injured children, especially younger children, have lower mortality when treated at PTC. However, we recognize that providing all injured children with care at PTC is not realistic or feasible. As a result, the implications associated with these findings are not geared toward redirecting children to one type of centre over another, but rather to target quality improvement initiatives where needed. Also, there appears to be a consistent gradient effect for children treated at ATC, MTC, and PTC, with a survival benefit for children treated at MTC versus ATC. Determining the causal pathways that confer injured children a survival benefit at MTC may also provide valuable information into what aspects of “added pediatric qualifications” can be added to ATC.
Further studies examining which processes of care at each centre are responsible for the differences in mortality are necessary. Identifying areas for improvement will allow for targeted quality improvement initiatives at each centre with a focus on additional resources and improved pediatric trauma education. In addition, future research incorporating pre-hospital data, EMS information, geographical analysis, and post-discharge status is warranted.

**Conclusions**

In this chapter, we found that injured children had a higher odds of dying when treated at ATC and MTC versus PTC. The survival benefit of PTC is most evident in younger children. Differences in centre volume did not account for the association between centre type and mortality. Efforts to determine what processes of care result in lower mortality at PTC and in some cases, MTC, should be undertaken to give ATC the ability to provide high-level care to all children.
CHAPTER 4 – Concordance of Performance Metrics Among U.S. Trauma Centres

Caring for Injured Children

Acknowledgment: Parts of this chapter are derived from material that is accepted for publication in the journal of trauma and acute care surgery. The exact reference cannot be provided as of yet, but all copyright permission requests for any material, tables, or figures presented in this chapter must be made to the primary copyright holder (Lippincott Williams & Williams). I would also like to acknowledge my co-authors: Paul W Wales, Damon C Scales, Paul J Karanicolas, Randall S Burd, Michael L Nance, Wei Xiong, Avery B Nathens for granting permission to reproduce this material.

4.1 Summary

In this chapter, we address research aim 2 and evaluate whether centre-level performance is consistent across multiple quality indicators. As reviewed in chapter 1, several quality indicators, or performance metrics, have been proposed to measure the quality of care at hospitals caring for injured children. Indicators of good quality pediatric trauma care include low in-hospital mortality, non-operative management of blunt splenic injury (BSI), use of intra-cranial pressure (ICP) monitors after severe traumatic brain injury (TBI), and craniotomy for children with severe TBI and an associated subdural or epidural hematoma. In many instances, quality improvement programs assign hospital performance status based on a single quality indicator. The underlying assumption to this approach is that hospitals providing high quality care based on one indicator provide high quality care across all indicators. It is unknown, however, if centre-level performance is consistent across different quality indicators. We sought to evaluate whether centre performance in one area of quality predicted similar performance in other areas of quality to better inform the development of pediatric trauma quality improvement initiatives.
We included patient’s aged ≤ 18 years who were hospitalized with an injury AIS ≥ 2 from 2010-2011 at trauma centres (n=150) participating in the Trauma Quality Improvement Program (TQIP). Random-intercept multi-level modeling was used to generate centre-specific adjusted odds ratios for each quality indicator. Hospitals were ranked into quartiles of performance depending on the magnitude of their respective odds ratio in each metric, with quartile 1 and 4 representing low and high performing centres, respectively. We evaluated correlations between centre-specific adjusted odds ratios of each quality indicator and mortality using Pearson correlation coefficients (PCC). Weighted kappa statistics were then used to test multiple pairwise agreements between indicators and the overall agreement across all four indicators.

Among 84,880 injured children who met our inclusion criteria, 3603 had blunt splenic injury, 3503 had severe traumatic brain injury, and 1286 had an associated epidural or subdural hematoma. A negative correlation between centre-specific odds of mortality and craniotomy was present (PCC (-0.18, p=0.03)). There were no significant correlations between other indicators. Although kappa statistics showed slight agreement for the pairwise comparison of odds of mortality and craniotomy (0.17 (0.02, 0.32)), there was no agreement for all other pairwise comparisons or the overall comparison of all four indicators (-0.01 (-0.07, 0.06)).

Our findings demonstrate a lack of concordance in centre-level performance across pediatric trauma quality metrics such as mortality rate, splenectomy rate, ICP monitor utilization, and craniotomy rate. Trauma centres that are high or low performers in one area of quality may not perform similarly in other domains of quality. These findings should be considered
during the development of pediatric trauma quality improvement initiatives to allow for comprehensive measurement of hospital quality as opposed to benchmarking using a single indicator.

4.2 Introduction

In the United States, unintentional injury is responsible for 44% of all child deaths after infancy, resulting in roughly 12,000 pediatric deaths annually. In addition, 9.2 million children are treated for injuries in emergency departments and 225,000 require hospitalization every year. As such, childhood injury continues to be a major public health concern. In recognition of the growing need to provide injured children with optimal care, the American College of Surgeons (ACS) Committee on Trauma recently outlined pediatric-specific resource requirements pertaining to hospitals that care for a high volume of injured children or wish to become verified as pediatric trauma centres. These criteria were meant to address the unique injury characteristics and management needs of children. However, due to limited availability of centres with pediatric expertise, most injured children in the U.S. are treated by adult specialists at trauma centres or in non-designated hospitals. In many cases, these non-pediatric hospitals either lack the resources required to care for injured children or have been slow to adopt pediatric-specific trauma guidelines. As a result, there is significant variation in practice patterns and outcomes across U.S. hospitals caring for injured children.

In an effort to improve pediatric trauma care across the U.S., quality improvement initiatives, such as the ACS Trauma Quality Improvement Program (TQIP), have recently implemented pediatric-specific initiatives. These programs facilitate external benchmarking of hospitals based on risk-adjusted performance data of patient processes and outcomes. By doing so,
weaknesses can be identified and targeted quality improvement initiatives can be implemented where required.\textsuperscript{70,103} Integral to the benchmarking process is the development of reliable and valid measures of quality of care, often referred to as quality indicators, or performance metrics.\textsuperscript{70} A number of quality indicators specific to pediatric injury care have been proposed.\textsuperscript{65} Commonly cited indicators of good quality pediatric trauma care include low in-hospital mortality,\textsuperscript{65} non-operative management of blunt splenic injury (BSI),\textsuperscript{65,73} use of intra-cranial pressure (ICP) monitors after severe traumatic brain injury (TBI),\textsuperscript{65,73} and craniotomy for children with severe TBI and an associated subdural or epidural hematoma.\textsuperscript{65,73} The latter two metrics are considered the standard of care by the Brain Trauma Foundation\textsuperscript{74} and have been independently associated with lower in-hospital mortality.\textsuperscript{47,74,76} In addition, non-operative management of blunt splenic injuries in children has been associated with faster recovery, shorter hospital length of stay, and decreased chance of overwhelming post-splenectomy sepsis.\textsuperscript{54} As indicators of the standard of care, these quality metrics help to identify high and low performing trauma centres. For instance, among centres that care for children with blunt splenic injury, those with relatively low risk-adjusted splenectomy rates would be high performers (strong adherence to the standard of care), whereas those with above-average adjusted splenectomy rates would be considered low performers.\textsuperscript{68}

As part of quality improvement activities, hospitals caring for injured children are often assigned a performance status based on a single quality indicator.\textsuperscript{69} This approach is simple and requires limited data collection and analyses. However, the underlying assumption to this approach is that hospitals provide high quality care based on this single indicator. While it is plausible that a single indicator represents “quality” care across several areas, it is more likely that each indicator demonstrates the quality of care only for those patients in whom the indicator is relevant. For instance, mortality-based benchmarking is commonly used to measure and compare the overall
quality of pediatric trauma care across hospitals. However, it is unknown if hospitals that perform well with respect to mortality (low risk-adjusted mortality) also perform well across other measures, such as the management of blunt splenic injury and traumatic brain injury.

To better understand the balance between more comprehensive quality measurement using multiple indicators and a parsimonious approach with a single indicator, we sought to evaluate the relationship between centre-level performance in one quality metric versus another. We hypothesized that centres would not perform consistently across indicators and therefore, would come to different conclusions about the quality of care delivered depending on which performance metric was being used.

4.3 Methods

Study Design

This observational study was designed to evaluate whether centre-level performance relative to peers is consistent across different performance metrics. Multivariable regression analyses were used to develop centre-specific adjusted odds ratios pertaining to each quality indicator. Correlations between centre-specific odds of mortality and other quality indicators were tested. Furthermore, a heat map was generated to visually depict the consistency of centre-level performance across quality metrics and weighted kappa statistics were used to test for agreement. This work was approved by the Research Ethics Board at Sunnybrook Health Sciences Centre, Toronto, Ontario.

Data Sources and Participating Centres
Data were derived from 150 U.S. trauma centres (adult, mixed, or pediatric) participating in the American College of Surgeons (ACS) adult (n=112) or pediatric pilot (n=38) Trauma Quality Improvement Program (TQIP).\textsuperscript{68} TQIP is a voluntary performance improvement program that was created to provide level I and II trauma centres with feedback on risk-adjusted outcomes for quality-improvement purposes.\textsuperscript{68} Inclusion criteria for entry into TQIP require an International Statistical Classification of Diseases, Ninth Revision (ICD-9CM) diagnosis of 800–959 excluding late effects of trauma (905–909), superficial injuries (910-924), or foreign bodies (930-939). A number of institutional variables are recorded in the dataset, including patient injury characteristics and severity, physiological variables, in-hospital procedures and complications, and outcomes including in-hospital mortality and discharge disposition.\textsuperscript{68} Although the ACS oversees the maintenance of this database, the authors of this study are solely responsible for the analysis and conclusions presented here.

**Study Cohort**

We identified patients aged 18 years or younger who were hospitalized at a TQIP centre from January 2010 to December 2011. We included patients with either blunt or penetrating trauma with a minimum Abbreviated Injury Score (AIS) ≥ 2 in any body region. We excluded patients with superficial injuries, those who were transferred to another hospital or home directly from the emergency department, and those who were dead on arrival.

Mortality was evaluated among all injured children who met our inclusion criteria. ICP monitor placement rates were evaluated in children with severe traumatic brain injury, defined as those with a presenting total Glasgow Coma Scale (GCS) score ≤ 8 (Brain Foundation Guidelines)\textsuperscript{74}
and a head AIS ≥3. We excluded patients with penetrating TBI and those with head AIS of 6 due to the unsurvivable nature of these injuries. Craniotomy rates were examined among children with severe TBI and an associated epidural (AIS-98 codes: 140630, 140632, 140634, 140636) or subdural hematoma (AIS-98 codes: 140650, 140652, 140654, 140656). Lastly, splenectomy rates were assessed in children with blunt injury mechanism and an associated splenic injury (AIS-98 codes: 544210, 544212, 544214, 544220, 544222, 544224, 544226).

Outcomes and Covariates

Different subsets of children were evaluated depending on the quality indicator being assessed. As case mix may vary significantly across centres, we used multivariable regression analyses to adjust for the unique differences in each subset of children. Clinically important confounders were included in each model a priori. The variance inflation factor (VIF) was used to check for multicollinearity within each model.

In our mortality model, the primary outcome was in-hospital death, which included patients who either died in the emergency department or during their hospital admission. We adjusted for a number of patient-level characteristics including age, sex, transfer status (transfer to centre or direct from scene), insurance type (commercial vs. non-commercial), age-adjusted hypotension as defined by the American Heart Association, presenting motor Glasgow Coma Scale score (mGCS), injury mechanism (motor vehicle collision (MVC), motorcycle, fall, pedestrian, other blunt, firearm, cut/pierce), and the presence of severe injury (AIS ≥ 3) in the body region of head, chest, or abdomen. In addition, we used an ICD-9 derived injury severity score based on survival risk ratios (SRRs). SRR is defined as the number of patients who survive a given ICD-9 coded injury divided by the total number of patients who sustain the injury. We used the SRR
from the single worst injury (SWI) for each patient, given its superiority over other risk-adjustment methods.\textsuperscript{83,93}

In our model evaluating ICP monitor placement rates, we adjusted for age, gender, transfer status, mGCS score, age-adjusted hypotension, head AIS, severe injury (AIS $\geq 3$) in body region chest or abdomen, and type of intra-cranial lesion (epidural hematoma, subdural hematoma, traumatic subarachnoid hemorrhage, intracerebral mass lesion, compressed/absent basal cisterns, brainstem/cerebellar lesion). We adjusted for similar covariates when evaluating craniotomy rates; however, type of intra-cranial lesion was limited to epidural vs. subdural. Also, head AIS was not included because all children with an epidural or subdural hematoma had an AIS $\geq 4$.

When evaluating splenectomy rates, we adjusted for age, gender, transfer status, age-adjusted hypotension, mGCS score, splenic injury grade (low grade (1-3) vs. high grade (4-5)),\textsuperscript{107} severe injury (AIS $\geq 3$) in body region head and chest, and severe (AIS $\geq 3$) concomitant non-splenic abdominal injury.

**Statistical Analysis**

Baseline patient characteristics for children meeting inclusion criteria for each performance metric were summarized. Random-intercept multi-level modeling was used to develop centre-specific adjusted odds ratios (OR) and 95\% confidence intervals (CI) pertaining to each quality indicator. Using this approach, each centre had an adjusted odds of mortality, splenectomy, ICP monitor placement, and craniotomy. In addition to controlling for a number of covariates, we accounted for the clustering of patients within centres using hierarchical multi-level modeling.\textsuperscript{97}
Shrinkage adjustments were used to improve the reliability of estimates among centres with small sample sizes.\(^{108}\)

The goodness of fit of each model was tested using the Hosmer-Lemeshow test (non-significant \(p\)-values demonstrating good fit). Model discrimination was evaluated using the c-statistic. Less than 5% of patients had missing data for age-adjusted hypotension, mGCS score, and insurance type. Multiple imputation with 5 datasets was used to reduce the potential for introducing bias from these missing variables.\(^{99}\)

We then assessed the extent of inter-hospital variation in rates of mortality, splenectomy, ICP monitor placement, and craniotomy by calculating the median odds ratio (MOR) of each metric. The MOR is the median value generated by comparing the adjusted odds of a given outcome if the same child was admitted to one randomly selected hospital versus another.\(^{109}\) A higher MOR represents increased inter-hospital variance in outcome. The MOR is always higher than 1 because it compares higher to lower ranked hospitals.\(^{109}\) MOR was used rather than intraclass correlation coefficient (ICC) given its better interpretability when using multi-level modeling to analyze binary outcomes and its non-dependence on the prevalence of the outcome of interest.\(^{109,110}\)

**Correlation Between Quality Indicators and Mortality**

We chose to use trauma centre mortality as our primary indicator for comparison and assessed correlations between centre-specific adjusted odds ratios of each quality indicator and mortality using scatter plots. Regression lines were fit to each plot to display the trend of correlation. A
Pearson correlation coefficient (PCC) was generated for each pairwise comparison to determine the extent of correlation and statistical significance.

**Agreement Across Quality Indicators**

To evaluate the agreement between performance metrics, centres were ranked into performance quartiles depending on the magnitude of their respective OR within each metric. Quartile 1 and 4 represented low and high performing centres, respectively. As a result, each centre had four separate quartile rankings depending on how they performed within each metric. Ranking centres into quartiles ensured that performance status was based on relative centre performance within each metric as opposed to the magnitude of the odds ratio alone.

A heat map, which assigns a specific color to each centre based on quartile of performance, was then generated to depict consistency of centre-level performance across each indicator. Each row represents a specific centre, while columns pertain to each centre’s respective performance within each metric. Centres that performed similarly across all indicators would have the same color horizontally across all four metrics. The heat map provides a visual representation of the level of consistency of centre performance across metrics.

To evaluate statistical agreement, Cohen’s weighted kappa was used to test for multiple pairwise agreements between indicators. Light’s weighted kappa was used to test for overall agreement between all 4 indicators. All statistical analyses were performed using SAS, version 9.3, Cary, NC, except for weighted kappa statistics that were computed using R (version 3.0.0). All tests were two-sided with p-values <0.05 considered statistically significant.
4.4 Results

Baseline characteristics among children meeting inclusion criteria for each quality indicator were summarized (Table 4.1). Among 84,880 injured children identified for mortality analysis, splenectomy rates were assessed in 3603 children with blunt splenic injury, ICP monitor utilization rates were evaluated in 3503 children with severe traumatic brain injury, and craniotomy rates were evaluated in 1286 children who had severe TBI and an associated epidural or subdural hematoma.

Patient characteristics differed across subsets of injured children that were evaluated for different indicators. Compared to all injured children, those with severe TBI were more likely to have been injured as a result of motor vehicle crash, have higher injury severity scores, lower mGCS scores, higher rates of hypotension, and higher rates of concomitant severe chest and abdominal injuries (Table 4.1). The most common types of intra-cranial injuries among children with TBI were subdural hematomas (55.9%) and subarachnoid hemorrhages (47.3%). In the subset of children with TBI and an associated epidural or subdural hematoma, most had subdural hematomas (84.0%). Children with blunt splenic injury were more likely to be older and have an MVC injury mechanism, higher injury severity scores, and concomitant severe chest injury than children with all injuries (Table 4.1). One quarter (25.2%) of children with blunt splenic injury had high-grade splenic injuries. In contrast, the population of all injured children had lower injury severity scores and falls were the most common injury mechanism (Table 4.1).
<table>
<thead>
<tr>
<th>Characteristic</th>
<th>All Injured Children (In-Hospital Mortality)</th>
<th>Blunt Splenic Injury (Splenectomy)</th>
<th>Traumatic Brain Injury (ICP Monitor Placement)</th>
<th>Traumatic Brain Injury and Epidural/Subdural Hematoma (Craniotomy)</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>84880</td>
<td>3603</td>
<td>3503</td>
<td>1286</td>
</tr>
<tr>
<td>Outcome (%) *</td>
<td>1312 (1.6)</td>
<td>227 (6.3)</td>
<td>682 (19.5)</td>
<td>282 (21.9)</td>
</tr>
<tr>
<td>Age (SD)</td>
<td>10.0 (5.9)</td>
<td>12.8 (4.6)</td>
<td>11.4 (6.0)</td>
<td>11.2 (6.1)</td>
</tr>
<tr>
<td>Male Sex (%)</td>
<td>56311 (66.3)</td>
<td>2533 (70.3)</td>
<td>2365 (67.5)</td>
<td>889 (69.2)</td>
</tr>
<tr>
<td>Transfer Patient (%)</td>
<td>36812 (43.4)</td>
<td>1800 (50.0)</td>
<td>1324 (37.8)</td>
<td>543 (42.2)</td>
</tr>
<tr>
<td>Injury Mechanism (%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MVC</td>
<td>14775 (17.4)</td>
<td>1336 (37.1)</td>
<td>1482 (42.3)</td>
<td>491 (38.2)</td>
</tr>
<tr>
<td>Motorcycle</td>
<td>1066 (1.3)</td>
<td>71 (2.0)</td>
<td>90 (2.6)</td>
<td>24 (1.9)</td>
</tr>
<tr>
<td>Fall</td>
<td>35973 (42.4)</td>
<td>676 (18.8)</td>
<td>551 (15.7)</td>
<td>270 (21.0)</td>
</tr>
<tr>
<td>Pedestrian</td>
<td>20842 (24.6)</td>
<td>1017 (28.2)</td>
<td>977 (27.9)</td>
<td>349 (27.1)</td>
</tr>
<tr>
<td>Other Blunt</td>
<td>7575 (8.9)</td>
<td>503 (14.0)</td>
<td>403 (11.5)</td>
<td>152 (11.8)</td>
</tr>
<tr>
<td>Firearm</td>
<td>2984 (3.5)</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Cut/Pierce</td>
<td>1665 (2.0)</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>ISS (%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4-8</td>
<td>38801 (45.7)</td>
<td>576 (16.0)</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>9-15</td>
<td>28165 (33.2)</td>
<td>924 (25.7)</td>
<td>347 (9.9)</td>
<td>--</td>
</tr>
<tr>
<td>16-24</td>
<td>11954 (14.1)</td>
<td>1040 (28.9)</td>
<td>996 (28.4)</td>
<td>452 (35.2)</td>
</tr>
<tr>
<td>≥25</td>
<td>5960 (7.0)</td>
<td>1063 (29.5)</td>
<td>2160 (61.7)</td>
<td>834 (64.9)</td>
</tr>
<tr>
<td>Age Adjusted Hypotension (%)</td>
<td>3111 (3.7)</td>
<td>177 (5.0)</td>
<td>408 (11.9)</td>
<td>142 (11.3)</td>
</tr>
<tr>
<td>Motor GCS score (%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1-2</td>
<td>4196 (4.9)</td>
<td>418 (12.0)</td>
<td>2671 (77.2)</td>
<td>989 (77.9)</td>
</tr>
<tr>
<td>3-4</td>
<td>1188 (1.4)</td>
<td>83 (2.4)</td>
<td>518 (15.0)</td>
<td>188 (14.8)</td>
</tr>
<tr>
<td>5-6</td>
<td>74865 (88.2)</td>
<td>2973 (85.6)</td>
<td>271 (7.8)</td>
<td>93 (7.3)</td>
</tr>
<tr>
<td>Severe Injury (AIS ≥ 3) (%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Head</td>
<td>18084 (21.3)</td>
<td>571 (15.9)</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Chest</td>
<td>9574 (11.3)</td>
<td>1348 (37.4)</td>
<td>1499 (42.8)</td>
<td>476 (37.0)</td>
</tr>
<tr>
<td>Abdomen</td>
<td>5087 (6.0)</td>
<td>--</td>
<td>371 (10.6)</td>
<td>111 (8.6)</td>
</tr>
<tr>
<td>Upper Extremities</td>
<td>5734 (6.8)</td>
<td>95 (2.6)</td>
<td>89 (2.5)</td>
<td>34 (2.6)</td>
</tr>
<tr>
<td>Lower Extremities</td>
<td>11242 (13.2)</td>
<td>493 (13.7)</td>
<td>500 (14.3)</td>
<td>153 (11.9)</td>
</tr>
<tr>
<td>Spine</td>
<td>2006 (2.4)</td>
<td>118 (3.3)</td>
<td>213 (6.1)</td>
<td>68 (5.3)</td>
</tr>
</tbody>
</table>

*Proportion of patients with the outcome as specified in the column header
After adjustment, each multi-level model demonstrated good fit (Hosmer-Lemeshow, p > 0.1) and adequate to outstanding discrimination (c-statistic range 0.71-0.97). There was no significant multicollinearity in any of the models (VIF<4). The median odds ratio (MOR) for each performance metric was as follows: 2.0 for mortality, 1.96 for splenectomy, 1.46 for craniotomy, and 2.92 for ICP monitor placement. This demonstrates significant inter-hospital variation in the use of ICP monitors with a nearly 3-fold increase in the odds of receiving an ICP monitor if any given child is treated at one randomly selected hospital versus another. The same concept applies to the MOR for mortality, splenectomy, and craniotomy; however, these performance metrics demonstrated less inter-hospital variation than ICP monitor placement.

**Correlation Between Quality Indicators and Trauma-Related Mortality**

We evaluated the correlation between each of the indicators and mortality. The scatter plot of centre-specific adjusted odds of splenectomy and death showed no obvious correlation (Figure 4.1). Furthermore, the Pearson correlation coefficient (PCC) was not significant, showing that no statistical correlation was present (PCC = 0.08, p=0.36). Similarly, no correlation was evident between the centre-specific odds of ICP monitor placement and death (Figure 4.2. PCC = -0.02, p=0.84)). The scatter plot of centre-specific odds of craniotomy and death, however, did show a significant negative correlation (Figure 4.3). This was further supported by a statistically significant PCC (-0.18, p=0.03), suggesting that higher craniotomy rates correlated with lower mortality.
**Figure 4.1. Center-Specific Adjusted Odds of Splenectomy vs. Death**

![Scatter plot of center-specific adjusted odds of splenectomy versus death. Regression line fit to display the trend of correlation and Pearson correlation coefficient calculated to determine the statistical significance of the correlation.](image)

**Figure 4.1.** Scatter plot of centre-specific adjusted odds of splenectomy versus death.

Regression line fit to display the trend of correlation and Pearson correlation coefficient calculated to determine the statistical significance of the correlation.
Figure 4.2. Scatter plot of centre-specific adjusted odds of intracranial pressure (ICP) monitor placement versus death. Regression line fit to display the trend of correlation and Pearson correlation coefficient calculated to determine the statistical significance of the correlation.
Figure 4.3. Center-Specific Adjusted Odds of Craniotomy vs. Death

Figure 4.3. Scatter plot of centre-specific adjusted odds of craniotomy versus death.
Regression line fit to display the trend of correlation and Pearson correlation coefficient (PCC) calculated to determine the statistical significance of the correlation.
Agreement Across Quality Indicators

After ranking all 150 centres by performance quartile in each metric, only three centres performed similarly across all four metrics. Two of these centres performed in the third highest quartile in each metric and one centre performed in the highest quartile of performance in each metric. Our heat map further illustrated a general lack of concordance among indicators (Figure 4), with very few centres performing consistently across metrics. Though some centres performed similarly with respect to mortality and craniotomy rates (same color across each metric), agreement between these two indicators was limited. Cohen’s weighted kappa showed slight agreement for the pairwise comparison of mortality and craniotomy (0.17 (0.02, 0.32)); however, there was no significant agreement between other pairwise comparisons. Light’s overall weighted kappa demonstrated no significant agreement between all four indicators (-0.01 (-0.07, 0.06)).
Figure 4.4. Heat map visually depicting the consistency of hospital performance across four quality indicators. Each row represents a specific trauma centre and columns display performance in each indicator based on centre-specific adjusted odds ratios. Performance is color-coded, with darker blue representing the lowest quartile of performance and lighter blue representing the highest quartile of performance. Hospitals that perform similarly in each indicator have the same color across all columns.
4.5 Discussion

We have shown that centre-level performance among U.S. trauma centres caring for injured children is not consistent across quality indicators evaluated in this study. When assessing variation in outcomes and practice patterns across centres, the inter-hospital variation in ICP monitor usage was highest, followed by mortality, splenectomy, and then craniotomy. We found a negative correlation between the centre-specific odds of mortality and craniotomy, in addition to slight agreement between these two indicators. However, there was no significant correlation between the centre-specific adjusted odds of mortality and other quality indicators. There was no significant agreement between all other pairwise comparisons or overall among all four indicators. Our results suggest that a centre’s performance in one domain of quality does not necessarily predict performance in other domains, highlighting the importance of a multi-faceted approach to measuring trauma-related quality of care.

While several studies have evaluated the pediatric trauma quality indicators we explored in isolation, however, none have evaluated how these indicators relate to each other. Our findings are consistent with adult studies warning of the risks of relying on one quality indicator for hospital performance evaluation. In a recent systematic review, Pitches et al. reviewed the literature to assess whether hospitals with higher risk-adjusted mortality provided poorer quality of care. These investigators found that only 51% of studies demonstrated a positive correlation between better quality of care, as demonstrated by process indicators, and risk-adjusted mortality. In another study, Sharma et al. evaluated centres caring for adults with traumatic brain injury and found that centres classified as high performers with respect to mortality did not perform similarly with respect to functional outcome. Hashmi et al. showed that mortality-based benchmarking of adult trauma centres did not predict which centres had high complication
These investigators advocated for better benchmarking mechanisms to incorporate non-mortality measures of trauma care quality. Our study highlights that many of these findings from the adult literature are also applicable to the pediatric trauma population.

A number of strengths to this study exist. By evaluating agreement across multiple indicators as opposed to just one indicator and mortality, we were able to determine how a variety of different indicators relate to one another. As a result, we demonstrated that inconsistencies in centre performance across metrics exist not only between mortality and other indicators, but also between indicators distinct from mortality. Also, to ensure our results were reliable, we evaluated the level of concordance among indicators using several different methods, all of which reached similar conclusions. By using a geographically diverse and nationally representative dataset, we were able to compare the performance status of a large number of U.S. trauma centres that cared for injured children. In addition, our sample size was sufficiently large enough to study all outcomes of interest, including relatively rare outcomes such as in-hospital mortality. The comprehensiveness of data in our dataset allowed us to control for a number of covariates that were pertinent to each indicator being evaluated. As a result, we produced centre-level risk-adjusted odds of mortality, splenectomy, ICP monitor placement, and craniotomy. Lastly, by using hierarchical multi-level regression, we were able to account for the clustering of patients within centres and use shrinkage adjustments to produce more realistic estimates (closer to the grand mean) among centres with small sample sizes.

There are also several limitations to our study that should be considered. The data we used were derived from a voluntary trauma registry of level 1 and 2 U.S. trauma centres. Voluntary participation may introduce selection bias as we evaluated centres that ultimately chose to participate in TQIP. Furthermore, our study focused on a handful of pediatric trauma quality...
indicators, mostly related to outcome and process measures. Though we selected commonly used pediatric trauma quality indicators, other important markers of quality also exist, including those related to post-hospital care and quality of life, such as Disability-Adjusted Life Years (DALY) lost, long-term functional outcome, complication rates, and readmission rates. As a result, our findings only pertain to the indicators evaluated herein and may not extend to other quality indicators. Lastly, limits with regards to our data may introduce residual confounding from unmeasured covariates (e.g. pre-hospital care), which could falsely attribute a certain performance status to centres. We limited this potential by adjusting for most clinically relevant covariates in each of our models.

Our study demonstrates that among U.S. trauma centres caring for injured children, centre-level performance is not consistent across the four pediatric trauma quality indicators we evaluated. These findings have significant implications for trauma quality improvement efforts. Assessment of quality based on a single indicator, such as in-hospital mortality, does not predict performance in other relevant areas. Instead, multiple quality indicators should be taken into consideration to better guide performance improvement activities. Furthermore, any composite measure of quality must be sufficiently sophisticated to account for the inconsistencies in centre performance across indicators. Quality improvement programs, such as ACS TQIP, should consider these findings as they develop trauma quality improvement initiatives specific to children.

Further research examining how other pediatric trauma quality indicators relate to one another and to the indicators evaluated in this study is required. This will allow for a comprehensive understanding of how pediatric trauma quality indicators reflect different elements of quality and will better inform the development of pediatric quality improvement initiatives. By improving
the way in which quality improvement programs measure the quality of pediatric trauma care, weaknesses at the centre-level will be accurately identified and targeted support can be provided.

Conclusions

In this chapter, we have shown that trauma centres that are high or low performers in one area of pediatric trauma care may not perform similarly in other domains. We found little to no consistency in centre-level performance across pediatric trauma quality metrics such as mortality rate, splenectomy rate, ICP monitor utilization, and craniotomy rate. These findings should be considered during the development of pediatric trauma quality improvement initiatives to allow for more comprehensive measurement of hospital quality as opposed to benchmarking based on a single indicator, which will subsequently lead to better identification of weaknesses and improved trauma care for injured children.
CHAPTER 5: Discussion and Conclusions

5.1 Summary of Findings

The analyses herein demonstrated how health services research methods could be used to better understand differences in processes of care and outcomes among trauma centres caring for injured children. Chapter 3 and 4 of this thesis describe two observational studies that evaluated i) differences in risk-adjusted in-hospital mortality among different trauma centre types caring for injured children and ii) whether centres that perform well in one area of quality, such as in-hospital mortality, also perform similarly across other domains of quality. All studies were conducted using a cohort of injured children who were admitted to U.S. trauma centres participating in the American College of Surgeons Trauma Quality Improvement Program (TQIP).68

Chapter 3 addressed research aim 1 and evaluated differences in risk-adjusted in-hospital mortality among pediatric, mixed, and adult trauma centres. We found that children treated at pediatric trauma centres had higher rates of survival than those treated at adult or mixed trauma centres, even after controlling for differences in case mix. Furthermore, we determined that the association between trauma centre type and mortality was most evident in younger children aged 0-5 years. Our secondary analyses in a cohort of severely injured children also showed an associated survival benefit for children receiving care at pediatric trauma centres. Centre volume did not explain the observed differences in mortality across trauma centre types, suggesting that other factors intrinsic to the environment and practices within pediatric, mixed, or adult trauma centres were responsible for these differences. Our findings provide further evidence that injured
children treated at pediatric trauma centres have a survival benefit compared to those treated at mixed or adult trauma centres.

In chapter 4, we evaluated other quality indicators, as we recognize that mortality is not the only indicator of hospital quality. We sought to determine whether centres that perform well in one area of quality, such as in-hospital mortality, also perform well in other areas of quality, such as the non-operative management of blunt splenic injury and the use of ICP monitors and craniotomy in select children with severe TBI. To do so, we assessed the concordance of centre-level performance across commonly used indicators of quality pediatric trauma care. Among the four indicators we evaluated, which were in-hospital mortality, splenectomy rate, ICP monitor utilization, and craniotomy rate, we found little to no consistency in centre-level performance across these metrics. Hence, we concluded that centres that perform well in one area of quality might not perform similarly in other domains of quality.

From these analyses we ascertain that injured children treated at pediatric trauma centres have a lower in-hospital mortality compared to those treated at adult and mixed trauma centres. Efforts to determine how care or expertise differs in pediatric trauma centres must be undertaken to allow for targeted quality improvement at mixed and adult trauma centres. In addition, we also demonstrated that good performance with respect to mortality (low in-hospital mortality) does not necessarily reflect a centre’s performance in other areas of quality. As a result, several different indicators of quality should be taken into account when measuring pediatric trauma quality of care as opposed to benchmarking centres on a single indicator.

5.2 Limitations
Several limitations of our analyses must be considered when interpreting our findings. The specific limitations of each study are outlined in their respective chapters; however, we will broadly discuss the overall limitations of this thesis. As with any research, minimizing sources of bias is critical. Yet, when performing health services research using registry data, neither randomization nor prospective study design is feasible. Despite the use of advanced statistical methods to simulate a controlled experiment, the introduction of some element of bias is inevitable.

In our analyses, we derived data only from level I and II U.S. trauma centres that voluntarily participated in TQIP, which may introduce selection bias and limit external generalizability. Though this is mainly a selection issue as opposed to selection bias per se, it in itself can result in selection bias as participating centres may be significantly different than non-participating centres. For example, adult trauma centres that participate in TQIP may be more proactive with respect to quality improvement activities and may in fact provide better care for children than non-participating adult trauma centres. As a result, our analyses may underestimate differences in outcomes between adult and pediatric centres. Furthermore, our analyses do not incorporate level III and IV trauma centres or non-designated hospitals, both of which provide care to a large number of injured children. Hence, our particular exclusion and inclusion must be taken into consideration when evaluating the external generalizability of our findings. Inferences from our findings can only be made to populations of children similar to the cohort we evaluated, since the associations we found may not be significant in children treated at non-participating centres or in children treated in different healthcare systems.

Bias introduced by differential or non-differential misclassification of exposure, outcomes, or other patient characteristics by the observer, which in this case are specialized data registrars at
each hospital, is another important consideration. As evidenced in chapter 2, specialized training of data registrars, a national data standard to ensure consistent coding across sites, and quarterly external validation all assist in minimizing this type of bias. In our analyses in chapter 3, of particular importance is the potential for exposure misclassification bias. We classified centres as pediatric, mixed, or adult trauma centres based on their ACS verification or state designation status. However, there may be trauma centres that function as mixed centres but haven’t necessarily pursued pediatric accreditation. As a result, mixed centres may be incorrectly categorized as adult trauma centres. Furthermore, our dataset does not capture whether adult or pediatric trauma specialists treat injured children at mixed trauma centres. In some cases, the pediatric team at mixed centres is only activated upon request, whereas in other cases, they are automatically activated for all pediatric traumas. This uncertainty may introduce another element of exposure misclassification bias, as mixed trauma centres that don’t often activate the pediatric team may function more like an adult trauma centre than a pediatric trauma centre. In order to limit classifying all mixed trauma centres as either pediatric or adult trauma centres, we chose to evaluate mixed trauma centres separately to account for their unique organizational structure.

Confounding bias must also be considered. Though we minimized this bias by accounting for most confounders via regression analyses, we were not able to adjust for a number of unmeasured confounders, which may lead to residual confounding. We were limited by the lack of data in our dataset pertaining to particular clinical nuances, reasons for triage to a certain trauma centre type, proximity to the nearest trauma centre, mode of transport, time from injury to admission, and specifics about institutional resources and post-hospital care. As a result, despite the use of advanced statistical methods, we cannot be absolutely certain that the associations we reported are due to exposure effects rather than unmeasured confounding.
Furthermore, a lack of data pertaining to specific aspects of trauma care limited our ability to study certain processes of care and outcomes. We primarily focused on mortality, in addition to several other outcomes such as splenectomy rates, ICP monitor placement rates, and craniotomy rates. Although we evaluated relatively common outcomes and processes of care, we were unable to evaluate other important measures such as functional outcome and post-discharge quality of life. These outcomes are particularly important endpoints in pediatric trauma care, since outcomes such as mortality are relatively rare and injury results in significant long-term disability in children. With this in mind, it is important to consider that our findings are only applicable to the outcomes we studied and similar conclusions may not be reached if other processes of care and outcomes are studied.

5.3 Implications

The work presented in this thesis has important implications for clinicians, hospitals, policy makers, and quality improvement programs. With respect to survival, pediatric trauma centres offer injured children the most optimal care environment. We also observed a benefit of the added pediatric qualification at mixed trauma centres over adult trauma centres. These findings support increased efforts to determine what processes of care result in the survival benefit associated with care at pediatric trauma centres and in some instances, mixed trauma centres. We also demonstrated that the benefit of pediatric trauma centre care was most evident among younger children aged 0-5 years. Ideally, revisiting trauma triage guidelines to prioritize the transfer of younger children to pediatric trauma centres as opposed to adult centres is warranted. Also, increasing the availability and access to pediatric trauma centre care would be beneficial. However, we acknowledge that the inherent challenges of changing triage patterns and altering resource availability make these interventions largely unfeasible. Instead, our findings serve to
identify where weaknesses exist so that targeted quality improvement support can be implemented at centres with a focus on additional resources and pediatric trauma education.

Changes to accreditation standards may be also required to help incorporate beneficial practices at adult and mixed trauma centres caring for a large number of injured children.

Though trauma centre mortality is an important outcome by which to measure the quality of pediatric trauma care, chapter 4 highlights that centres that perform well in one performance metric, such as mortality, might not perform similarly in other metrics. These findings are especially important since centres are often benchmarked to one another using a single indicator.\textsuperscript{112,113} However, as we demonstrated, measuring quality based on one indicator does not adequately represent a centre’s performance across other indicators. Our findings should be considered by health services researchers and policy makers during the establishment of quality improvement initiatives. Quality improvement programs must adopt a multi-faceted quality measurement approach with several indicators in order to comprehensively measure the quality of pediatric trauma care at centres. Any attempt at a composite measure of hospital quality must have enough complexity to account for the inconsistencies in centre performance across different metrics.

Using health services research methodology, we were able to address clinically important research questions that may have been otherwise unfeasible to study using prospective or controlled trials due to impractical sample sizes and ethical issues. Our analyses highlight many of the advantages of this type of research, which include readily available data, inexpensive study conduction, the opportunity for ongoing assessment of registry data, and the analyses of real-world clinical data across many different hospitals.
5.4 Directions for Future Research

We have provided the framework for studying processes of care and outcomes among trauma centres caring for injured children. Future research can build on our findings and focus on a number of areas identified in this thesis, while also addressing many of the limitations that we encountered.

With respect to our analyses of mortality across trauma centre types in chapter 3, further study examining which structure and process of care elements are responsible for these differences in mortality is required. By doing so, quality improvement initiatives can be targeted toward these areas to improve survival. Evaluating traumatic brain injury management strategies may be a useful starting point, as this injury is the most common cause of death among injured children\(^7\) and there are documented survival benefits associated with particular pediatric traumatic brain injury management strategies.\(^{46}\) Hence, evaluating differences in processes of care related to traumatic brain injury, such as ICP monitor utilization, craniotomy practices, and the presence of neurosurgical and intensivist-related resources, across centre types may prove useful. Other processes of care related to the management of abdominal, chest, and orthopedic trauma should also be evaluated across different trauma centre types.\(^{46}\) Notable differences in these processes of care may yield valuable information regarding the survival benefit associated with care at pediatric trauma centres. Furthermore, if not associated with mortality, these process measures may be associated with functional outcome, post-hospital recovery or healthcare cost, all of which are important outcomes to consider when comparing different trauma centre types.\(^{46}\)

The use of a more comprehensive dataset in future research will allow for the evaluation of a number of other important factors that may influence mortality, such as processes related to
hospital personnel (e.g. surgeons, ICU staff, specialists, pediatric specialists, etc.) and resources (e.g. operating room facilities, CT scanners). By including these factors into future analyses, the contribution of these factors toward mortality differences can be assessed and analyses can be adjusted accordingly. In addition, the collection of pre-hospital data elements, such as geographical proximity to the nearest trauma centre, severity of injury in the field, time to transfer, and mode of transport, will allow for more refined analyses with a reduction in residual confounding. In particular, data regarding the geographical proximity of pediatric, mixed, or adult trauma centres would allow for the development of a propensity score that measures each patient’s propensity to be triaged to one centre versus another. Studies should aim to develop and evaluate this type of propensity score to strengthen future studies by allowing for the use of a propensity-matched approach.

While our analyses focused on level I and II pediatric, mixed, and adult trauma centres, future studies can expand to include level III and IV trauma centres and non-designated hospitals, all of which care for a significant number of injured children. Efforts should be undertaken to expand TQIP to include all levels of trauma centres. Doing so will improve the external generalizability of our findings. Furthermore, similar analyses using expanded data collection via administrative databases may help to substantiate our results using population-based analyses.

In chapter 4, where we evaluated the relationship of different quality indicators to one another, many of the aforementioned future directions for research also apply. A particularly important area for future research involves expanding analyses to evaluate the consistency of centre-level performance across a broader range of quality indicators. Over one hundred different pediatric trauma quality indicators exist, but many are impractical for reporting purposes. Some important indicators to consider include metrics related to functional outcome and quality of life. Future
studies should evaluate how indicators we assessed in this thesis relate to other indicators not evaluated herein. Researchers can also assess the utility of a composite measure of hospital quality, which may or may not be feasible. Any composite measure must be sophisticated enough to account for the inconsistencies in centre performance across metrics, while also providing an accurate measure of overall hospital quality of care. A better understanding of how to measure hospital quality will provide significant insight into the development of pediatric trauma quality improvement activities and benchmarking practices. As quality improvement initiatives evolve, studies to evaluate the effectiveness of quality improvement activities are necessary. Studies should focus on following centre performance longitudinally and determining whether improvement in one area quality also predicts improvement in other areas of quality.

Going forward, a critical element of research evaluating differences in processes of care and outcomes across hospitals caring for injured children will be a mixed methods approach, using both quantitative and qualitative analyses. Qualitative analyses via surveys and interviews will service to identify the nuances of management strategies and practice patterns across centres, the subtly of which may not be captured in quantitative datasets. This will help to determine the mechanisms of inconsistencies that exist in processes of care and outcomes. In addition, mixed methods will allow researchers to comprehensively evaluate the quality of pediatric trauma care at hospitals, from the perspective of the practitioner and patient. As a result, this may produce a more complete picture of the healthcare system, which will subsequently aid in identifying weaknesses.

With respect to Canadian trauma systems, future research can expand on these analyses to include Canadian data as well. As we outlined in chapter 1, trauma systems in Canada do not differ significantly from the U.S. Hence, many of the findings from our research are likely
applicable to Canadian trauma systems. However, given differences in population density, the urban/rural divide,\textsuperscript{64} triage patterns, and access to pediatric trauma centre care, research focusing on trauma systems in Canada must be undertaken to evaluate the hypotheses in this thesis in the Canadian context.

Health services research serves to provide health care practitioners and policy makers with data to help guide quality improvement practices and improve patient outcomes. As we have demonstrated in this thesis, practice patterns and outcomes across centres caring for injured children are quite variable. We acknowledge that certain aspects of the healthcare system cannot be practically changed. Hence, future research should focus on the areas of weakness identified in this thesis and elucidate actionable items that quality improvement programs can act on to improve pediatric trauma care.
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