The mortality cost of undertriage of major trauma in Ontario

by

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A thesis submitted in conformity with the requirements for the degree of Doctor of Philosophy
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Abstract

Introduction: Multiple studies suggest that severely injured patients treated at trauma centers have a lower mortality compared to patients treated at non-trauma centers. In many trauma systems, a significant proportion of patients continue to be transported from the scene to a non-trauma center (undertriaged); only a fraction of these patients are subsequently transferred to trauma center care. Although previous analyses have attempted to examine the mortality associated with transfer and with undertriage, these studies were not population-based, and therefore potentially underestimated the mortality cost of undertriage at the system level.

Methods: In this dissertation, we developed an algorithm to convert ICD-10 diagnosis codes to Injury Severity Score. This algorithm allowed us to utilize population-based data to examine the outcomes of all severely injured patients surviving to reach an emergency department in Ontario. We examined whether, among severely injured patients, transfer from a non-trauma center to a trauma center is associated with increased mortality compared to direct transport from the scene.
In addition, we used an instrumental variable analysis to produce a population-based estimate of the mortality cost of undertriage in a subset of patients injured in motor vehicle collisions.

**Results:** Patients requiring transfer to trauma center care have significantly higher mortality at 30 days than patients transported directly from the scene of injury (Odds ratio 1.24; 95% CI, 1.10-1.40). Among patients involved in motor vehicle collisions, only 45% were transported directly to a trauma center. In this subset of patients, those triaged directly to a trauma center had significantly lower mortality at 24 hours (Odds ratio 0.58, 95% CI 0.41-0.84) and 48 hours (Odds ratio 0.68, 95% CI 0.48-0.96) compared to undertriaged patients. There was a trend towards decreased mortality among patients triaged to a trauma center at 7 days and 30 days.

**Conclusions:** Undertriage and transfer after major trauma are associated with substantial increase in mortality compared to direct transport to a trauma center. These data suggest a need to design strategies to improve access to trauma center care in Ontario.
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List of Abbreviations

AAAM – Association for the Advancement of Automotive Medicine

AIS – Abbreviated Injury Scale

ACS COT – American College of Surgeons Committee on Trauma

CI – Confidence interval

CIHI – Canadian Institute for Health Information

DAD – Discharge Abstract Database

DALY - Disability-Adjusted Life Year

ICC – Intraclass Correlation Coefficient

ICES – Institute for Clinical Evaluative Sciences

ISS – Injury Severity Score

ICD – International Classification of Diseases

ICD-9 – Ninth Revision of the International Classification of Diseases

ICD-CM-9 – Clinical Modification of the Ninth Revision of the International Classification of Diseases

ICD-10 – Tenth Revision of the International Classification of Diseases

IKN – ICES Key Number
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Chapter 1
Literature Review

1.1 Traumatic injury: a global epidemic

Injury represents a major cause of death both in developed countries and in underdeveloped countries, and the proportion of deaths attributable to injury worldwide is increasing. In 2002, the World Health Organization (WHO) published a report on injury based on data derived from the Global Burden of Disease 2000 database, the most comprehensive source of data regarding global morbidity and mortality currently available. This report identified that injury was the leading cause of death and disability worldwide for all age groups below the age 60. The leading causes of injury-related deaths identified in this report were road traffic injuries (1,259,838 deaths in the year 2000) and self-inflicted injuries (814,778 deaths in the year 2000). When disability and death were examined together, road traffic injuries were the 9th leading cause of disability-adjusted life years (DALYs) lost, and accounted for 41,234,097 DALYs. In addition to a direct effect on the health of individuals, injury has a significant, global economic impact. For example, road traffic injuries alone are estimated to result in global losses of US$ 518 billion annually and to cost governments up to 5% of their gross national product. It is evident that injury control is an important global public health priority.

There have been important changes in the causes of injuries on a global level over the past two decades. Specifically, compared to previous reports, the 2002 WHO report demonstrated a significant decrease in the frequency of injuries due to war or large-scale conflict. In 1994, war was the 13th most frequent cause of death among children aged 0 to 4, and the 6th most frequent cause of death among individuals aged 5-44. In contrast, in 2000, war was no longer among the fifteen most important causes of death among children aged less than 5.
Among individuals aged 5 to 14 and those aged 30 to 44, war as a cause of death also became significantly less frequent\(^1\). In contrast, road traffic injuries have increased significantly. Although, in 2004, road traffic injuries accounted for 2.4% of all deaths worldwide, it is anticipated that this figure will rise to 3.6% by 2030, resulting in road traffic injuries becoming the 5\(^{\text{th}}\) leading cause of death worldwide\(^4\). These changes in patterns and frequency of injuries have important implications for public health policy and prevention strategies.

1.2 The burden of traumatic injury in Canada and in Ontario

As on a global level, the social costs of injury in Canada are enormous. Injury is the leading cause of death in Canada for individuals aged between 1 and 44, and the fourth leading cause of death overall\(^5\). Approximately 13,500 deaths occur due to injury in Canada every year; there are 42 injury-related deaths per 100,000 Canadians annually\(^6\). In addition to deaths, in 2004, injury resulted in approximately 211,768 hospitalizations in Canada\(^7\). Overall, injury resulted in 97.14 hospitalizations per 100,000 Canadians.

The economic cost of injury in Canada is also significant. Because of the relatively young age of a large proportion of injured individuals, injury results in significant economic losses. The annual cost of injury in Canada has been estimated at $19.8 billion\(^6\). This estimate includes both direct costs (i.e. health care costs arising from injuries) and indirect costs (i.e. costs related to reduced productivity from hospitalization, disability, and premature death). Approximately 46% of injury-related costs are indirect in nature\(^6\).

In 2004, in Ontario, 4,643 patients died as a result of injury and 71,727 were hospitalized\(^6\). Injuries account for approximately 6% of all hospitalizations\(^8\). In addition, injuries result in over one million emergency department visits in Ontario on an annual basis - one
quarter of all emergency department visits\(^6\). The direct costs of injury in Ontario in 2004 were $3.7 billion, and the total costs were estimated at $6.8 billion\(^6\). Strategies which could reduce the burden and costs of injuries in Canada and in Ontario are required.

### 1.3 The public health approach to injury

Given the enormous social and economic impact of injury, identifying interventions to reduce the incidence and consequences of injury is imperative. The most common conceptual framework used in injury control is the Haddon Matrix. Prior to the introduction of Haddon’s approach, injuries were studied using a “descriptive” approach, which views them purely as “accidents.” The Haddon Matrix, which was introduced by William Haddon in 1970, examines injury through a public health perspective, and represents the key to understanding current efforts in trauma health services research\(^9\).

Haddon noted that “widely believed folklore notwithstanding, all known injury distributions are highly nonrandom in time, place, and person, just as one would expect from the nonrandomness of their causes”\(^10\). His framework divided injury events into three phases (pre-event, event and post-event), which correspondingly offers the opportunity to identify strategies for primary, secondary and tertiary prevention. In addition, at each phase, the causes of injury are understood through a classic host-agent-environment framework, allowing further opportunities to implement prevention or harm reduction strategies (Table 1.1). The agent of injury in Haddon’s framework is the exchange of energy – the necessary agent for injury to occur\(^10\). This agent is carried by the vector or vehicle of injury, the specific means by which the injury occurs. The vehicle or vector of injury may be a vehicle in the case of a collision, a tall building in the case of a fall, or another individual in the case of inter-personal violence. Finally, the host of injury is the victim of the injury itself.
Haddon’s approach suggests that efforts to reduce injuries may be effective at any of the three phases of injury. Additionally, his approach suggests that, rather than changing the “host” (i.e. patient behaviour), injury and its effects can be reduced by modifying the agent/vector or the environment itself. As Haddon himself emphasized, “with injuries, as with various other pathological conditions long since brought under control, this preference for emphasizing the individual typically results in blame being placed on the victim. As a result, it is argued that measures directed elsewhere and the idea that a responsibility exists to employ them deserve no consideration.” The Haddon matrix, which emphasizes that important opportunities exist to modify the risk of injury outside of the victim’s behavior, represents a fundamental departure from this view. Installing airbags (modifying the vector), reducing speed limits (modifying the environment) and other public health initiatives can therefore be understood to directly correspond to Haddon’s approach.

In addition to shifting the model of injury from one focused on individual behavior towards one based on an interaction of behavior and environment, the Haddon matrix is relevant to the present discussion also due to its emphasis on tertiary prevention. While prevention of the injury through primary or secondary prevention is preferable, mitigating the consequences of injury once it has occurred is a key component of the Haddon approach: “Once appreciable injury to man or to other living structure occurs, complete elimination of undesirable end results is often impossible, though appreciable reduction is commonly achievable.” In the case of injury, tertiary prevention can be achieved by ensuring the injured individual has adequate access to appropriate care. Ideally, such care would reduce the morbidity or mortality associated with the injury and, by extension, reduce the personal and economic costs of injury on the injured individual and on society as a whole.
Tertiary prevention following injury is the focus of the present thesis. In this dissertation, we will present evidence that strongly suggests that outcomes following severe injury are highly modifiable with appropriate care. This dissertation will focus on the question of what constitutes appropriate care following severe injury, as well as the effects of this care on outcomes following severe injury.

1.4 Organized systems of trauma care

Post-injury care can be divided into three distinct phases: prehospital care, acute care, and post-acute (rehabilitation) care. In most jurisdictions in North America, this post-injury care has been integrated, at least to some degree, into a single organized system of care for the injured patient: a trauma system. Although trauma systems vary significantly in structures and processes, they share a common objective: rapidly identifying severely injured patients and ensuring that they reach appropriate care.

1.4.1 The history of organized systems of trauma care

Modern civilian trauma systems are modeled on military trauma systems that evolved during the first two thirds of the 20th century\textsuperscript{11,12}. The principle of triage (sorting patients based on perceived severity of injury) is clearly derived from military practice. In addition, during the major conflicts of the 20th century, a number of innovations were introduced in the military setting that proved critical to reducing military deaths. These innovations included rapid evacuation, bypass of non-equipped facilities and regionalization of care; the translation of these innovations into civilian practice resulted in the modern trauma system.

At the onset of World War II, care for injured soldiers was provided in large, fixed field hospitals located at airfields and other locations convenient for evacuating soldiers out of the
During the war, however, it became evident that the delays associated with transporting soldiers to these field hospitals were causing unnecessary mortality. The military shifted its approach to developing forward medical units, which were able to provide life-saving care close to the frontlines. These changes in organization were highly successful, and led to shorter evacuation times, earlier resuscitation and reduced mortality.

The principle of providing medical and surgical care in a rapid manner and close to the conflict zone was further developed during the Korean War. During that conflict, frontline medical units (known as mobile auxiliary surgical hospitals, or MASH) were supplemented with helicopter evacuation. Furthermore, when it was observed that a significant number of deaths were occurring at “battalion aide stations,” directly in conflict zones, staffing practices at these stations were modified to ensure the presence of personnel capable of performing life-saving interventions like tourniquets and chest tubes. The American military’s emphasis on early management and rapid evacuation to definitive care further progressed during the Vietnam conflict. For example, during the military conflict in Vietnam, human and physical resources were distributed in such a way as to ensure that soldiers were constantly within 35 minutes of a medical facility capable of providing definitive trauma care. The gradual innovations that occurred in military medicine over the course of the 20th century were associated with significant reductions in military mortality. Whereas field casualty rates remained relatively stable from World War I to the Vietnam War, post-evacuation mortality rates fell from 8.5% to 3.6%.

Following the Korean and Vietnam wars, it became evident that standards of civilian trauma care lagged far behind what was available to injured soldiers of the era. In 1966, the National Academy of Sciences published a report titled “Accidental Death and Disability: The Neglected Disease of Modern Society.” The report highlighted the magnitude of the civilian
trauma problem, and the preventable nature of many of these deaths. In addition, the report examined the resources in place for the injured patient, which were extremely minimal. As one of the report authors recalled, “[t]he only requirement for an ambulance in the 1950s was that the vehicle permit the patient to lie down. There were then 12,000 ambulance services in the United States, 50% of which were run by morticians. One could almost imagine a conflict of interest.”

The report also highlighted the inadequacy of hospital care for the injured; patients were simply transported to the closest hospital, where the emergency department might be closed or inadequately staffed.

The publication of the National Academy of Sciences report on injury, along with the influx of medical personnel from theatres of war, led to “an avalanche of remedial action.” In 1966, the federal government enacted the Highway Safety Act, which gave the Department of Transportation the authority to set standards for highway safety programs. Among these highway safety programs was one that required states to set specific standards for ambulance programs.

By 1971, injury related initiatives were also introduced by a variety of other governmental and non-governmental organizations, including the National Institutes of Health, the American Medical Association, the National Academy of Sciences and the United States Public Health Service. New initiatives were also accompanied by dedicated federal and state funding to study, prevent and treat injury.

A large number of initiatives were also introduced by the American College of Surgeons Committee on Trauma (ACS COT), an organization which has since become a guiding force in trauma system organization throughout North America. Among the Committee’s activities were the publication of “Standards for Emergency Ambulance Services” in 1967, as well as “Guidelines for Design and Function of a Hospital Emergency Department” in 1970. In 1976,
the Committee on Trauma published the report entitled “Optimal Resources for the Care of the Seriously Injured,” in the American College of Surgeons Bulletin. The report clearly outlined the resources required by centers dedicated to the care of injured patients, and described a program of external verification for these centers. These dedicated centers have come to be known as trauma centers.

1.4.2 Trauma center accreditation guidelines

Trauma centers are the central component of any trauma system. These hospitals have been identified as having the specialized resources required to manage injured patients. Trauma centers are identified through two separate processes: designation and accreditation/verification. Centers can be designated by regional, state or provincial health authorities, as part of governmental plan for the management of injured patients in the authority’s jurisdiction. In contrast, accreditation or verification can be conducted by either a governmental or non-governmental agency. Unlike designation, the accreditation or verification process involves visits to the institution by delegates, and an evaluation of the center’s resources and programs based on strict criteria. Trauma centers can therefore be designated, accredited/verified or both.

Existing trauma designation and accreditation schemes recognize that institutions have different resource levels, and therefore differ in their capabilities with regards to managing injured patients. Trauma centers are categorized into “levels” from I to V based on their resources and capabilities. Broadly speaking, level I and level II centers are equipped to provide definitive management to severely injured patients. Lower level (level III, IV and V) centers provide preliminary care to severely injured patients, and definitive care to patients with less severe injuries.
Since their inception in 1976, the trauma center classification guidelines used by the ACS COT have provided the basic framework for trauma center designation in North America. They are similar to those published by the Trauma Association of Canada (TAC) and are also the guidelines most commonly used to classify trauma centers in the trauma systems research literature.

In Canada, trauma center accreditation is performed by TAC. TAC developed its first trauma center accreditation standards in 1993. According to TAC, it is the responsibility of individual health authorities to designate an appropriate number of trauma centers based on the provincial population, and to organize the trauma system based on the provincial trauma plan. TAC has been conducting external verification of designated trauma centers since 1995 and, since 2007, has adopted the level I, II, III, IV and V classification scheme across Canada. At the time of the publication of this dissertation, the TAC accreditation guidelines were undergoing revision. However, the standard process for TAC accreditation during the time period of the data described in this dissertation is available from previously published guidelines.

The ACS COT and TAC trauma center accreditation guidelines are closely related, and share many similar elements. Highlights from the ACS COT and TAC accreditation guidelines are presented below.

**Level I centers**

Level I centers are a regional resource capable of providing the highest level of care to the severely injured patient. In addition, Level I centers hold a leadership role in the regional trauma system, both clinically and academically. Level I centers must maintain a high annual volume of trauma admissions; volume criteria differ somewhat across ACS COT and TAC.
guidelines. According to ACS COT guidelines, the level I center must treat one of: 1,200 trauma patients annually, 240 patients with severe injury or 35 patients with severe injury per trauma surgeon. In contrast, TAC guidelines suggest that level I centers should treat at least 400 patients with severe injury, and preferably 650 such patients, annually. Additionally, according to TAC guidelines, level I centers should treat at least 1000 trauma patients annually.

Both in Canada and in the United States, Level I centers must maintain 24-hour availability of the key personnel needed for the immediate resuscitation and management of the severely injured patient. These personnel must include representatives from trauma surgery, emergency medicine, orthopedic surgery, neurosurgery and anesthesia. A level I center must have quaternary care services, such as a plastic surgery program and spinal injury management capabilities. To complement these services, operating rooms and radiology resources must be adequately staffed and immediately available. In addition, a level I center must maintain a surgically directed trauma service and a trauma team, and participate in the education and training of residents. Finally, the level I center must demonstrate regional leadership within the trauma system by means of outreach and education programmes, trauma research and injury prevention programmes. The level I center must also maintain a quality improvement programme and contribute to the national trauma registry (National Trauma Data Bank or the National Trauma Registry).

Level II centers

The ACS COT accreditation guidelines describe level II centers as functioning in two distinct settings: 1) in urban areas, where the level II supplements the resources of the level I and
2) in less population dense areas, where the level II serves as the lead regional trauma center; similar roles are described for level II centers in the TAC guidelines.

Like level I centers, level II centers are expected to provide definitive care to the most severely injured patients; many of the guidelines for level I and level II centers are therefore similar. However, unlike level I centers, level II centers do not have volume requirements, although TAC guidelines stipulate that “[i]nstitutional caseload of Level II Centres should strive to approximate those of Level I Centres”. In addition, level II centers are not required to maintain specialized surgical services, such as microvascular surgery or spine surgery.

ACS COT and TAC guidelines differ subtly in regards to availability of certain human and physical resources within the level II center. The ACS COT stipulates that level II centers must have operating room resources available promptly after a patient’s arrival, but need not be available immediately; in contrast, TAC guidelines require immediate availability of operating rooms, even at level II centers. Similarly, according to ACS COT guidelines, radiology technologists need not be in-house at level II centers; again, TAC guidelines require in-house personnel in the radiology department. Resident training and a trauma research program are not requirements for level II centers in either American or Canadian guidelines.

Level III centers

Level III centers are smaller regional centers that have the capability to provide initial resuscitative care to severely injured patients. It is understood that these centers may need to transfer the most severely injured patients to a level I or level II center, and they are therefore required to have transfer agreements with nearby level I/II institutions. Continuous general surgery coverage is considered the mainstay of the care offered by level III centers and, as at
level I and II centers, the general surgery-trained trauma surgeon is expected to provide care to severely injured patients within 30 minutes of their arrival. However, other subspecialty coverage may be limited at level III hospitals. For example, neurosurgery coverage is generally limited or absent at level III centers, and orthopedic surgery services are typically highly variable in their scope. As in level II centers, surgical staff must be involved in the provision of critical care services, but 24-hour coverage by a physician in the intensive care unit is not required for accreditation. As at centers of higher designation, injury prevention and local outreach programmes are considered functions of the level III center, though to a lesser degree than centers of a higher designation. For example, under the ACS COT guidelines, level III centers are not required to have a designated injury prevention coordinator, do not have to provide evidence of participation in regional or national prevention programmes, and their staff do not have to participate in continued medical education programmes. Finally, level III centers are expected to have an ongoing performance improvement programme and trauma registry.

**Level IV centers and level V centers**

Definitions of level IV/V centers differ markedly in the ACS COT and COT guidelines

*American College of Surgeons Committee on Trauma guidelines*

Level IV centers are hospitals located in rural areas that “supplement care within a larger trauma system”\(^\text{18}\). Although level IV centers are required to have 24-hour coverage by a physician, subspecialty services (i.e. general surgery, other surgical specialties) may not be available. Level V centers are not recognized by the ACS COT.
Trauma Association of Canada guidelines

TAC defines a level IV center as a hospital in an urban setting with a nearby major trauma center. Level IV centers provide definitive care to less severely injured patients (largely single system injuries), thereby decreasing the caseload of level I/II centers. Severely injured patients are rapidly transferred to neighboring level I/II centers. In contrast, level V centers are rural centers in areas with no immediate access to a major trauma center. Level V centers provide initial resuscitation and stabilization prior to transferring patients to higher levels of care. Level V centers may also admit a small number of patients with non-severe or non-complex injuries.

Not all trauma systems have trauma centers at all five levels of designation. In fact, individual trauma systems differ from each other significantly in terms of the number and types of trauma centers they designate. As will be discussed in detail, these differences may have an impact on the type of care patients receive, and on the outcomes these patients experience.

1.4.3 Pre-hospital triage guidelines

As outlined in the previous section, level I and level II trauma centers are equipped to manage the most severely injured patient. However, trauma centers can only be effective within a system that ensures severely injured patients are identified in the field and transported to the appropriate facility. In addition, a system must be in place to ensure that patients with non-severe injuries do not overwhelm the resources of level I and level II centers, and are managed at centers with lower designation or at non-trauma centers. Finally, since 50% of deaths occur within 1 hour of hospital presentation, the identification of severely injured patients in the prehospital setting must occur in a rapid fashion. These three goals are accomplished through a
system of pre-hospital triage. As such, prehospital triage guidelines and bypass protocols have become an essential element of the modern trauma system.

The 1976 version of the ACS COT report “Optimal Resources for the Care of the Seriously Injured” did not specifically address preshopital triage. However, the ACS COT, recognizing the importance of prehospital triage guidelines, soon developed a set of consensus guidelines for the field triage of injured patients. The first version of these guidelines, known as the Triage Decision Scheme, was published in the 1987 version of the “Optimal Resources for the Care of the Seriously Injured.” These guidelines have since undergone multiple revisions.

Most recently, in 2005, with support from the National Highway Traffic Safety Administration, the United States Centers for Disease Control sponsored a revision of the American College of Surgeons decision scheme by hosting a series of meetings of the National Expert Panel on Field Triage. The Expert Panel reviewed currently available evidence regarding the existing criteria for field triage, and made a number of recommendations based on this evidence. These meetings resulted in the 2006 version of the ACS COT prehospital triage decision scheme. The Decision Scheme continues to serve as the guide for field triage protocols in the majority of emergency medical services across North America, and is the most evidence-based approach to the field triage of severely injured patients.

Although the ACS COT Decision Scheme often undergoes modification during regional implementation, its fundamental structure is similar to that of prehospital triage guidelines used in many jurisdictions. An understanding of the components of the Decision Scheme is therefore useful to the understanding of the data that will be presented in this dissertation.
The 2006 field triage Decision Scheme is centered on a four step evaluation of the patient. These four steps assess four domains for estimating the probability of severe injury: physiologic derangement, anatomic injury, mechanism of injury and special patient characteristics. Physiologic criteria and anatomic criteria attempt to identify the most severely injured patients, who should then be preferentially triaged to a level I or level II center.

Physiologic criteria for triage to a level I or II trauma center include: Glasgow Coma Scale score <14; systolic blood pressure <90 mmHg; and/or respiratory rate <10 or >29 breaths per minute. Anatomic criteria for triage to a level I or II trauma center include: penetrating injuries to head, neck, torso, and proximal extremities; flail chest; two or more proximal long-bone fractures; crushed, degloved, or mangled extremity; amputation proximal to the wrist or ankle; pelvic fracture; open or depressed skull fracture; and/or paralysis.

It is evident that the physiologic and anatomic criteria of the decision scheme are easily evaluated in the field with minimal equipment. Additionally, there is evidence to suggest that these criteria are highly effective in identifying severely injured patients. A 2010 prospective, multi-site study of 6,259 patients meeting 2006 physiologic criteria demonstrated a mortality rate of 23.5%. In addition, 58.0% of the cohort either died or had a hospital length of stay longer than two days. Although 42.0% of patients were discharged within 2 days, the authors were unable to generate a decision rule based on physiologic measures which performed better (improved specificity without substantial loss of sensitivity) than the existing guideline. These data suggest that the current physiologic criteria successfully identify severely injured patients.

Data examining the performance of the 1990 version of the Decision Scheme demonstrated that the addition of the anatomic criteria to the physiologic criteria further improved sensitivity and positive predictive value for identifying patients with severe injury.
that study, physiologic criteria alone had a sensitivity of 70% and positive predictive value of 42% for severe injury; the addition of anatomic criteria increased the guidelines’ sensitivity to 80% (albeit at the cost of a decrease in their positive predictive value).

Patients meeting neither physiologic nor anatomic criteria are evaluated based on mechanism of injury and patient characteristics. Those that meet these criteria (in step 3 or step 4 of the Decision Scheme) should be considered for transport to a level I or level II center. These criteria have undergone considerable revision since the inception of the Decision Scheme in order to improve sensitivity and specificity. Mechanisms of injury associated with high risk of injury are: falls >20 feet (with specific criteria for children); motor vehicle collision causing > 12 inches of intrusion on the occupant site; motor vehicle collision causing > 18 inches of intrusion at any site; motor vehicle collision causing ejection from the vehicle; motor vehicle collision causing death in the same passenger compartment; motorcycle crash occurring at >20 miles per hour; auto vs. pedestrian/bicyclist who is thrown, run over, or with significant (>20 miles per hour) impact; and/or vehicle telemetry data consistent with high risk of injury. Patient characteristics increasing the risk of severe injury, and included in the Decision Scheme, include: advanced age; young age; anticoagulation and bleeding disorders; burns; end-stage renal disease requiring dialysis; and/or pregnancy beyond 20 weeks gestational age. Finally, paramedic judgment is included as a criterion for transport to a level I or level II trauma center.

With evidence-based, adequately implemented prehospital triage guidelines, a trauma system is expected to achieve low rates of undertriage (triage of severely injured patients to non-trauma centers), and acceptable rates of overtriage (triage of non-severely injured patients to a trauma center). The ACS COT recommends that, at the system level, undertriage rates should be in the range of 0 to 5%, and that overtriage rates between 25 - 50%, are acceptable. Clearly,
these suggested rates emphasize the paramount importance of ensuring that all severely injured patients reach trauma center care, and acknowledge that high sensitivity of prehospital triage criteria may lead to decreased specificity. Furthermore, these guidelines suggest that rates of undertriage significantly above 5% represent an important opportunity for quality improvement at the level of the trauma system.

1.4.4 Trauma system organization

Although trauma centers and prehospital care and guidelines are essential components of an organized trauma system, multiple other factors are now acknowledged to be important components of the modern trauma system. Considerable controversy exists, however, regarding precisely which components are essential in a trauma system, and which are not.

In 1988, West and colleagues published the results of a survey examining trauma system development in the United States26. In this document, the authors outlined what they believed to be eight key components of an organized trauma system, as stipulated by the American College of Surgeons (Figure 1.1). The survey, which was conducted in 1987, collected data from state EMS directors, health departments having responsibility over emergency and trauma planning, and state chairpersons of the ACS COT. Survey data demonstrated that only 2 states had all eight essential trauma system components in place. In addition, 29 states had not yet started the process of trauma center designation. The survey also demonstrated significant heterogeneity in trauma system configuration; this heterogeneity persists to the present time and has, as will be discussed below, important implications for patient outcomes.

Following the publication of West’s report, the United States Health Resources and Services Administration published the “Model Trauma Care Systems Plan” in 1992, which
States could “use as a reference guide in the development of a comprehensive trauma care system plan as part of the statewide Emergency Medical Services (EMS) plan.”\textsuperscript{27} Notably, the Model Trauma Care Systems Plan emphasized the concept of inclusive trauma systems, “in which every health care provider or facility with resources to care for the injured patient is incorporated”.\textsuperscript{27} The Plan also outlined the key organizational and structural components required for an effective trauma system, including an agency dedicated to trauma system planning, trauma system-specific legislation, and dedicated funding.

The Model Trauma Care Systems Plan was further refined by the ACS COT, who developed a Trauma Systems Consultation Program in 1996.\textsuperscript{28} Like the Model Trauma Care Systems Plan, the ACS COT Consultation Program outlines essential components of a trauma system. Among the principles outlined in the Consultation Program is the concept that trauma systems should be inclusive.\textsuperscript{28}

Despite the initiatives by the ACS COT and the United States Health Resources and Services Administration, heterogeneity in trauma system configuration persists in the United States. There is also significant trauma system heterogeneity in Canada, where TAC states that provincial health authorities should determine “system configuration and the component parts of the system within the region, consistent with the provincial trauma plan.”\textsuperscript{19}

The heterogeneity of trauma system organization was well documented by Bazzoli and colleagues who, in 1992, performed a second survey of trauma systems in the United States.\textsuperscript{29} The authors surveyed 41 regional and state organizations that had legal authority to administer trauma systems and that had at least one designated trauma center. Firstly, the authors demonstrated significant heterogeneity in the level of government involved in organizing
individual trauma systems; trauma systems were organized at the county/ regional level or the state level, through a combination of agencies at different levels of government and with the occasional involvement of private agencies. In addition, Bazzoli and colleagues demonstrated persistent variation in the implementation of the essential components of organized trauma systems outlined by West et al. (Figure 1.1). In particular, few systems designated centers based on need (i.e. any hospital meeting criteria could become a trauma center). Finally, although all trauma systems had a formal method for designating trauma centers and all had standardized prehospital triage protocols, the authors demonstrated that individual trauma systems differed significantly from each other in terms of certain aspects of prehospital care (e.g. standardized training program for EMS personnel, compliance assessment and involvement of medical oversight), interfacility transfer (e.g. standardized interfacility transfer protocols and interfacility transfer criteria) and ongoing system evaluation. The variations in system structure identified by Bazzoli and colleagues suggest that the care provided to patients may vary significantly across systems.

Variations in trauma system organization were also identified by the next inventory of trauma center resources, which was published by Mackenzie and colleagues in 2003. The inventory was developed by the American Trauma Society’s Trauma Information Exchange Program, with the objective of “establishing a national network of trauma centers to be used for ongoing communication and collaboration among centers across state boundaries.” In their inventory, they identified that only 35 states and Washington D.C. had a formal trauma system at the state level.

As in Bazzoli’s survey, Mackenzie’s inventory demonstrated that states continued to differ significantly from each other in terms of the inclusivity of their trauma system. Whereas
24 states had not designated any level III, IV, or V trauma centers, six states had categorized all or almost all acute care hospitals as trauma centers at some level. The other states with formal trauma systems designated lower level centers to varying degrees. The authors concluded that their data supported the need for significant improvements in access to trauma care in several regions of the United States. The authors also advocated for the development of evidence-based guidelines regarding the optimal number of level I and II trauma centers in a given population. Finally, Mackenzie and colleagues concluded that more information regarding the role of lower level centers within regional trauma systems was required.

Similar variations in trauma system structure described in Bazzoli and Mackenzie’s reports exist in Canadian trauma systems. In a study sponsored by the Research Committee of the Trauma Association of Canada, Hameed and colleagues reviewed access to trauma center care across all Canadian provinces. Although their study focused primarily on trauma center catchment areas, the authors did identify a number of variations in trauma system structure across provinces. Firstly, while certain provincial trauma systems designate both level I/II centers and lower level centers (British Columbia, Quebec), other provinces designate only a small number of level I and level II centers, and do not integrate other hospitals into their trauma system (Ontario). In addition, Hameed’s paper identified differences across trauma systems in the availability of dedicated trauma program funding and in the presence of a trauma registry. However, at the time of the writing of this dissertation, no study expressly focused on the structures and processes of trauma systems across Canada has been conducted.
1.5 Evidence regarding the relationship between injury mortality and type of care received

Given the significant resources that have been invested in trauma centers and trauma systems, evidence of their effectiveness is critical. Over the past five decades, considerable evidence supporting a relationship between specialized injury care and reduced mortality has been accrued. As trauma centers became established in the last quarter of the 20th century, evidence linking trauma center care with improved patient outcomes has also accumulated. In this section, we will review the evidence supporting specialized injury care and trauma center care.

One of the earliest reviews of the care provided to injured patients is that published by Zollinger in 1955. Zollinger reviewed 9,050 emergency department visits that occurred at his institution in 1953, with a particular focus on visits resulting from traffic injuries. Among the 724 visits for traffic injuries, one quarter resulted in admissions to hospital. Although Zollinger did not directly examine the quality of care patients received, his report carefully documents injury patterns and types of treatment received. As such, this report represents an early attempt to categorize and evaluate the treatment of the injured patient.

In 1961, Van Wagoner published a review of 606 non-combat deaths among military personnel. Van Wagoner reviewed patients’ injuries, and classified cases as having received “adequate treatment”, “inadequate treatment” or “questionable” treatment. Van Wagoner reported that only half of the patients included in his series received adequate treatment. Although cases were reviewed by a single individual, and classification of treatment adequacy was not based on rigorous criteria, Van Wagoner’s paper was one of the earliest to review the
quality of care administered to injured patients, and to identify potential opportunities for improvement.

In 1972, a report on traffic injury-related deaths in Baltimore was the first to incorporate hospital type into the authors’ analyses of preventable injuries. Among 33 deaths, the authors reported “errors or inordinate delay in diagnosis” among 21 patients. Additionally, the authors compared the distribution of all patients injured in traffic injuries (as well as DOAs) with the distribution of traffic injury-related deaths across Baltimore’s 14 hospitals. They noted an unusually low number of deaths from abdominal injuries at university-affiliated hospitals, and an unusually high number of deaths from abdominal injuries at low volume hospitals (Figure 1.2). Although the statistical analysis performed by the authors in 1972 would not meet reviewers’ standards at the time of the publication of this dissertation, the report by Gertner and colleagues nevertheless represented an important step in evaluating the relationship between hospital type and mortality following severe injury.

Between Wagoner’s study in 1961 and 1985, there were 26 additional articles published which reviewed series of trauma deaths, and evaluated the preventability of these deaths. The data used for these studies, methods of judging preventability and quality of these studies were highly variable. However, the majority of these studies demonstrated that a high proportion of trauma-related deaths could have been prevented with appropriate care. By the mid 1970’s, these series began to explicitly examine the impact of trauma centers on patient outcomes.

1.5.1 Evidence regarding the relationship between injury mortality and trauma center care

One of the landmark papers examining the impact of trauma center care on patient mortality was published in 1979 by West, Trunkey and Lim. West and colleagues examined
100 consecutive motor vehicle collision fatalities in two counties in California: San Francisco County, where all patients were brought to a single trauma center, and Orange County, where patients were brought to the closest receiving facility. Death certificates, coroners' reports, and autopsy data were systematically reviewed in all cases, and a standard injury severity scoring system used. Medical record data were only available in San Francisco County. The authors then classified deaths as clearly preventable, potentially preventable, or not preventable, and achieved consensus through discussion. Finally, deaths due to traumatic brain injury (TBI) were analyzed separately from deaths due to other causes. The authors found that more than a third of non-TBI deaths in Orange County were clearly preventable, and that the majority of patients who died a preventable death died of hemorrhage amenable to surgical control. In San Francisco County, only one non-TBI death was judged potentially preventable, and none was judged clearly preventable. Among TBI-related deaths, the authors also identified a high rate of missed injury in Orange County, but did not identify similar problems in San Francisco County. Clearly, the paper by West and colleagues has significant limitations, including potentially biased categorization of deaths as preventable and lack of access to medical records for Orange County patients. Nevertheless, data published by West et al. suggested that regionalized trauma center care might benefit patients. As the authors themselves noted, “Our data suggest that the San Francisco County system, which includes a trauma center, works quite well, while the Orange County system, which lacks a trauma center, does not.”

Hypothesizing that the presence of a trauma center would lead to decreased injury-related mortality at the population level, Rutledge and colleagues examined county-level injury hospitalization rates and mortality rates using a series of population-based databases in North Carolina. They included county level geographic, patient and health system factors in their
analyses. Medical system factors that were examined included presence of a trauma center in the county, type of emergency medical services, presence of 911 emergency access, number of general surgeons, number of hospitals and mean time spent by ambulances at the scene of injury. The only system factor that was significantly associated with the per-capita, in-hospital injury-related mortality rate was the presence of a trauma center; the presence of a trauma center was also associated with an overall reduction in injury-related mortality at the county level. Although these findings added further support to the concept that trauma centers decrease injury-related mortality, the analysis performed by Rutledge and colleagues was ecologic in nature (did not examine patient level outcomes). As a result, they were unable to capture relevant patient-level factors, such as age, mechanism of injury or injury severity, which affect injury mortality, might have varied significantly across counties, and might have confounded the relationship between injury mortality rates and the presence of a trauma center.

A follow-up study was conducted in Orange County after the implementation of a trauma system in 1980. As in the study by West, Trunkey and Lim, deaths due to motor vehicle collisions were reviewed using autopsy data. Findings were compared to those from Orange County prior to trauma system implementation, and to historical data from San Francisco County. Whereas in the 1973 study by West et al., 79% of non-TBI deaths in Orange County were preventable, after trauma system implementation, only 9% of deaths at Orange County trauma centers were judged preventable. In contrast, 67% of deaths at Orange County non-trauma centers were judged preventable. These data provided further support for the concept that trauma center care, hand in hand with trauma system implementation, was associated with a significant reduction in injury-related mortality.
In addition to the studies described, a number of other reviews of preventable deaths at trauma centers and non-trauma centers have been published; these have largely demonstrated lower preventable death rates at trauma centers compared to non-trauma centers, or in periods with trauma systems compared to periods without trauma systems \(^{35, 36, 40, 41}\). Although, given their significant methodological limitations, panel studies would generally be considered weak evidence, these data consistently point towards improved outcomes among severely injured patients who receive trauma center care. In addition, in the 1980s and 1990s, several retrospective cohort studies examining mortality rates at trauma centers and non-trauma centers also identified reduced mortality at trauma centers \(^{42-45}\). These retrospective studies had, however, significant limitations: small sample size, highly selected patient mix (e.g. limited to patients with femur fractures) \(^{42}\), inadequate risk adjustment \(^{42-45}\), and use of historical controls \(^{44, 45}\).

The strongest evidence supporting the benefits of trauma center care comes from the National Study on Costs and Outcomes of Trauma (NSCOT) \(^{46, 47}\). NSCOT was conducted in 15 metropolitan regions in 14 states across the United States. Within each region, the authors identified a representative sample of small, medium and large level 1 trauma centers and non-trauma centers treating at least 25 patients with major trauma annually. Patients included in the study were those patients aged 18 to 84 treated at a participating center for at least one moderate to severe injury. Patients were identified through the review of discharge records and emergency department logs. All deaths and a representative sample of patients discharged alive were selected at each center, and a quota sampling strategy was used to ensure a balanced distribution of young and elderly (age ≥ 65) patients across trauma centers and non-trauma centers. Data were collected through review of patients’ medical records, and patients were followed-up for up to one year after discharge by means of medical record review and telephone interview.
Outcomes were weighted based on the composition of the study sample to a reference population of over 15,000 patients.

The outcomes of NSCOT strongly support trauma center care for severely injured patients. Compared to patients treated at a non-trauma center, patients treated at trauma centers had a significantly lower relative risk of death at 30 days after injury (RR 0.76, 95% CI 0.58–1.00) and at 1 year after injury (RR 0.75, 95% CI 0.60–0.95)\(^3\). The survival benefit observed at trauma centers was, however, limited to younger patients (aged ≤ 55) and those with more severe injuries.

Although NSCOT offers strong evidence for the effectiveness of trauma center care, the patients and hospitals represented in NSCOT may not necessarily provide an accurate estimate of the benefit of trauma center care at the population or system level. Firstly, the non-trauma centers included in NSCOT were, on average, larger and more resourced than the average American or Canadian non-trauma center. On average, non-trauma centers included in NSCOT had 207 acute care beds and 19 ICU beds; small rural non-trauma centers were not included in the sample. In addition, many non-trauma centers included in NSCOT had trauma-specific resources, such as a trauma director or a trauma team. These factors may have biased findings in favour of non-trauma centers; it is possible the NSCOT underestimated the mortality-reduction associated with trauma center care at the population level.

1.5.2 Evidence regarding the benefits of organized systems of trauma care

In addition to evaluating the specific relationship between trauma center care and patient outcomes, numerous reports have examined the relationship between trauma system implementation and mortality. Clearly, in some of the studies previously described, trauma
center designation and trauma system implementation occurred concurrently; therefore regions or time periods with trauma centers also experienced improvements in trauma system structures and processes. As a result, differences in patient outcome might have been due to trauma center care, the presence of an organized trauma system, or both.

The state of the literature prior to the year 2000 regarding trauma system effectiveness is best summarized by a systematic review performed in 1999 by Mann et al. Acknowledging that trauma center designation is intimately related to trauma system implementation in the literature, they reviewed data examining both trauma system effectiveness and trauma center effectiveness. Overall, the authors concluded that published data was not of high quality. They identified three main categories of evidence: panel studies, registry studies and population-based studies. As previously described, panel studies evaluated preventable and non-preventable deaths prior to trauma system implementation, after trauma system implementation or during both time periods. These studies largely favoured trauma systems and trauma centers, but were generally highly susceptible to bias. Mann and colleagues found that the majority included unblinded reviewers from within the study area or center. Studies classified by Mann et al. as registry studies examined outcomes in a single trauma center or trauma system against “expected” outcomes, as derived from a historical data (usually the Major Trauma Outcomes Study). Like the panel studies, these data favoured trauma system or trauma center care. However, because “expected” outcomes were derived from historical data, estimates of benefit did not account for general improvements in medical care. Moreover, many studies utilized trauma registry data, which captures only patients arriving at a trauma center. As a result, these data could not evaluate the performance of a trauma system overall. The third category of evidence identified by Mann et al. were population-based studies of trauma system effectiveness. These studies utilized
trauma registry data, prehospital data, discharge data, emergency department records or autopsy data to evaluate the effect of trauma system implementation. Like the previous two categories of studies, the studies identified by Mann et al. as “population-based” suffered from substantial methodological limitations. Many studies did not appropriately risk adjust, studied a non-representative sample of hospitals or compared contemporary data with historical data. Moreover, all identified population-based studies examined limited geographic regions, such as several counties or a single state system. Finally, the findings of the population-based studies identified by Mann and colleagues were highly inconsistent in regards to the benefit of trauma system implementation.

The 1998 report by Mullins and colleagues, also identified in Mann’s review, provided the strongest evidence of decreased mortality at the population level after trauma system implementation. Mullins compared mortality in Washington state and Oregon during two time periods. During the first time period, neither state had an organized trauma system, whereas Oregon had implemented a trauma system during the second time period. Mullins and colleagues hypothesized that mortality rates should preferentially decrease in Oregon if there was an association between trauma system implementation and mortality rates. The authors found that, although risk-adjusted in-hospital mortality did not differ across states when neither had a trauma system, in-hospital mortality was significantly lower in Oregon compared to Washington after Oregon implemented a trauma system.

A symposium of 92 clinicians, administrators and academics was held in 1998 to review evidence regarding trauma system effectiveness accumulated in the review conducted by Mann et al. As described, the pre-symposium literature review “produced no studies providing direct, robust evidence regarding trauma system effectiveness.” Given this perceived lack of evidence,
symposium organizers used multiple surveys throughout the meeting to evaluate participants’ beliefs regarding trauma system effectiveness, the utility of various trauma system components and the optimal organization of trauma systems. Based on the available evidence, symposium participants concluded that trauma centers/systems have proven "effective" at reducing injury mortality in urban areas and among the severely injured, but that they were only "somewhat effective" when assessing rural regions. Participants also concluded that exclusive systems, wherein patients are treated at a limited number of centers, were “highly desirable”. Finally, panelists agreed that there was "weak" or "no" existing evidence that trauma centers/systems benefit patients undergoing interhospital transfer patients; this finding is particularly relevant to the work that will be presented in this thesis.

In 2000, Nathens and colleagues published two manuscripts examining the relationship between trauma system implementation and injury-related mortality that overcame some of the limitations associated with earlier literature on the subject. In both studies, injury-related mortality rates across all US states were analyzed in relation to the presence of a trauma system in that state. At the time of data collection (1995), 22 states had a trauma system in place, and 18 were in the process of implementing one. States with trauma systems were found to have lower mortality rates overall (Incidence rate ratio 0.91, 95% CI 0.89-0.92); in secondary analyses, this mortality benefit was also observed among patients with unintentional injuries and injuries caused by motor vehicle collisions. No mortality benefit was observed, however, among patients with injuries caused by intentional injury.

In their second analysis, Nathens and colleagues further focused on rates of mortality secondary to being an occupant in a motor vehicle collision. In this study, they examined the relationship between time of trauma system implementation and mortality. Included in their
analyses as potential confounders were state-level factors that might modify driving behavior and, therefore, motor vehicle collision-related mortality. These state-level factors included legislation regarding speed limits and seat belt legislation. The authors identified that, between 1979 and 1995, motor vehicle collision mortality rates decreased by 22% in the United States. States that implemented a trauma system had an 8% (95% CI, 5%-11%) greater reduction in mortality rates than those states that did not. Finally, the authors demonstrated that trauma system implementation had no effect on motor vehicle collision mortality in the first ten years of system implementation. The findings of Nathens and colleagues in both of their analyses of trauma system implementation provide strong evidence that trauma system implementation is associated with reduced injury-related mortality. However, their data did not directly examine the type of care patients received, nor the relationship between specific structures of care and mortality. As will be presented below, many trauma systems face continued challenges in ensuring patients within their jurisdictions reach appropriate trauma care. As such, the estimates of Nathens et al. may actually be underestimates; mortality reduction may be larger in trauma systems that more effectively ensure access to care. Furthermore, given that considerable heterogeneity in trauma system organization has been documented, significant variations may exist in the mortality reductions achieved by specific trauma system configurations.

1.5.3 Evidence regarding the relationship between injury mortality and trauma system configuration

As described earlier, Hameed, Mackenzie and Bazzoli identified differences across trauma systems in terms of the number of hospitals participating in the trauma system, and their designation. In general, these differences have led trauma systems to be broadly categorized as inclusive and exclusive. An inclusive system refers to one in which a large proportion of hospitals (or all hospitals) participate in the trauma system to the degree that their resources
allow. Such trauma systems generally designate a large number of trauma centers at a variety of levels (I,II,III,IV,V). In contrast, exclusive systems are centered around a small number of trauma centers with higher designation levels (I, II). Smaller hospitals do not participate in the trauma system in a systematic fashion. As previously mentioned, inclusive systems are advocated by United States Health Resources and Services Administration’s Model Trauma Care Systems Plan and by the ACS COT Trauma Systems Consultation Program. A landmark paper published by Utter and colleagues provided important insight into how inclusive trauma systems influence the processes of care offered to severely injured patients, as well as patient mortality.

In their study, Utter and colleagues examined discharge data for severely injured adults from 24 states. They categorized state trauma systems based on the proportion of all acute care hospitals that were designated as trauma center at any level, and divided systems into tertiles of “inclusivity”. Compared to exclusive system, the most inclusive systems were associated with significantly decreased inpatient mortality following severe injury, adjusting for both patient and system level factors (OR 0.77, 95% CI 0.60-0.99). However, there were no differences in the proportion of severely injured patients treated at level I or level II centers across the tertiles of inclusivity. These data suggest that the improved survival among severely injured patients observed in inclusive systems is not the result of differences in triage patterns. Rather, the data published by Utter and colleagues suggest that inclusive trauma systems may decrease patient mortality by improving the care at smaller hospitals (which do not participate in the system in exclusive systems) and by improving coordination of care throughout the system.

The study by Utter et al. has a number of important limitations. The study captures only in-patient deaths; it is possible that a substantial number of deaths among severely injured
patients occur in the prehospital setting, in the emergency department or even following discharge. In addition, the unadjusted rates of treatment at a regional (level I/II) center in Utter’s study ranged from 65.7% in the most exclusive systems to 70.2% in the most inclusive systems. It is possible that inclusive systems that do not achieve equally high rates of triage to a level I/II center may not achieve equally good outcomes.

Following the publication of the report by Utter and colleagues, similar findings regarding the mortality benefit of inclusive systems were reported by other groups\textsuperscript{63, 64}. However, these later papers were limited in the regions studied\textsuperscript{63, 64} and relied on historical comparisons within a single trauma system\textsuperscript{63}.

1.6 Inequities in access to trauma center care

Despite the evidence regarding the benefits of trauma center care, in many trauma systems, access to trauma center care continues to be limited for many patients. Several groups have attempted to examine the degree of undertriage (triage from the scene to a non-trauma center) that exists at the regional and national level.

In their analysis of trauma center access in the United States, Nathens and colleagues used hospital discharge records from 18 states to evaluate undertriage\textsuperscript{65}. Their data demonstrated that more than a third of severely injured patients received definitive care at a non-trauma center. This analysis, however, likely underestimates the degree of undertriage that existed in the states studied. Firstly, because they used discharge records, the authors were unable to evaluate patients who died in the emergency department prior to admission. Additionally, patients who were undertriaged and subsequently transferred to a trauma center could not be captured, and were potentially misclassified as having been transported to a trauma center from the scene. Finally,
Nathens and colleagues did not directly examine the relationship between undertriage and the presence of a trauma center; it could be speculated that patients simply did not have a trauma center within a reasonable distance from their location of injury.

It is evident that geographic barriers to trauma center care exist, particularly in rural regions. In the United States, 15% of the population lives more than an hour from a designated (level I-III) trauma center. In Canada, geographic information systems analyses have also been used to examine geographic barriers to trauma center access. In the study by Hameed and colleagues, 77.5% of Canadians lived within one hour of a trauma center (level I – III) by ground travel. The proportion of individuals with potential access to a trauma center varied considerably by province, however. Whereas up to 85% of Ontarians live within one hour of a trauma center, only 40% of individuals living in Newfoundland and Labrador have similar access.

Although a predominant majority of individuals in the United States and Canada live within one hour of a trauma center, it is clear that distance alone is not the only barrier faced by patients in accessing trauma center care. A clear discrepancy exists between the proportion of patients living within a reasonable transport distance of a trauma center and the proportion of severely injured patients who receive care at such an institution.

Vassar and colleagues specifically sought to address whether care of severely injured patients in non-trauma centers in their region (California) was due to physical barriers (excessive distance) to a trauma center. Like Nathens et al., their analysis utilized discharge data; the authors specifically focused on patients with severe injuries. Vassar et al. found that, between 1995 and 1997, only 56% of patients with injuries meeting criteria for trauma center care were
admitted at a trauma center. Moreover, although 81% of patients were located in a county with a trauma center, only 68% of patients in such counties received care at a trauma center. Clearly, the data published by Vassar and colleagues demonstrates that physical access to a trauma center does not ensure adequate access to care. As in the analysis by Nathens, Vassar and colleagues were unable to capture deaths in the emergency department, however; their data likely also underestimate the extent of undertriage in their region. Moreover, Vassar and colleagues considered level III centers equivalent to level I and level II centers, despite the significant difference in resources and care offered at these centers. This assumption may have led to a further overestimation of access to trauma center care in their region.

Hsia and colleagues reassessed access to trauma center care in California between 1999 and 2006; in their analysis, only level I or level II care was considered “trauma center care” for severely injured patients. Overall, only 66% of patients received care at a trauma center. There was a significant increase in trauma center utilization over time, however; by 2006, 71% of patients with severe injuries were treated at a trauma center. As in Vassar’s analysis, residing in a county with a trauma center increased the probability of trauma center care, but did not ensure access. 82% of severely injured patients residing in a country with a trauma center received care at such an institution, as compared to 31% of patients in a county without a trauma center.

1.7 Trauma system configuration in Ontario

Ontario is Canada’s most populous province. The Ontario trauma system serves a population of 12 million living across an area of approximately 1 million square kilometers. The majority of the population, however, live in urban areas; 88% of Ontario’s population lives within either Census Metropolitan Areas (CMA) or Census Agglomerations (CA). Eight-five percent of the population resides within a one hour driving distance from a trauma center.
Acute care hospitals and trauma centers

In the early 1990s, the Ontario Ministry of Health and Long-Term Care (MOHLTC) designated ten Lead Trauma Hospitals (LTH) to care for patients with severe traumatic injuries. Today, in Ontario, there are two pediatric and nine adult LTH, which are integrated into the Provincial Trauma Network; all are located in urban areas. Among the adult LTH, which are the focus of this dissertation, eight are level I equivalent centers and one is a level II equivalent center (Table 1.2). Among these nine centers, seven are also accredited by TAC as level I centers. All LTH have 24-hour Trauma Team Leader (TTL) coverage, have the clinical resources outlined for level I/II centers by TAC accreditation guidelines and have full neurosurgical coverage. In addition, all have designated program funding, as well as a formal trauma registry. Finally all Ontario LTH are accessible by rotary wing, and participate in a rotary wing prehospital program. The MOHLTC provides each LTH with dedicated funding for trauma program infrastructure (e.g. medical director, trauma coordinator, data analyst and secretary) and for 24-hour coverage by a TTL. In addition, incremental funding is provided for each additional major trauma case. Finally, the MOHLTC funds each institution to maintain a trauma registry.

In addition to Ontario’s level I and level II trauma centers, there are over 150 additional acute care hospitals in the province. These centers do not participate in the provincial trauma system; in contrast to other provincial trauma systems, there are no level III, IV or V trauma centers in Ontario. The care provided to injured patients at Ontario’s non-trauma centers is not guided by provincial standards. Non-trauma centers are not required to have a trauma team or a trauma transfer protocol, and emergency department personnel at non-trauma centers are not
required to have dedicated training in the preliminary care of the injured patient (Advanced Trauma Life Support). As such, Ontario would be considered an exclusive trauma system.

**Prehospital care**

Land ambulance services in Ontario have been de-centralized, and administered at the level of upper tier municipalities, since 2001. Costs of providing ambulance services are shared equally between the municipalities and the provincial government. Although the MOHLTC has established standards regarding qualifications of patient care providers, licensing of ambulance services and other issues, there are no province-wide field trauma triage criteria.

Ontario has had a single air ambulance provider since 2005. Originally known as the Ontario Air Ambulance Services Co., the organization was renamed Ornge in 2006. Ornge coordinates all fixed wing and rotary wing transports in the province. For injured patients, Ornge provides both on-scene services and, when required, interfacility transfer services. In addition, Ornge provides service by means of modified scene calls. Modified scene calls occur when Ornge is dispatched to the scene of a severely injured patient, but local ambulance services have initiated transport of the patient to a local hospital prior to the arrival of an Ornge aircraft. If, upon arrival to the local hospital, it is apparent that the patient requires trauma center care, Ornge is available to transfer the patient to a LTH. However, if resuscitative efforts are prolonged, or involve radiological or other procedures, Ornge will only accept the patient for transfer after a receiving institution is identified. In addition, if Ornge offers their services to the sending physician at the site of a modified scene call, the sending physician can decline the offer of a modified scene response.
Transfer and referral

Ontario has a central emergency referral service. Funded by the MOHLTC, CritiCall provides a 24-hour emergency referral service throughout Ontario. By calling a central, toll-free number, providers at any institution can request the transfer of a patient with needs that cannot be met by the institution in which they are currently being cared for. CritiCall facilitates physician to physician consultation regarding patient care and the need for transfer, helps identify an institution capable of accepting the patient in transfer and aims to expedite the transfer process. In the fiscal year of 2008-2009, CritiCall received 15,319 request for transfer, and arranged for (or coordinated) transfer for 9,548 patients. The average time to a physician response was 12 minutes. On average, trauma patients were accepted for transfer within 30 minutes of a request being made. The CritiCall system has, however, several limitations. CritiCall only facilitates the identification of a receiving institution, but does not have the mandate to require a specific provider or institution accept a patient. As a result, the transfer process may be delayed while numerous transfer requests are made; on average, more than 10 calls are made to organize a single transfer, and 2 physicians contacted. In addition, CritiCall does not directly organize the transportation resources required for transfer to be accomplished; the mode of transport to be used is made individually by each sending provider. Attempts to organize transportation resources can therefore potentially lead to significant delays.

Trauma system oversight

Oversight to Ontario’s trauma system is provided by the Provincial Trauma Network (PTN). The PTN began in 1999 as an informal gathering of the medical directors and coordinators from Ontario’s LTH, and was recognized by the MOHLTC in 2001 as an advisory
body to the Ministry. In addition to representatives from the LTH, the PTN currently includes representatives from the Ontario Trauma Data Analysts Network, the Canadian Institute for Health Information (CIHI), CritiCall and the Ontario Air Ambulance Program (Ornge). The PTN also receives funding from the MOHLTC.

1.8 Limitations of Ontario’s trauma system

In 2006, the MOHLTC established the Trauma Expert Panel, to “provide timely expert advice on improving the access, quality, efficiency, safety and accountability of trauma services in Ontario.” In their 2006 report, the Expert Panel concluded that “the way that Ontario currently provides trauma care to adults and children needs to be improved to meet the increasing demand for safe, high quality services.” The Expert Panel made multiple recommendations regarding changes to Ontario’s trauma system.

The Expert Panel noted that Ontario’s exclusive trauma system was not the optimal configuration for Ontario’s needs; the urban location of all Ontario trauma centers could lead to substantial challenges in access to care. The Expert Panel recommended the integration of existing non-trauma centers into the existing trauma system, to the degree that each hospital’s resources would allow. This integration would result in the classification of all Ontario acute care hospitalizations according to the revised TAC Trauma System Accreditation Guidelines. Prolonged transfer times were also identified as an ongoing impediment to high quality care. Data available to the Expert Panel demonstrated that injured adults spent, on average, 5.4 hours at a non-designated center prior to being transferred to a LTH. The Panel recommended that target times for transfers be developed.
Limitations of Ontario’s trauma system are also evident from our previously published data regarding access to trauma center care in the province. We have previously evaluated the relationship between access to trauma center care and location of death following injury. In this analysis, we utilized the Ontario Trauma Registry Death Data Set (OTR DDS) to identify all trauma-related deaths in Ontario between 2002 and 2003. For each patient, location of death, as derived from the OTR DDS, was analyzed in relation to the transport time to a trauma center from the census subdivision in which the death occurred. Our data demonstrated that more than half of injury-related deaths in Ontario occur in the prehospital setting; the proportion of deaths occurring in the prehospital setting increased substantially (> 75%) in areas with limited access to trauma center care. In addition, among patients who arrived alive to an emergency department, those injured in a census subdivision more than an hour away from a trauma center were substantially more likely to die in the emergency department, rather than after admission (OR 3.5, 95% CI 2.5 - 4.9). These data suggest that limited access to trauma center care exists in Ontario. Moreover, the relationship between distance to a trauma center and death in the emergency department (rather than in the operating room or intensive care unit) suggests that lack of access to trauma center care is associated with significant delays in care and potentially preventable deaths. However, this report did not provide a direct measure of triage to trauma center care in Ontario, nor did it directly evaluate data regarding transfer practices or transfer delays. Such data are currently not available in Ontario’s trauma system.
### 1.9 Tables for Chapter 1

**Table 1.1 – Example of a Haddon matrix for motor vehicle collisions**

<table>
<thead>
<tr>
<th></th>
<th><strong>Host factors</strong></th>
<th><strong>Vector or agent factors</strong></th>
<th><strong>Environment factors</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Pre-event</strong></td>
<td>Alcohol use</td>
<td>Brake quality</td>
<td>Street lighting</td>
</tr>
<tr>
<td></td>
<td>Fatigue</td>
<td>Headlight performance</td>
<td>Road conditions</td>
</tr>
<tr>
<td></td>
<td>Chronic health conditions</td>
<td>Tire quality</td>
<td>Road incline and curvature</td>
</tr>
<tr>
<td></td>
<td>Driving experience and skill</td>
<td>Size and weight of vehicle</td>
<td>Presence of median barrier</td>
</tr>
<tr>
<td></td>
<td>Risk taking behavior</td>
<td></td>
<td>Speed limits</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Drunk driving legislation</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Weather</td>
</tr>
<tr>
<td><strong>Event</strong></td>
<td>Seatbelt use</td>
<td>Speed at impact</td>
<td>Guard rails</td>
</tr>
<tr>
<td></td>
<td>Age and gender</td>
<td>Airbags</td>
<td>Presence or absence of fixed objects</td>
</tr>
<tr>
<td></td>
<td>Bone density</td>
<td>Crumple zones</td>
<td>Presence of median barrier</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Vehicle materials</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Size and weight of vehicle</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Head restraints</td>
<td></td>
</tr>
<tr>
<td><strong>Post-event</strong></td>
<td>Age and gender</td>
<td></td>
<td>9-1-1 access</td>
</tr>
<tr>
<td></td>
<td>Chronic health conditions</td>
<td></td>
<td>EMS service</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Triage guidelines for trauma</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Access to appropriate trauma care</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Quality of trauma care</td>
</tr>
</tbody>
</table>

Examples of factors influencing the incidence and outcome of injury within the Haddon matrix.
Table 1.2 – Designation and accreditation status of Ontario trauma centers

<table>
<thead>
<tr>
<th>Trauma center name</th>
<th>Location</th>
<th>Designation level&lt;sup&gt;21, 31&lt;/sup&gt;</th>
<th>TAC accreditation&lt;sup&gt;21&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hamilton Health Science Centre</td>
<td>Hamilton</td>
<td>I</td>
<td>2006</td>
</tr>
<tr>
<td>London Health Sciences Centre</td>
<td>London</td>
<td>I</td>
<td>2006</td>
</tr>
<tr>
<td>Ottawa Civic Hospital</td>
<td>Ottawa</td>
<td>I</td>
<td>2006</td>
</tr>
<tr>
<td>St. Michaels Hospital</td>
<td>Toronto</td>
<td>I</td>
<td>2006</td>
</tr>
<tr>
<td>Sunnybrook Health Sciences Centre</td>
<td>Toronto</td>
<td>I</td>
<td>2006</td>
</tr>
<tr>
<td>Hotel Dieu Grace Hospital</td>
<td>Windsor</td>
<td>I</td>
<td>2006</td>
</tr>
<tr>
<td>Kingston General Hospital</td>
<td>Kingston</td>
<td>II</td>
<td>None</td>
</tr>
<tr>
<td>St. Josephs Health Centre</td>
<td>Sudbury</td>
<td>I</td>
<td>2009</td>
</tr>
<tr>
<td>Thunder Bay Regional Health</td>
<td>Thunder Bay</td>
<td>I</td>
<td>None</td>
</tr>
</tbody>
</table>

TAC: Trauma Association of Canada
1.10 Figures for Chapter 1

**Figure 1.1** - Essential components of trauma systems

<table>
<thead>
<tr>
<th>Essential components of trauma systems in the USA and Canada</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Presence of a lead agency with legal authority to designate trauma centers</td>
</tr>
<tr>
<td>• Use of a formal process for designation of trauma centers</td>
</tr>
<tr>
<td>• Use of American College of Surgeons’ (or similar) standards for verification of trauma centers</td>
</tr>
<tr>
<td>• Use of an out-of-area survey team for designation of trauma centers</td>
</tr>
<tr>
<td>• Mechanism to limit the number of designated trauma centers in a community on the basis of community need</td>
</tr>
<tr>
<td>• Written triage criteria that form the basis for bypassing non-designated centers</td>
</tr>
<tr>
<td>• Presence of continuous monitoring systems for quality assurance (e.g. trauma registry)</td>
</tr>
<tr>
<td>• Statewide availability of trauma centers</td>
</tr>
</tbody>
</table>

Fig 1.2 – An early analysis of the relationship between deaths following traffic injury and hospital type

One of the first published analyses relating outcomes following severe injury to the type of hospital care received by the patient. (Gertner HR, Jr., Baker SP, Rutherford RB, Spitz WU. Evaluation of the management of vehicular fatalities secondary to abdominal injury. *J Trauma.* May 1972;12(5):425-431)
Chapter 2
Research Aims and Hypothesis

2.1. Rationale

The data presented in Chapter 1 have demonstrated that injury is a major public health concern, at the global level and in Ontario. The conceptual framework of the Haddon Matrix suggests that tertiary prevention, in the form of acute care following injury, is an essential component of injury control. Multiple lines of evidence support the concept that trauma centers and trauma systems are essential to tertiary prevention following injury, and are associated with a reduction in mortality. There is also substantial data demonstrating that, despite the benefits of trauma center care, existing trauma systems do not provide adequate access to trauma centers. A large proportion of severely injured patients are transported from the scene of injury to a non-trauma center (undertriaged). Together, these data suggest that undertriage may be responsible for a large number of preventable deaths across North America and in Ontario specifically. Estimates regarding the mortality cost of undertriage, at the population level, would be of substantial value to decision-makers and trauma system planners.

Despite abundance of evidence regarding the benefits of trauma center care in the literature, available data have a number of limitations which preclude their use towards accurately estimating the mortality associated with undertriage at the system or population level:

1) The best available estimates of the benefits of trauma center care compare outcomes at trauma centers with resource-rich non-trauma centers. Population-based estimates of the
mortality associated with undertriage require that the mortality associated with care at small, resource-poor non-trauma centers also be considered.

2) Previous studies examining access to trauma center care across large regions were not population-based, and were predominantly based on discharge data. Patients dying in emergency departments were excluded, and patients transferred to a trauma center from a non-trauma center were potentially misclassified as having direct access to trauma center care. Estimates of the mortality associated with undertriage at a population level require data that capture emergency department deaths and that accurately classify transfers.

3) Trauma system configuration varies substantially across regions, and may influence mortality among severely injured patients. Thus, estimates of the benefits of trauma center care may vary substantially between systems with different configurations. Trauma system configuration must be explicitly considered within an evaluation of the mortality associated with undertriage at the system level.

This thesis will focus on evaluating the mortality associated with undertriage at the population level, and will focus specifically on Ontario’s exclusive trauma system. We will employ Ontario’s unique, population-based datasets to obtain accurate estimates of trauma system performance.

2.2. Hypothesis

We hypothesize that within a regional trauma system, undertriage is associated with excess mortality among severely injured patients, as compared to direct triage to a trauma center.
2.3. Research Aims

Given our overarching hypothesis, this thesis will be divided into the following specific aims:

Specific aim 1: To develop an algorithm to derive Injury Severity Score from International Classification of Diseases, version 10, diagnoses.

Specific aim 2: To estimate the population-based mortality risk associated with transfer following severe injury, as compared to direct transport to a trauma center.

Specific aim 3: To estimate the population-based mortality risk associated with undertriage following severe injury.


Chapter 3
General Methods

3.1. Overview

The work described in this thesis was conducted at St Michael’s Hospital and at the Institute for Clinical Evaluative Sciences (ICES) in Toronto, Ontario. Research Ethics Board (REB) approval for this work was obtained either from St Michael’s Hospital in Toronto, Ontario, or from Sunnybrook Health Sciences Centre, Toronto, Ontario, as appropriate. Work that was completed at ICES was approved by the Privacy Officer and C.E.O. of ICES.

3.2. Data sources

3.2.1. Administrative databases

The administrative databases used in this dissertation (Table 3.1) are held at ICES, which is a prescribed entity under Ontario’s Personal Health Information Protection Act, with special obligations under this Act allowing the collection and use of health data for planning and managing the provincial health care system. As a result, patients do not have to provide consent for their personal health information to be included in ICES holdings. In order to maintain patient privacy in the absence of a consent process, ICES must adhere to specific procedures. These procedures include: anonymization of data, physical security measures, data encryption, and regular audits. ICES’ privacy policy and procedures are internally implemented, monitored and enforced by the ICES Privacy Officer, and externally reviewed by the Information and Privacy Commissioner of Ontario. The ICES holdings used for the purposes of this dissertation are described below.
**Discharge Abstract Database**

The Discharge Abstract Database (DAD) is a population-based, administrative database that contains data for hospital discharges (inpatient acute, chronic and rehabilitation care), as well as day surgeries in some Canadian provinces. The DAD is considered a “core” database by CIHI, and DAD data are directly transferred into other CIHI datasets, including the Ontario Trauma Registry (OTR). The DAD contains demographic, administrative (e.g. institution number, admission date, discharge date) and clinical information (e.g. diagnosis codes, discharge disposition).

**National Ambulatory Care Reporting System**

The National Ambulatory Care Reporting System (NACRS) is a population-based, administrative database that contains data for all hospital-based and community-based ambulatory care, including day surgery, outpatient clinics and emergency departments. For the purposes of this dissertation, data for emergency department visits were used. NACRS captures demographic, clinical (e.g. diagnosis codes, discharge disposition) and administrative information (e.g. triage time, discharge time).

**Registered Persons Database**

The Registered Persons Database (RPDB) contains demographic information on all persons who are eligible and registered for the Ontario Health Insurance Plan. Information in the RPDB includes name, gender, date of birth and vital status.
The RPDB used for this dissertation is held by ICES, where the dataset is modified and enhanced with additional administrative data\textsuperscript{81}. This modified dataset is referred to as the ICES-linked RPDB. Modifications include:

- De-identification of all patient data

- Linkage to other administrative datasets

- Identifying the best known or most recent postal code and/or location of residence for each person in the dataset, as of July 1st of each year. This is achieved through a hierarchical algorithm which examines data from DAD, NACRS, the Continuing Care Reporting System (CCRS), the Levels of Care Classification System (LOC) and the National Rehabilitation System (NRS).

- Enhancing information regarding vital status based on information available in other ICES datasets. This is also achieved using data from DAD, NACRS, CCRS, LOC and NRS.

3.2.2. Clinical registries

**Ontario Trauma Registry Comprehensive Data Set**

The Ontario Trauma Registry Comprehensive Data Set (OTR CDS) contains information about patients admitted with major trauma at the eleven LTH in Ontario\textsuperscript{82}. Major injury in the OTR CDS is defined as an Injury Severity Score greater than 12. In addition, patients must have an external cause of injury and meet one of the following criteria: admission to the participating facility; treatment in the emergency department of the participating facility without admission; or death in the emergency department of a participating facility\textsuperscript{82}. The OTR CDS provides highly detailed information about injured patients, including patient characteristics, injury
characteristics (e.g. injury severity, mechanism of injury) and clinical information (e.g. vitals signs, Glasgow Coma Scale score, procedures). However, because the OTR CDS captures only patients treated at LTH, it cannot be used to evaluate the outcomes of patients with major injury who are admitted at non-trauma centers. Given this limitation, the OTR CDS cannot be used to evaluate trauma system performance as related to appropriate triage of severely injured patients.

3.2.3. Data validation

Discharge Abstract Database

In 2009, CIHI published the results of a study examining the quality of data submitted to the DAD in 2005-2006. The study compared original medical record data to that recorded in the DAD. During the study time period, 175 institutions in Ontario submitted a total of 1,138,401 patients abstracts to the DAD.

For the purposes of the re-abstraction study, 50 acute care facilities in Canada were identified, based on a probability sample that was related to their geographic location and their volume of abstracts containing an ambulatory care-sensitive condition, hip replacement surgery or percutaneous coronary intervention. Facilities submitting fewer than 500 abstracts during the study period and facilities submitting fewer than 150 abstracts containing an ambulatory care-sensitive condition, hip replacement surgery or percutaneous coronary intervention were excluded. Agreement rates were calculated for a variety of parameters; results were weighted to reflect estimated rates for the entire DAD population.

The accuracy of diagnosis codes in the DAD is of particular interest; as will be described in the methods sections of subsequent chapters, diagnosis codes were used to estimate the severity of injury of patients studied in this dissertation. On re-abstraction, among all major
diagnoses eligible to be recorded in the DAD, 76% had been reported on the DAD abstract as a significant diagnosis. In Ontario specifically, 75% of patient diagnoses had been recorded in the DAD. Conversely, among diagnoses reported in the DAD, 75% were supported by information in the patient chart; in Ontario, the rate of accuracy for DAD diagnoses was 73%.

**National Ambulatory Care Reporting System**

In 2008, CIHI published the results of a study examining the quality of emergency department data submitted to the NACRS\(^83\). The quality of this data was reviewed using data from unplanned emergency department visits that occurred in Ontario during the 2004-2005 fiscal year. Facilities included in the study were identified using a two stage sampling strategy. Institutions were the primary sampling unit, and emergency department visits within the identified institutions were secondary sampling units. Institutions were stratified based on Local Health Integration Network. Patients who left without being seen, patients who were dead on arrival and patients who were transferred to the facility from another emergency department were not sampled. All other patients were divided into four groups based on visit disposition: Discharged/Left, Admitted, Transferred and Deaths.

Non-clinical demographic data elements used in the present dissertation were found to be highly accurate. Accuracy for health care number, postal code, gender and birth date ranged from 99.7% +/- 0.2 to 100.0% +/- 0.1. In addition, data regarding transfers were examined. The identification of a sending institution (Institution From) was accurate in 99.3% cases (+/- 0.5%). Similarly, identification of a receiving institution (Institution To) was accurate in 97.7% of cases (+/- 0.5%). However, these accuracy rates reflect the accuracy of these fields among all patients, not only patients who underwent transfer; it is possible that in a significant proportion of cases,
re-abstraction resulted in agreement in these fields because no transfer occurred and the fields were blank. In addition, only unscheduled visits were examined within the scope of this re-abstraction study. Transfers to the emergency department from another emergency department, however, are frequently coded as scheduled visits. As such, the accuracy of the fields Institution From and Institution To is difficult to assess within the context of data used for this dissertation. The fields Institution From and Institution To were not used in this dissertation.

The CIHI report also examined the accuracy for date and time information recorded in NACRS. Date and time information is used in the present dissertation to calculate length of stay in the emergency department, and time to death among patients who died in the emergency department. Accuracy for triage and visits completed dates was very high, greater than 99%. Discrepancies were identified in data pertaining to visit times, however. Overall, triage time was found to be accurate to within 15 minutes in 89.2% of cases (+/- 3.8%), and visit completed time was found to be accurate to within 15 minutes in 86.5% of cases (+/- 7.8%). The degree of discrepancy in re-abstracted length of stay varied significantly based on patients’ visit disposition, however. While overall agreement for length of stay (within 15 min) was 80%, it was only 40.1% for admitted patients, 77.6% for transferred patients and 53.1% for patients that died. These discrepancies in accuracy between patients discharged home and those patients not discharged home likely reflect inadequate documentation among patients admitted, transferred or dying in the emergency department. It should be noted, however, that inter-rater reliability among re-abstractors for length of stay also varied significantly. Although, when data were re-abstracted by 2 individuals, the mean difference in length of stay was 2 minutes, the difference between the re-abstractors was, on average, 21 minutes for admitted patients, 5 minutes for transferred patients and 20 minutes for patients who died.
Finally, the accuracy of diagnostic coding in NACRS is highly relevant to the present project. On re-abstraction of ICD-10 codes, exact agreement was reported for the entire ICD-10-CA code in 78.5% of diagnoses (+/- 2.3%) and in 88.8% of case (+/- 0.7%) when ICD-10-CA three character classification category was considered. Among diagnoses in the range of ICD-10-CA chapter XIX (Injury, poisoning and certain other consequences of external causes), exact agreement for entire ICD-10-CA codes was recorded in 72.3% (+/- 5.3%) of diagnoses, and in 77.2% (+/- 0.6) of diagnoses when only ICD-10-CA three character classification category was considered. When only chapter XIX of ICD-10-CA diagnosis was considered, agreement was found for 98.9% (+/- 1.5%) of diagnoses in the injury range. These data suggest that accuracy for identifying patients who have sustained any injury is extremely high, and accuracy for specific injury diagnosis is also very high.

**Registered Persons Database**

A 2008 report compared death counts in the ICES-linked RPDB and in data from the MOHLTC used for health planning purposes (that includes Ontario Registrar General Vital Statistics death data and Statistics Canada death data). Data for this report included the years from 1993-2003. Death counts across datasets were highly comparable: in the years 2000-2003, the percent difference in counts across datasets was less than 1%.

**Ontario Trauma Registry – Comprehensive Dataset**

No specific information regarding quality of data in OTR CDS is currently available.
### 3.3. Tables for Chapter 3

**Table 3.1** – Data sources used in each specific aim of dissertation

<table>
<thead>
<tr>
<th>Specific aim</th>
<th>Data sources</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific aim 1: To develop an algorithm to derive Injury Severity Score from International Classification of Diseases, version 10, diagnoses.</td>
<td>OTR CDS</td>
</tr>
<tr>
<td>Specific aim 2: To estimate the population-based mortality risk associated with transfer following severe injury, as compared to direct transport to a trauma center</td>
<td>NACRS, DAD, RPDB</td>
</tr>
<tr>
<td>Specific aim 3: To estimate the population-based mortality risk associated with undertriage following severe injury</td>
<td>NACRS, DAD, RPDB</td>
</tr>
</tbody>
</table>

**OTR CDS**: Ontario Trauma Registry Comprehensive Dataset

**NACRS**: National Ambulatory Care Reporting System

**DAD**: Discharge Abstract Database

**RPDB**: Registered Persons Database
Portions of Chapter 4 have previously appeared in


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Chapter 4
Development and validation of an ICD-10 to Injury Severity Score crosswalk

4.1. Summary

Background

In this study, we have created and validated a crosswalk to derive Injury Severity Score (ISS) from injury-related diagnosis codes in the Tenth Revision of the International Classification of Diseases (ICD-10).

Methods

The validity of the crosswalk was assessed using data from the Ontario Trauma Registry Comprehensive Dataset (OTR CDS). AIS and ISS scores derived using the crosswalk were compared to those assigned by expert abstractors. The ability of the crosswalk to identify patients with AIS scores of \( \geq 3 \) was evaluated. Kappa and intraclass correlation coefficient (ICC) were used as measures of concordance.

Results

10,431 patients were identified in OTR CDS. The crosswalk accurately identified patients with at least one AIS score \( \geq 3 \) (Kappa 0.65), as well as patients with a head AIS score \( \geq 3 \) (Kappa 0.78). Mapped and abstracted ISS were similar; ICC across the entire cohort was 0.83 (95% CI: 0.81-0.84), indicating good agreement. When comparing mapped and abstracted ISS, the difference between scores was \( \leq 10 \) in 87% of patients. Concordance between mapped and abstracted ISS was similar across strata of age, mechanism of injury and mortality status.
Conclusion

Our ICD-10 to ISS crosswalk produces reliable estimates of injury severity from data available in administrative databases. This crosswalk can facilitate the use of administrative data for population-based injury research in jurisdictions using ICD-10.

4.2. Introduction

The overall objective of this dissertation is to evaluate the relationship between undertriage and mortality at the population level within a regional trauma system. In order to achieve this goal, we must utilize datasets that capture all injured patients treated at an acute care hospital within the trauma system. Unlike specialized trauma registries, such as the OTR CDS, administrative databases capture all patients within the trauma system. As described in the previous chapter, NACRS captures all emergency department visits in Ontario, and the DAD captures all acute care hospitalizations. Together, therefore, NACRS and the DAD represent the ideal data sources for examining injury-related mortality at the population level.

In the context of injury research, however, a reliable and accurate means of estimating injury severity is important for meaningful evaluations of patient outcomes, intervention effectiveness or hospital performance. Without a measure of injury severity, differences in outcomes across centers might simply be the result of differences in case mix. The Injury Severity Score (ISS), and the Abbreviated Injury Scale (AIS) from which it is derived, has been the most widely used approach to injury severity scoring\(^{84-86}\). ISS has been shown to be closely associated with risk of death following injury\(^{85}\).

AIS coding is standardized and consensus based, with oversight and education provided by the Association for the Advancement of Automotive Medicine (AAAM). To calculate injury
severity, AIS scores are assigned to one of each of nine body regions on a 6 point ordinal scale based on the anatomic severity of injury (Appendix A). Scores range from a severity of 1 (minor injury) to a severity 6 (universally fatal – e.g. liver avulsion). AIS scores of 3 or greater are considered to be severe injuries.

AIS scores form the basic building blocks for calculating ISS. Based on AIS scores, each of six ISS body regions is assigned a score from 1 to 6 (Appendix A). The scores for the three most severely injured body regions are squared and then summed to derive ISS. An ISS of greater than 15 is considered severe injury.

AIS and ISS, while highly useful measures of injury severity, require the expertise of experienced trauma registrars in order to be captured accurately. Thus, these scores are typically only available in trauma centers, and are not available in administrative databases, such as the DAD or NACRS. Rather than relying on injury-specific injury scores, administrative databases generally use the International Classification of Diseases (ICD) system, published by the WHO, to index hospital records. Unfortunately, although widely available, ICD diagnoses do not provide a direct means of estimating injury severity. As a result, many administrative databases have been of limited utility in the context of injury research.

Recognizing the utility of using administrative data sources for the purposes of injury-related research, an automated algorithm to convert ICD diagnoses to AIS scores has previously been developed for the Clinical Modification of the Ninth Revision of the ICD (ICD-CM-9). This crosswalk has been validated, and has been of demonstrable utility in a variety of settings focusing on population-based analyses of trauma care.
In 1990, the development of the Tenth Revision of the ICD (ICD-10) was endorsed; this modification substantially broadened the scope of the classification system. ICD-10 includes expanded injury codes and greater specificity in code assignment. Versions of the ICD-10 system have been adopted in a number of jurisdictions, including Canada. Among the Canadian databases that utilize the ICD-10 system are the DAD and NACRS. With the objective of utilizing Canadian administrative databases to examine injury-related outcomes, the first specific aim of this dissertation was the development and validation of an ICD-10 to ISS algorithm. Such an algorithm would allow us to identify severely injured patients from administrative data, and to accurately risk adjust injury severity.

4.3. Methods

The development of the ICD-10 to ISS crosswalk was comprised of two components: crosswalk development and validation. The final crosswalk consists of an automated computer algorithm.

Data sources

The validity of the crosswalk was tested using the OTR CDS, admission years 2002-2004. The OTR CDS includes patients managed at a designated trauma center with moderate to severe injuries (ISS ≥ 12) in the province of Ontario, Canada. The OTR CDS includes AIS scores and ISS scores calculated by expert abstractors by means of chart abstraction. The dataset also includes ICD-10 injury diagnoses and external cause of injury codes for each patient.
Crosswalk development

In consultation with a member of the AAAM AIS faculty and a certified AIS Specialist, each injury-related diagnosis code in the ICD-10 lexicon (codes ranging from S00 to T79.0) was assigned to one of nine AIS body regions and one of six ISS body regions (Appendix A). Each ICD-10 diagnosis was also assigned to an appropriate AIS severity code based on the 1998 update of the AIS system\textsuperscript{86}. ICD-10 diagnoses related to foreign bodies (T15-T19), burns and corrosion injury (T20-T32), poisoning (T36-T65) and environmental exposure (T33-T35, T66-78) were excluded; these injuries are typically not preferentially triaged to trauma centers, and are beyond the scope of this dissertation. Complications of medical care and late effects of injury (T80-T98) were also excluded. The Canadian Modification (ICD-10-CA)\textsuperscript{93} was used to define AIS codes, since it is this version of the ICD-10 that is used in Canadian administrative databases.

Each ICD-10 diagnosis was assigned the lowest or most conservative AIS score with which it could be accurately associated. In cases where an ICD-10-CA diagnosis code described injuries to more than one organ, each with a different AIS score, but within the same ISS body region, the lowest AIS score was assigned. ICD-10 diagnoses that could not be assigned an accurate AIS score were assigned an AIS score of 9. AIS scores of 9 are equivalent to “not applicable” or “missing”, and are not included in ISS calculation. Specifically, an AIS score of 9 was assigned when an ICD-10-CA diagnosis code described injuries to multiple organs in different ISS body regions, described injuries to an unidentified body region, or described multiple injuries of more than one type to a body region (e.g. S09.7 – multiple injuries of head).
Crosswalk validation

Injury mechanism was assigned by means of external cause of injury code (E-code), according to Center for Disease Control External Cause of Injury Mortality Matrix for ICD-10\(^4\).\(^5\) Patients with a primary mechanism of injury of burn, poisoning, drowning, exposure, suffocation, overexertion, hanging or submersion were excluded from the cohort. Patients with missing E-codes were also excluded, as the mechanism of injury for these patients could not be ascertained. Using the crosswalk, we derived AIS and ISS scores from the ICD-10 diagnoses recorded in the OTR CDS.

Validity of the crosswalk was assessed in two ways. First we determined the extent of agreement between the AIS scores in the OTR CDS (considered the gold standard) with those derived from the crosswalk. In addition, we determined the agreement between the ISS scores derived from the two methods. Concordance between maximum AIS (AIS\(_{\text{max}}\)) by body region obtained from the ICD-10 crosswalk and from registry data was measured as percentage of exact agreement. Patient data were further stratified by age group (<15 years, \(\geq 15\) years) and injury mechanism (blunt, penetrating) to assess crosswalk performance across patient groups.

Concordance across mapped and abstracted scores in detecting severe injury (AIS \(\geq 3\)) by body region was measured using exact agreement and the kappa coefficient.

The degree of concordance between mapped and abstracted ISS was analyzed using two approaches. First, we compared the absolute difference between the two scores to estimate the percentage of patients where the difference was \(\leq 10\). This is a non-parametric approach to the Bland-Altman method of measuring agreement, which is useful in cases where data are not normally distributed\(^96\). We also evaluated concordance using the intraclass correlation coefficient
(ICC). Ranging from 0 to 1.0, ICC accounts for two sources of variation in ISS scores: variations in scores across different patients and variations due to a lack of concordance across methods (crosswalk and abstraction). A high ICC suggests high concordance between methods. The 95% CI for ICC was computed using bootstrapping methodology. In the estimation of ICC, a margin of error of $\pm 3$ for ISS was allowed, given the known inter-rater reliability of chart abstractors in assignment of an ISS score. As above, analyses were also stratified by age group (<15 years, $\geq$15 years), injury mechanism (blunt, penetrating) and survival status (in-hospital death, alive at discharge).

**Statistical analysis**

Descriptive statistics were calculated for demographic and injury data in the OTR CDS. Means and standard deviations were calculated for continuous variables with a normal distribution, and medians and interquartile ranges were calculated for continuous variables with a non-normal distribution. Absolute and relative frequencies were measured for discrete variables. In all statistical analysis, p<0.05 was considered significant. All data were analyzed using SAS (version 9.1, Cary, NC).

4.4. Results

**Crosswalk development**

There are a total of 1,542 ICD-10 included diagnoses codes in the range S00 to T79.0. Twenty-nine ICD-10 diagnosis codes (1.8%) could not be assigned an AIS body region. An additional 196 ICD-10 diagnoses could not be assigned an AIS severity, and were assigned an AIS severity score of 9. Of the ICD-10 diagnoses that could not be assigned an injury severity,
27% were in the region of the abdomen, and 26% were in the region of the lower extremities. Overall, 85% of ICD-10 diagnoses were assigned an AIS body region and severity.

**Validation of the ICD-10 to AIS crosswalk**

There were 10,431 patients meeting inclusion criteria within OTR CDS over the years 2002-2004 (Table 4.1). The majority of patients were male (71.6%), with a mean age of 44 years. The most frequent mechanisms of injury were motor vehicle collisions (51.6%) and falls (34.3%). Crude in-hospital mortality in this cohort was 10.8%. Overall, 20 patients had ICD-10 diagnoses which could not be translated into an ISS score.

**Concordance of crosswalk and abstracted AIS scores**

To provide a greater understanding of the strengths and weakness of the ICD-10 to AIS crosswalk, we evaluated the concordance of AIS_max across all body regions, as well as the ability of the crosswalk to identify the presence or absence of a severe injury (AIS≥3) in each body region. The AIS_max for each patient identified by crosswalk and from chart abstraction were in exact agreement in 57% of patients (Table 4.2). This degree of agreement is similar to that previously observed in studies of inter-rater reliability among AIS abstractors. The body regions with the highest proportion of agreement for AIS_max were the face (68%), neck (71%) and upper extremities (72%). When comparing AIS_max obtained from the crosswalk and by abstraction, exact agreement was lowest for head injuries (52%), chest injuries (51%) and lower extremity injuries (51%). When patients were stratified by age and mechanism of injury, overall agreement between abstracted and crosswalk AIS_max was lowest for patients with penetrating injuries (48%).
Because, in the context of risk adjustment, AIS is most commonly used as a means of identifying the presence or absence of severe injury in a particular body region, we examined the ability of the crosswalk to identify severe injury (AIS ≥ 3) in each body region (Table 4.3). The crosswalk demonstrated highest concordance with mapped AIS in identifying patients with severe head injuries (kappa 0.78, 95% CI 0.76-0.80). Conversely, the crosswalk performed least well in identifying severe injuries to the face (kappa 0.14, 95% CI 0.10-0.17).

*Concordance of crosswalk and abstracted ISS*

Overall, mapped and abstracted ISS were similar (Table 4.4). The difference between ISS scores obtained by crosswalk and abstracted scores was ≤ 10 in 87% of patients. When patients were stratified by age, mechanism of injury and discharge status, ISS scores obtained from the crosswalk and from chart abstraction were similar within each stratum. The greatest variation in the differences between mapped and abstracted ISS was observed among patients with penetrating injuries, where the difference between the two scores was ≤ 10 among 82% of patients.

The concordance of ISS across methods was also evaluated using ICC. Across the entire patient cohort, the ICC demonstrated excellent agreement between ISS obtained by mapping of ICD-10 diagnoses and by chart abstraction (ICC 0.83, 95% CI 0.81 to 0.84). Although ISS concordance across methods was excellent among patients with blunt injuries, patients aged 15 and older and patients discharged alive (Table 4.4), ICC ranged from 0.64 to 0.79 among pediatric patients, patients with penetrating injuries and patients who died in-hospital. All ICCs were consistent with substantial to excellent agreement, indicating that the crosswalk was internally valid, and a reliable means of obtaining ISS scores from ICD-10 diagnosis codes.
4.5. Discussion

Introduced in 1971 and 1974 respectively, the AIS and ISS scoring systems have proven to be an accurate and replicable means of estimating the degree of anatomic injury among trauma patients. Although a number of alternative scoring systems aimed at improving on the predictive performance of ISS have been proposed, including the ICD-based Injury Severity Score (ICISS), the Anatomic Profile (AP) and the Trauma and Injury Severity Score (TRISS), AIS and ISS remain the most widely used means of identifying severity of injury and of risk-adjusting trauma-related outcomes for variations in injury severity. Despite the availability of these injury scores in trauma registries and specialized trauma databases, AIS and ISS are not typically available from administrative and other non-specialized datasets.

In this Chapter, we developed a novel ICD-10 to ISS conversion algorithm, which will allow ISS to be derived from administrative datasets employing ICD-10. By examining the concordance of AIS and ISS scores derived from ICD-10 mapping to scores provided by expert abstractors in the OTR CDS, we have demonstrated that mapped scores are accurate compared to those provided by chart abstraction.

Alternative methods of estimating injury severity from administrative data have been proposed, with the ICISS system being the most prominent. The ICISS system relies on estimates of the survival risk ratios associated with each ICD diagnosis. ICISS scores are derived empirically from each dataset, and have been shown, in some studies, to be more accurate than crosswalk-derived ISS. The accuracy of ICISS, however, may vary across datasets, and may be inaccurate for rare diagnoses when derived from small datasets. Because our ICD-10 to AIS crosswalk is based on consensus definitions rather than empirically-derived data, crosswalk performance should be minimally dependent on data sources. Moreover,
previous work has shown that, when incorporated into a risk adjustment model that includes other predictors of injury-related death, algorithm-derived ISS and ICISS produced risk-adjustment models with similar performance\textsuperscript{105}.

More recently, an injury severity model (TMPM-ICD9) based on regression modeling of mortality and ICD has been developed using data from NTDB and ICD-9 diagnosis codes\textsuperscript{106}. This model has been shown to be more accurate than ICISS, and the methodology could theoretically be replicated with ICD-10 diagnosis codes. However, once again, because this method is dependent on the composition and size of the data source, model validity would vary across datasets, with smaller data sources likely to produce less accurate models.

The ICD-10 to ISS crosswalk described in this study has a number of limitations. The ability of the crosswalk to identify severe injury varied by body region. While the crosswalk reliably identified severe injuries in the head, chest and abdomen region, agreement between the crosswalk and abstracted scores was low in other body regions. These differences are likely related to variations in the degree of granularity of ICD-10 diagnosis codes across body regions. However, body regions where the crosswalk had lower performance were also body regions where injuries were less common in the population. As a result, the impact of crosswalk error on risk-adjustment of mortality in large datasets or population analyses is likely to be small.

Concordance between ISS scores calculated by expert abstractors and by the crosswalk was also not perfect. This may be a reflection of the quality of ICD-10 diagnostic coding in the database used. Nevertheless, the concordance between scores obtained by mapping and abstractions was very similar, or better, than concordance observed between human abstractors. In this study we demonstrated an ICC of 0.83, overall, for ISS obtained by algorithm and from
abstracted data. A previous study demonstrated an ICC of 0.83 for physician abstractors, and an ICC of 0.66 for ISS scores obtained by medical record technicians and research assistants\(^9\).

Data from trauma registries that provide ISS is only reliable if AIS and ISS scores are assigned by trained abstractors who accurately capture all patient injuries. Similarly, the accuracy of ISS scores derived from the crosswalk will be dependent on the quality of ICD-10 coding data available in the database to which it is being applied. While we have provided evidence of the reliability of our data sources in Chapter 3, other researchers using the crosswalk must ensure that ICD-10 scores are reliably coded in the database which will be used; the crosswalk cannot accurately assign accurate ISS scores if ICD-10 codes are not entered accurately. More broadly, if there are biases in the accuracy of ICD-10 code assignment across institutions or across time periods, risk adjustment using crosswalk-derived ISS may not be accurate.

In conclusion, in this Chapter, we have developed a crosswalk which reliably and accurately maps ICD-10 diagnoses to ISS. We have demonstrated the validity of this instrument using multiple approaches. This crosswalk will facilitate the use of administrative data to study injury outcomes, not only for the purposes of this dissertation but for other injury-related studies that utilize administrative data. This crosswalk will ensure that trauma-related health services research captures the outcomes of patients currently not adequately characterized in specialized trauma registries.
4.6. Tables for Chapter 4

Table 4.1 - Description of patient cohort used to validate the ICD-10 to ISS algorithm, as identified in the Ontario Trauma Registry Comprehensive Data Set

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of patients</td>
<td>10,431</td>
</tr>
<tr>
<td>Male, n (%)</td>
<td>7,469 (71.6)</td>
</tr>
<tr>
<td>Mean age (SD)</td>
<td>43.7 (23.2)</td>
</tr>
<tr>
<td><strong>Mechanism, n (%)</strong></td>
<td></td>
</tr>
<tr>
<td>Blunt</td>
<td></td>
</tr>
<tr>
<td>Fall</td>
<td>3,574 (34.3)</td>
</tr>
<tr>
<td>MVC</td>
<td>5,388 (51.6)</td>
</tr>
<tr>
<td>Other blunt</td>
<td>776 (7.4)</td>
</tr>
<tr>
<td>Other</td>
<td>193 (1.8)</td>
</tr>
<tr>
<td>Penetrating</td>
<td></td>
</tr>
<tr>
<td>Stabbing</td>
<td>289 (2.8)</td>
</tr>
<tr>
<td>Firearm</td>
<td>211 (2.0)</td>
</tr>
<tr>
<td><strong>Injury severity</strong></td>
<td></td>
</tr>
<tr>
<td>Median ISS (IQR)</td>
<td>22 (16-27)</td>
</tr>
<tr>
<td>ISS range</td>
<td>12-75</td>
</tr>
<tr>
<td><strong>Mortality, n (%)</strong></td>
<td>1,129 (10.8)</td>
</tr>
</tbody>
</table>

OTR CDS – Ontario Trauma Registry Comprehensive Dataset; MVC – Motor vehicle collision;
ISS – Injury Severity Score; SD – Standard deviation
Table 4.2 - Percentage (%) of exact agreement for maximum AIS score by body region derived from abstracted scores and from mapped scores

<table>
<thead>
<tr>
<th></th>
<th>Overall</th>
<th>Age&lt;15</th>
<th>Age&gt;15</th>
<th>Blunt injuries</th>
<th>Penetrating injuries</th>
</tr>
</thead>
<tbody>
<tr>
<td>All body regions</td>
<td>57</td>
<td>59</td>
<td>57</td>
<td>58</td>
<td>48</td>
</tr>
<tr>
<td>Head</td>
<td>52</td>
<td>47</td>
<td>52</td>
<td>52</td>
<td>55</td>
</tr>
<tr>
<td>Face</td>
<td>68</td>
<td>74</td>
<td>67</td>
<td>68</td>
<td>58</td>
</tr>
<tr>
<td>Neck</td>
<td>71</td>
<td>89</td>
<td>70</td>
<td>74</td>
<td>66</td>
</tr>
<tr>
<td>Chest</td>
<td>51</td>
<td>44</td>
<td>52</td>
<td>53</td>
<td>31</td>
</tr>
<tr>
<td>Abdomen</td>
<td>62</td>
<td>74</td>
<td>61</td>
<td>65</td>
<td>39</td>
</tr>
<tr>
<td>Spine</td>
<td>58</td>
<td>59</td>
<td>58</td>
<td>58</td>
<td>60</td>
</tr>
<tr>
<td>Upper extremity</td>
<td>72</td>
<td>82</td>
<td>71</td>
<td>72</td>
<td>64</td>
</tr>
<tr>
<td>Lower extremity</td>
<td>51</td>
<td>59</td>
<td>50</td>
<td>50</td>
<td>71</td>
</tr>
</tbody>
</table>

AIS – Abbreviated Injury Scale
Table 4.3 - Agreement in identifying patients with AIS score ≥ 3 by body region, derived from mapped scores and from abstracted scores

<table>
<thead>
<tr>
<th>Body Region</th>
<th>AIS score ≥ 3, mapped scores (%)</th>
<th>AIS score ≥ 3, abstracted scores (%)</th>
<th>Exact agreement (%)</th>
<th>Kappa</th>
</tr>
</thead>
<tbody>
<tr>
<td>All body regions</td>
<td>50</td>
<td>62</td>
<td>83</td>
<td>0.65</td>
</tr>
<tr>
<td>Head</td>
<td>80</td>
<td>85</td>
<td>94</td>
<td>0.78</td>
</tr>
<tr>
<td>Face</td>
<td>2</td>
<td>20</td>
<td>82</td>
<td>0.14</td>
</tr>
<tr>
<td>Neck</td>
<td>15</td>
<td>21</td>
<td>85</td>
<td>0.51</td>
</tr>
<tr>
<td>Chest</td>
<td>88</td>
<td>84</td>
<td>92</td>
<td>0.67</td>
</tr>
<tr>
<td>Abdomen</td>
<td>40</td>
<td>53</td>
<td>79</td>
<td>0.59</td>
</tr>
<tr>
<td>Spine</td>
<td>30</td>
<td>57</td>
<td>66</td>
<td>0.35</td>
</tr>
<tr>
<td>Upper extremity</td>
<td>14</td>
<td>30</td>
<td>79</td>
<td>0.40</td>
</tr>
<tr>
<td>Lower extremity</td>
<td>37</td>
<td>62</td>
<td>68</td>
<td>0.39</td>
</tr>
</tbody>
</table>

AIS – Abbreviated Injury Scale
**Table 4.4 - Comparison of ISS in the Ontario Trauma Registry Comprehensive Data Set**  
(crosswalk versus abstracted)

<table>
<thead>
<tr>
<th>Category</th>
<th>n (%)</th>
<th>ICC (95% CI)</th>
<th>Difference between ISS (mapped) and ISS (abstracted) ≤ 10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall</td>
<td>10,431</td>
<td>0.83 (0.81-0.84)</td>
<td>87%</td>
</tr>
<tr>
<td>Age</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;15</td>
<td>896 (8.6%)</td>
<td>0.79 (0.75-0.83)</td>
<td>88%</td>
</tr>
<tr>
<td>≥15</td>
<td>9,535 (91.4%)</td>
<td>0.83 (0.81-0.84)</td>
<td>87%</td>
</tr>
<tr>
<td>Mechanism</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Penetrating</td>
<td>500 (4.8%)</td>
<td>0.64 (0.57-0.71)</td>
<td>82%</td>
</tr>
<tr>
<td>Blunt</td>
<td>9,931 (95.2%)</td>
<td>0.83 (0.82-0.84)</td>
<td>88%</td>
</tr>
<tr>
<td>Discharge Status</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alive</td>
<td>9,302 (89.2%)</td>
<td>0.82 (0.81-0.83)</td>
<td>87%</td>
</tr>
<tr>
<td>Dead</td>
<td>1,129 (10.8%)</td>
<td>0.79 (0.74-0.83)</td>
<td>87%</td>
</tr>
</tbody>
</table>

ICC – intraclass correlation coefficient; ISS – Injury Severity Score
Portions of Chapter 5 have previously appeared in


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Chapter 5
Evaluation of the mortality associated with transfer to trauma center care

5.1. Summary

Background

Injured patients cared for in trauma centers have a lower risk of death than those cared for in non-trauma centers. However, many patients are transported to a non-trauma center following injury (undertriaged), and require transfer to trauma center care. Previous analyses of transfer focused only on survivors to trauma center care, and were potentially subject to survivor bias. Using a novel population-based design, we evaluated the true mortality cost of transfer.

Methods

We used a retrospective cohort design and included severely injured patients surviving to reach an Emergency Department (ED) within the province of Ontario, Canada. Those patients who were triaged to a non-trauma center as their first hospital exposure were the UNDERTRIAGE cohort. UNDERTRIAGE cohort patients were either transferred to a trauma center (TRANSFER cohort) or died before transfer could be accomplished (ED-DEATH cohort). Patients that were transported directly from the scene of injury to a trauma center represented the DIRECT cohort. Thirty day mortality in undertriaged patients was analyzed using two approaches: allowing for survivor bias (TRANSFER vs. DIRECT) and without survivor bias (UNDERTRIAGE vs. DIRECT).

Results
Among 11,398 patients, 66% were transported directly to a trauma center, and 30% were transferred. 4% died prior to transfer (22% of all deaths). Reproducing approaches that ignore survivor bias, mortality in the TRANSFER and DIRECT cohorts was equivalent. However, unbiased assessment demonstrated that mortality was significantly higher in the UNDERTRIAGE cohort than the DIRECT cohort (OR 1.24, 95% CI 1.10-1.40).

Conclusions

Undertriage and transfer following major trauma are associated with significant mortality. These data suggest a need to design strategies to improve triage to trauma centers.

5.2. Background

As was discussed in Chapter 1, numerous studies have demonstrated that injured patients cared for in designated trauma centers have a significantly lower risk of death than those cared for in non-trauma centers.\(^{36,38,47}\). Given the impact of trauma center care on survival, severely injured patients should be transported from the scene of injury directly to a trauma center, even if this requires bypassing closer hospitals.\(^{19}\). Many severely injured patients, however, continue to be transported from the site of injury to the emergency department of a non-trauma center.

In some cases, initial transport of severely injured patients to a non-trauma center (undertriage) is inevitable; for example, distances to the nearest trauma center might preclude direct transport for those injured in rural areas. In other instances, however, undertriage occurs because a judgment is made in the prehospital setting that trauma center care would not be beneficial or is not required. Once in the emergency department of a non-trauma center, these undertriaged patients will either die in the emergency department, be admitted to hospital or undergo interfacility transfer to a trauma center for definitive care.
More than a third of patients with severe injuries in the United States, and as many as 60% in certain regional trauma systems, are admitted to non-trauma centers\textsuperscript{65, 68, 107, 108}. However, because there is strong evidence that admission at non-trauma centers is associated with excess mortality, it is generally accepted that admission at such centers is not desirable\textsuperscript{19, 47}. In contrast, transfer would appear to be an acceptable alternative for patients who are undertriaged.

Several large cohort studies have shown no increase in mortality or have demonstrated lower mortality among transfer patients compared to patients transported directly to a designated center\textsuperscript{109-114}. These data would suggest that undertriage is not harmful if definitive care is eventually provided at a trauma center. However, previous studies examining the effect of interfacility transfer on mortality among undertriaged patients have had significant methodological limitations. Specifically, these studies have largely drawn their data from trauma center registries\textsuperscript{109-111, 113, 114}. Because trauma center registries only collect data on patients surviving to the trauma center, they are subject to survivor bias; deaths attributable to undertriage that occur prior to arrival at the trauma center are not counted. This informative censoring might underestimate the harm of undertriage. In this Chapter, we postulate that a correct (unbiased) analysis of outcomes among patients requiring transfer, including those who die prior to arrival at a trauma center, will demonstrate a significantly higher mortality compared to patients triaged directly to a trauma center. If correct, these findings would argue for the need to improve access to trauma center care in underserved areas, to implement policies to minimize undertriage in areas where trauma centers are accessible, and to improve the care of patients for whom undertriage is unavoidable.
5.3. Methods

Study design

We performed a retrospective cohort study of severely injured patients in Ontario, and examined the relationship between undertriage, interfacility transfer and mortality using two analytic approaches. First, we used a database that captured all deaths among injured patients transported to hospital in our region to estimate the mortality associated with undertriage. We then contrasted our findings with those that would be obtained through the more common trauma registry perspective. This strategy allowed us to produce an unbiased estimate of the mortality attributable to transfer, and to estimate the bias associated with previous trauma registry-based analyses of undertriage and transfer.

Study subjects

NACRS, which records all emergency department visits in the region, was deterministically linked to the DAD, which records all acute care hospitalizations. Records were linked using a unique identification number (IKN) used at ICES. As such, both in-hospital and emergency department deaths occurring prior to admission were captured. Within this dataset, we identified adult subjects (age ≥ 18) presenting to any emergency department (trauma center or non-trauma center) with a severe injury between July 1, 2002 and December 31, 2007.

The presence of injury was identified by means of an injury-related ICD-10 diagnosis code (range S-T14.9). Severe injury was defined as either an ISS > 15 or death within 24 hours of presentation. This definition of severe injury assumes that early death is a result of injuries that would have been assigned an ISS > 15 if the patient had survived long enough to have
undergone complete diagnostic assessment. AIS scores and ISS were obtained from ICD-10 codes by means of the ICD-10 to ISS crosswalk algorithm described in Chapter 4. ICD-10 diagnoses in the DAD were used to calculate ISS for all patients with an admission record. If no admission record was identified (i.e. the patient died in the emergency department), ICD-10 diagnoses from the NACRS records were used to calculate ISS.

Patient demographics (age and sex) were captured from NACRS. Patient comorbidities were identified using a two-year look back period in the DAD. An unweighted Charlson score was calculated for each patient. The Charlson score identifies the following comorbidities: myocardial infarct, congestive heart failure, peripheral vascular disease, cerebrovascular disease, dementia, chronic pulmonary disease, connective tissue disease, peptic ulcer disease, liver disease, diabetes, hemiplegia, moderate or severe renal disease, diabetes with end organ damage, any malignant or non-malignant solid neoplasm, metastatic solid neoplasm, leukemia, lymphoma and AIDS

Injury mechanism was assigned by means of external cause of injury code (E-code), and using the Center for Disease Control External Cause of Injury Mortality Matrix for ICD-10 (Appendix B). Patients with injuries due to burns and corrosion injury, poisoning or environmental exposure, and patients with complications of medical care and late effects of injury were excluded; these patients are not typically triaged to trauma centers, and are not thought to benefit from trauma center care.

Patients who had a NACRS record with an injury diagnosis code within 3 months of the index event were also excluded, in order to exclude patients presenting for complications of
earlier injuries. Finally, patients discharged home from the emergency department were excluded, as these patients likely did not have severe injuries.

Patients who were dead on arrival (DOA) to the emergency department were also excluded from the analysis, as their outcomes will not be influenced by the type of care received. The definition of DOA was operationalized to include patients with an emergency department discharge diagnosis of DOA in NACRS and patients who died within 30 minutes of emergency department presentation. Time to death in the emergency department was calculated using the difference between triage time and visit completed time in NACRS. Finally, because the ability of pre-hospital personnel to perform a declaration of death varies across Ontario, patients with a non-urgent triage acuity score (Canadian Triage Acuity Scale 4 or 5)\textsuperscript{116} and death in the emergency department were also excluded, as these cases likely represent patients transported to the emergency department for declaration of death.

Patients admitted to non-trauma centers were not included in analysis. In this chapter, we wished to examine the relative mortality of direct transport versus transfer to a trauma center. Since patients admitted to a non-trauma center are not eligible for care at a trauma center, their outcomes are not relevant to this analysis. Outcomes among patients admitted to non-trauma centers will be discussed in Chapter 6.

Patients were considered to be transferred if they had two hospital records within a 24 hour period, the first at a non-trauma center and the second at a trauma center. This 24 hour period began with the triage time recorded in the first NACRS record for the patient. For all patients, we identified patients who had a NACRS record at a second institution with a triage time within 24 hours of the first, or a DAD record at a second institution with an admission time
within 24 hours of the first; such patients were considered transferred. Patients transferred from a
non-trauma center to another non-trauma center were excluded, as were patients who were
transferred more than once.

Institutions were classified as either trauma centers or non-trauma centers based on the
list of trauma centers presented in Chapter 1, Table 1.2. One additional institution that is not a
designated trauma center was included in the list of trauma centers. This non-trauma center has a
dedicated neurosurgical intensive care unit which acts as an adjunct to nearby trauma centers. It
was felt that identifying this institution as a trauma center would more accurately reflect practice
within the province.

**Study groups**

Among study subjects, we identified three groups of patients (Figure 5.1). The DIRECT
group consisted of patients who were transported directly from the scene to a trauma center. The
TRANSFER group was comprised of patients who were successfully transferred from a non-
trauma center to a trauma center. These two patient groups would generally be represented in
trauma center registries, and conventional analyses have simply compared outcomes in the
TRANSFER group to those in the DIRECT group. This study allowed us to identify a third
group of interest: patients triaged to a non-trauma center that died in the non-trauma center
emergency department prior to successful transfer or admission to the non-trauma center (ED-
DEATH group). We classified patients in the ED-DEATH group as potential transfers, as in
virtually all cases, there was likely an intent to transfer, with limited access to in-hospital
resources and to transportation assets contributing to death at the non-trauma center. We
considered the combined TRANSFER and ED-DEATH groups as the true cohort of undertriaged patients who required interfacility transfer – the UNDERTRIAGE group.

Classification of ED-DEATH patients in the UNDERTRIAGE group was based on a number of considerations. First, by excluding early deaths (<30 minutes), patients in the ED-DEATH cohort had survival times of adequate length for transfer to be considered. This assumption would also be confirmed by our sensitivity analysis (described below). In addition, prolonged emergency department times in the absence of hospital admission among these patients suggest that providers at non-trauma centers recognized that these severely injured patients should be admitted elsewhere. Together, these characteristics strongly suggested that patients dying prior to transfer were potential candidates for trauma center care, and thus transfer.

**Outcome analyses**

The primary outcome for this study was 30 day mortality, identified using the RPDB. We first reproduced previous trauma registry analyses, comparing outcomes in the TRANSFER group to DIRECT group to derive estimates of the relative risk of death among undertriaged patients ignoring survivor bias. We then evaluated the relative risk of death in the UNDERTRIAGE group compared to the DIRECT group, mitigating the potential for survivor bias.

It is plausible that in some circumstances, undertriage is a necessity due to geography or other external factors (e.g. adverse weather conditions). However, as previously outlined, 85% of Ontario’s population lives within a 1 hour catchment area of a trauma center. We therefore performed a sensitivity analysis which compared the UNDERTRIAGE group to the DIRECT
group, and limited the UNDERTRIAGE group to those surviving at least one hour in an emergency department at a non-trauma center. In addition, time to death was recorded among all patients dying in the emergency department to establish whether transfer would have been feasible for patients in the ED-DEATH group for whom undertriage was truly inevitable.

**Statistical analysis**

As undertriage might depend on several patient characteristics that could confound the relationship between undertriage, transfer and mortality, logistic regression models were used to produce adjusted mortality estimates. Patient characteristics included in these models were age, gender, comorbidity, mechanism of injury, ISS and severe injury (AIS ≥ 3) in the head, chest and abdomen region. Patients with missing values were included in the model, with the missing value replaced with a missing indicator. Model calibration was estimated using the Hosmer-Lemeshow statistic and discrimination using the c-statistic. In each model, the c-statistic exceeded 0.8, suggesting excellent discrimination, and models demonstrated adequate calibration.

Means and standard deviations were calculated for continuous variables and absolute and relative frequencies were measured for discrete variables. Continuous and categorical variables were compared using the standardized difference. Standardized difference of less than 10% represents negligible imbalance in the covariate across groups\textsuperscript{117,118}. All data were analyzed using SAS (9.1, Cary, NC).

**5.4. Results**

There were 11,398 severely injured patients who met inclusion criteria, 2,065 (18%) of whom died within 30 days. 7,481 (66%) patients were transported directly to a trauma center (DIRECT group), and 3,469 (30%) patients were successfully transferred to a trauma center from
non-trauma center (TRANSFER group). An additional 448 patients (4%) died prior to transfer (ED-DEATH group). Patients in the ED-DEATH group constituted 11% of the UNDERTRIAGE group but 51% of deaths among undertriaged patients and 22% of all deaths in the study. The median time to death among patients at non-trauma center EDs was 2.7 hours (IQR 1.2-4.6). Of the 448 patient dying prior to transfer, 93 (21%) died within one hour of presentation.

There were significant differences in baseline characteristics of patients across study groups (Table 5.1 and Table 5.2). Patients in the UNDERTRIAGE and DIRECT groups had a similar distribution of demographic characteristics, but patients in the DIRECT group had more penetrating injuries and lower ISS. Patients who died prior to successful transfer were more likely to be female, older, and to have comorbidities, penetrating trauma and severe head injuries (Table 5.3).

**Conventional (trauma registry) analyses**

We examined the mortality among patients who experienced undertriage and transfer, as compared to mortality among patients triaged directly to a trauma center. This approach replicated estimates that would be produced from trauma registry analyses (Figure 5.2). The crude mortality in the TRANSFER group was 12% (n = 425), compared to 16% (n = 1,192) in the DIRECT group (unadjusted OR 0.74, 95% CI 0.65-0.83). After adjustment the risk of death was equivalent at 30 days (OR 0.91, 95% CI 0.80-1.04) in the TRANSFER group compared to the DIRECT group. Thus, conventional analyses suggest direct transport to a trauma center offers no benefit over transfer.
Population-based analyses

We repeated our estimates of mortality comparing the population-based group of undertriaged patients (UNDERTRIAGE) to the DIRECT group (Figure 5.2). When patients who died awaiting transfer were included in estimates of crude mortality, the calculated mortality rate among undertriaged patients increased from 12% to 22% (n = 3,917). The unadjusted OR for death in the UNDERTRIAGE group, compared to the DIRECT group, was 1.51 (95% CI 1.37-1.67). After adjusting for potential confounders of injury-related mortality, the adjusted OR for death in the UNDERTRIAGE group compared to the DIRECT group was 1.24 (95% CI 1.10-1.40). Population-based analyses of patients requiring interfacility transfer to trauma center care were therefore the reverse of estimates from conventional analyses of the same data, and suggest that the true cost of undertriage at a population level is an excess mortality of almost 25%.

We repeated both conventional and population-based analyses limiting to patients surviving at least one hour after emergency department presentation at a non-trauma center. This time point was selected as, if patients could have survived at least one hour, they would have likely survived to reach a trauma center if transported directly there from the field. Excluding these patients did not materially change the results (Figure 5.2).

5.5. Discussion

Previous studies have suggested that patients reaching trauma center care by means of interfacility transfer have mortality rates equivalent to, or lower than, patients transported directly from the scene of injury\(^{109-114}\). These data suggest that the process of interfacility transfer to trauma center care carries no additional risk compared to direct trauma center transport, and mitigates the potential risks associated with undertriage. However, virtually all
published evidence regarding the impact of undertriage among patients who receive interfacility transfer has relied on data from trauma center registries\textsuperscript{109-111, 113, 114, 119}, which systematically exclude patients dying prior to transfer.

In this Chapter, we compared mortality estimates for patients requiring transfer estimated using two approaches: an approach that produced mortality estimates based on simulated trauma center registry data, and an approach that produced mortality estimates derived from population-based data. Our objectives were to produce accurate estimates of the mortality attributable to the process of undertriage and transfer, and to evaluate the degree of bias associated with previous estimates. We demonstrated that 11\% of patients eligible for transfer died in the emergency department of a non-trauma center waiting for transfer to occur. Emergency department deaths at non-trauma centers accounted for half of all deaths among undertriaged patients – deaths that have been systematically missed in studies using trauma center registry data. By including outcomes among patients both awaiting and receiving transfer, we have shown that transfer status (or intent to transfer) is associated with a mortality increase of approximately 25\%. These data suggest that the mortality costs of undertriage are significantly higher than previously thought. Trauma center care by means of transfer is inferior to direct transport. Our data also support the need to utilize population-based data when evaluating the mortality associated with undertriage and with transfer at the system level.

Our findings are likely representative of triage and transfer patterns in other trauma systems. The rate of undertriage in Ontario is within the range of others previously reported\textsuperscript{47, 65, 68, 107, 108}. Transfer patients represented 32\% of trauma center admissions in this analysis, which is similar to transfer rates at level 1 trauma centers throughout North America\textsuperscript{110, 112, 120, 121}. Additionally, the impact of deaths occurring in the prior to transfer among undertriaged patients
is not entirely unique to our study. For example, in a study of patients first treated at rural hospitals across Oregon and Washington state, 18% of deaths occurred in the emergency department of rural hospitals, prior to admission or transfer to a higher level of care\textsuperscript{122}. In another study examining the benefits of transfer to a level 1 or 2 center, patients dying in the emergency department prior to admission or transfer were excluded\textsuperscript{123}. However, these patients would have represented 38% of all study deaths. Together, these data suggest that a high rate of emergency department deaths among undertriaged patients is not unique to the region studied.

Some degree of undertriage will occur in any trauma system. Among these patients, geographic distance and limitations of transportation resources preclude direct transport. Although direct triage is preferable, transfer to higher levels of care confers a survival advantage compared to admission at a non-trauma center in this population\textsuperscript{123}. However, in the present analysis, the prolonged intervals between arrival at a non-trauma center and death in the ED death group suggest that transfer patients in Ontario are experiencing considerable delays during the transfer process. In other reports examining the transfer process, patients spent an average of 2.5 to 4 hours in the emergency department of a non-trauma center prior to transfer\textsuperscript{109, 110, 124-126}. Given that approximately 20% of trauma deaths occur between the first and sixth hour after injury, shortening emergency department lengths of stay might lead to improved survival in those patients where undertriage is unavoidable\textsuperscript{22, 127}. However, due to the exclusive trauma system currently in place in Ontario, no standardized transfer protocols are required at non-trauma centers. The implementation of such protocols might substantially influence outcomes among those patients requiring transfer to trauma center care.

This study has a number of potential limitations. Because administrative data does not contain physiologic data or other direct indicators of injury severity (e.g. Glasgow Coma Scale
scores), important confounders of injury-related outcomes might have been omitted from our regression models. However, given that all other indicators of injury severity were similar across the DIRECT and UNDERTRIAGE groups, it is unlikely that residual confounding would significantly affect our major finding. Our findings are also dependent on the quality of administrative data in the DAD and in NACRS. While external validation studies have shown that the databases used reliably identify patients with injuries, underreporting of ICD-10 diagnoses may have led to an underestimation of injury severity\textsuperscript{128,129}. We attempted to minimize this possibility by including all patients who died within 24 hours of presentation.

In conclusion, in this Chapter, we have used population-based data to generate accurate estimates of the excess mortality attributable to undertriage and transfer to trauma center care. We have demonstrated that at the population level, access to trauma center care by means of transfer is associated with significantly higher mortality than direct transport. Significantly reducing current levels of undertriage should be a priority. In addition, efforts must be made to reduce transfer times and to expedite the transfer process among patients living in remote regions where direct transport to a trauma center is impossible.
5.6. Tables for Chapter 5

Table 5.1 – Baseline patient characteristics among patients triaged directly to a trauma center and patients requiring transfer to trauma center care

<table>
<thead>
<tr>
<th></th>
<th>DIRECT</th>
<th>UNDERTRIAGE</th>
<th>Standardized difference (%) *</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of patients</td>
<td>7,481</td>
<td>3,917</td>
<td></td>
</tr>
<tr>
<td>Mean age (SD)</td>
<td>49 (22)</td>
<td>48 (21)</td>
<td>7</td>
</tr>
<tr>
<td>Male gender (%)</td>
<td>5,232 (70)</td>
<td>2,746 (70)</td>
<td>&lt;1</td>
</tr>
<tr>
<td>Charlson score (%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>6,890 (92)</td>
<td>3,700 (94)</td>
<td>9</td>
</tr>
<tr>
<td>1</td>
<td>332 (4)</td>
<td>123 (3)</td>
<td>7</td>
</tr>
<tr>
<td>≥2</td>
<td>259 (3)</td>
<td>94 (2)</td>
<td>6</td>
</tr>
<tr>
<td>Injury mechanism (%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MVC</td>
<td>3,309 (44)</td>
<td>2,234 (57)</td>
<td>26</td>
</tr>
<tr>
<td>Fall</td>
<td>2,716 (36)</td>
<td>1,120 (29)</td>
<td>16</td>
</tr>
<tr>
<td>Other blunt</td>
<td>526 (7)</td>
<td>268 (7)</td>
<td>1</td>
</tr>
<tr>
<td>Stabbing</td>
<td>433 (6)</td>
<td>108 (3)</td>
<td>14</td>
</tr>
<tr>
<td>Firearm</td>
<td>175 (2)</td>
<td>61 (2)</td>
<td>5</td>
</tr>
<tr>
<td>Other/missing</td>
<td>322 (4)</td>
<td>126 (3)</td>
<td>6</td>
</tr>
</tbody>
</table>

*Standardized difference of <10% represents negligible imbalance in the covariate across groups. MVC: Motor vehicle collision
Table 5.2 – Injury severity and distribution among patients triaged directly to a trauma center and patients requiring transfer to trauma center care

<table>
<thead>
<tr>
<th></th>
<th>DIRECT</th>
<th>UNDERTRIAGE</th>
<th>Standardized difference (%)†</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of patients</td>
<td>7,481</td>
<td>3,917</td>
<td></td>
</tr>
<tr>
<td>Injury Severity Score (%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>16-24</td>
<td>3,420 (46)</td>
<td>1,545 (39)</td>
<td>13</td>
</tr>
<tr>
<td>25-47</td>
<td>3,624 (48)</td>
<td>1,923 (49)</td>
<td>1</td>
</tr>
<tr>
<td>48-75</td>
<td>273 (4)</td>
<td>127 (3)</td>
<td>2</td>
</tr>
<tr>
<td>Missing/Other*</td>
<td>164 (2)</td>
<td>322 (8)</td>
<td>30</td>
</tr>
<tr>
<td>Severe injury AIS ≥ 3 (%)††</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Head</td>
<td>4,092 (56)</td>
<td>2,024 (56)</td>
<td>1</td>
</tr>
<tr>
<td>Chest</td>
<td>3,300(45)</td>
<td>1,661 (46)</td>
<td>2</td>
</tr>
<tr>
<td>Abdomen</td>
<td>569 (8)</td>
<td>261 (7)</td>
<td>2</td>
</tr>
</tbody>
</table>

*Patients with Missing/Other Injury Severity Score represent those who died within 24 hours of presentation, where missing or low Injury Severity Scores are attributed to incomplete injury ascertainment.

†Standardized difference of <10% represents negligible imbalance in the covariate across groups.117, 118

†† Proportion of patients with severe injury, excluding patients with Missing/Other Injury Severity Score.

AIS: Abbreviated Injury Scale
Table 5.3 – Patient and injury characteristics among transfer patients

<table>
<thead>
<tr>
<th></th>
<th>TRANSFER</th>
<th>ED-DEATH</th>
<th>Standardized difference (%)†</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of patients</td>
<td>3,469</td>
<td>448</td>
<td></td>
</tr>
<tr>
<td>Mean age (SD)</td>
<td>48 (20)</td>
<td>59 (23)</td>
<td>57</td>
</tr>
<tr>
<td>Male gender (%)</td>
<td>2,465 (71)</td>
<td>281 (63)</td>
<td>18</td>
</tr>
</tbody>
</table>

| Charlson score (%)       |          |          |                             |
| 0                       | 3,304 (95) | 396 (88) | 30                          |
| 1                       | 102 (3)   | 21 (5)   | 10                          |
| ≥2                      | 63 (2)    | 31 (7)   | 34                          |

| Injury mechanism (%)     |          |          |                             |
| MVC                     | 2,019 (58) | 215 (48) | 21                          |
| Fall                    | 964 (28)  | 156 (35) | 16                          |
| Other blunt             | 247 (7)   | 21 (5)   | 10                          |
| Stabbing                | 87 (3)    | 21 (5)   | 13                          |
| Firearm                 | 46 (1)    | 15 (3)   | 16                          |
| Missing/Other           | 106 (3)   | 20 (4)   | 7                           |

| Injury Severity Score (%)|          |          |                             |
| 16-24                   | 1,491 (43) | 54 (12)  | 65                          |
| 25-47                   | 1,846 (53) | 77 (17)  | 74                          |
| 48-75                   | 119 (3)    | 8 (2)    | 9                           |
| Missing/Other*          | 13 (<1)   | 309 (69) | 410                         |

| Severe injury AIS ≥ 3 (%)†† |          |          |                             |
| Head                      | 1,934 (56) | 90 (65)  | 40                          |
| Chest                     | 1,621 (47) | 40 (29)  | 38                          |
| Abdomen                   | 259 (7)    | 2 (1)    | 123                         |

*Patients with Missing/Other Injury Severity Score represent those who died within 24 hours of presentation, where missing or low Injury Severity Scores are attributed to incomplete injury ascertainment.

†Standardized difference of <10% represents negligible imbalance in the covariate across groups.117, 118

††Proportion of patients with severe injury, excluding patients with Missing/Other Injury Severity Score.

MVC: Motor vehicle collision; AIS: Abbreviated Injury Scale
5.7. Figures for Chapter 5

Figure 5.1 – Study cohort for Chapter 5

Allocation of patients into study groups based on receiving hospital and outcome
Figure 5.2 – Mortality among patients requiring transfer to trauma center care compared to patients triaged directly to a trauma center

Comparison of conventional and population-based analyses
Portions of Chapter 6 have previously appeared in


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Chapter 6
A population-based analysis of the mortality associated with undertriage in Ontario

6.1. Summary

Background

By ensuring timely access to trauma center care, well organized trauma systems have the potential to significantly reduce injury-related mortality. However, undertriage continues to be a significant problem in many regional trauma systems. Taking a novel, population-based approach, we estimated the potential detrimental impact of undertriage to a non-trauma center within a regional system.

Methods

We performed a population-based, retrospective cohort study of trauma center effectiveness in a region with urban, suburban and rural areas. Data were derived from administrative databases capturing all ED deaths and admissions in the region. Adult motor vehicle collision (MVC) occupants presenting to any ED in the study region were included (2002-2010). Data were limited to patients with severe injury. The exposure of interest was initial triage destination (trauma center or non-trauma center), regardless of later transfer to a trauma center. Mortality was compared across groups, using an instrumental variable analysis to adjust for confounding.

Results

Among 6,341 MVC occupants, 45% (n = 2,857) were triaged from the scene of injury to a trauma center. Among patients transported from the scene to a non-trauma center, 57% (n = 2,003) were transferred to a trauma center within 24h of initial evaluation. Compared to patients
triaged to a non-trauma center, adjusted mortality was lower among patients triaged directly to a trauma center, both at 24 hrs (OR 0.58, 95% CI 0.41-0.84) and at 48 hrs (OR 0.68, 95% CI 0.48-0.96). A trend towards reduced mortality with trauma center triage was also observed at 7 days and 30 days.

Conclusions

Our data are population-based evidence of the early benefits of direct triage to trauma center. Although many surviving patients are later transferred to a trauma center, initial triage to a non-trauma center is associated with at least a 30% increase in mortality in the first 48 hours following injury.

6.2. Introduction

Access to trauma center care among severely injured patients is an essential measure of trauma system performance\[^{19,28}\]. One of the significant challenges in system design is maintaining acceptably low rates of undertriage. A critical step in effecting change is an understanding of the risk of adverse outcomes associated with undertriage. However, most prior evaluations lead to biased estimates of undertriage rates as well as the mortality attributable to undertriage. Either data are derived only from admission records (thus excluding deaths in the emergency department), or patients accessing trauma center care after initial undertriage to a non-designated center are analyzed with those who are appropriately triaged\[^{65,68,130}\]. In the previous Chapter, we reported the limitations of the latter approach, which typically grossly underestimates the mortality associated with transfer to a trauma center from a non-designated center\[^{131}\]. Finally, rather than examining outcomes among all patients injured within a trauma system, previous analyses have focused on populations at select institutions. What is currently
lacking is an accurate estimate of the benefits of triage to a trauma center at the system level. An improved understanding of the magnitude and the impact of undertriage might be a very effective catalyst for change. In this Chapter, we address the gap in estimating the mortality benefits of triage to a trauma center. We employed a novel, population-based approach to capture all injured patients in our region, regardless of the site of initial presentation, with the goal of producing unbiased estimates of the mortality associated with triage of a severely injured patient to a non-designated center.

6.3. Methods

We performed a population-based, retrospective cohort study of all severely injured motor vehicle collision (MVC) occupants presenting to an emergency department (ED) in the province of Ontario between July, 2002 and January, 2010. Our objective was to evaluate mortality among patients triaged from the scene of injury to a trauma center, as compared to patients who were triaged to a non-trauma center. We focused on patients injured as a result of MVC because these patients represent a relatively homogeneous population, have severe, multi-system injuries that challenge institutional resources, and are likely to benefit from trauma center care.\(^6\)

Data sources

As in Chapter 5, NACRS and the DAD were used to evaluate the trajectory of all injured patients, from emergency department presentation to discharge. All deaths occurring within 30 days of injury were captured using the RPDB.
Study subjects

All patients aged 18 or over presenting to an ED with an injury-related diagnosis in NACRS (ICD10 diagnosis code range S-T14.9) were captured\(^9^3\). The study population was limited to patients with severe injury who were MVC occupants. MVC occupants were identified using the Centers for Disease Control External Cause of Injury Mortality Matrix for ICD-10\(^9^4,9^5\) (Appendix B). As in Chapter 5, severe injury was defined as either an ISS >15 or death within 24 hours of presentation. ISS was obtained from ICD-10 codes in NACRS or DAD by means of the ICD-10 to Abbreviated Injury Scale (AIS) crosswalk algorithm developed in Chapter 4.

Patients discharged home from the ED were excluded, as these patients were not likely to have had severe injuries. In order to ensure the exclusion of patients presenting to the ED with complications from previous injuries, we excluded all patients with an injury-related ED visit in the 3 months prior to the index event. As we wished to examine the effect of trauma center care on patient outcomes, we excluded patients who were dead on arrival and who died within 30 minutes of ED presentation, as outcomes of these patients were likely not modifiable.

Patients who were transferred from a non-trauma center to a trauma center were identified. Patients who had records at two different institutions within 24 hours, where the first was a non-trauma center and the second a trauma center, were considered transfers. Patients who were transferred more than once within 24 hours were excluded (<5% of cohort).

Patient demographics (age and sex) were captured from NACRS. Patient comorbidities were identified using a two-year look back period in the DAD. An unweighted Charlson score was calculated for each patient\(^1^1^5\).
Analytic approach

We evaluated the association between triage to a trauma center from the scene of injury and mortality at 24 hours, 48 hours, 7 days and 30 days after injury. Transport of a patient from the scene to a trauma center is not random, however; EMS personnel may be more likely to transport more severely injured patients or patients in a specific demographic to a trauma center than to a non-trauma center. Such systematic differences across patient groups might confound the relationship between trauma center care and mortality.

An instrumental variable analysis was used to estimate the mortality benefit of triage to a trauma center. The main assumption underlying an instrumental variable is that it is highly correlated with the treatment (triage to a trauma center or non-trauma center), but that it is otherwise unrelated to measured or unmeasured risk factors for death following injury. As such, the instrumental variable is not directly or indirectly associated with patient outcome, except through the treatment. Instrumental variable analysis is frequently compared to the process of randomization in a randomized controlled trial, where allocation to the treatment group is very closely linked to the probability of treatment, but unrelated to outcome.

We defined a “county-level trauma center transport rate” to be used as the instrumental variable, defined as the proportion of severely injured patients in a county that were transported directly to a trauma center among all persons severely injured in that county. With this approach, all patients within a county are assigned the same value for the instrument. Patients with severe injury at the county level were defined as those patients presenting to the ED with an injury-related diagnosis in NACRS (ICD10 diagnosis code range S-T14.9) and with severe injury. Note the denominator excludes patients who died at the scene. The county-level trauma center
transport rate is a valid instrumental variable because patient-level factors related to the probability of death following an MVC are likely comparable across regions with significantly different rates of transport to a trauma center. The use of a regional rate of transport to trauma center care is analogous to instruments previously used to evaluate the benefits of cardiac catheterization following myocardial infarction.\textsuperscript{134}

Our analysis relies on the assumption that patients in counties with low and high trauma center referral rates have similar severity of illness, mechanisms of injury, comorbidity, and other factors that would determine outcome. Although it is possible to explore the relationship between county-level trauma center transport rate and patient-level predictors of injury-related mortality, the independence of the instrumental variable and of these factors cannot be proven directly. However, we examined the association between the county-level trauma center transport rate and known confounders of injury-related mortality.

Counties were ranked based on their county-level trauma center transport rate, and then separated into quartiles with approximately equal numbers of patients. Using standardized differences, patient and injury characteristics were compared across quartiles of counties with the highest and with the lowest county-level trauma center transport rates. In addition to age, gender, and comorbidities, we also evaluated the distribution of ISS and severe (AIS $\geq 3$) head, chest and abdominal injuries across quartiles of county-level trauma center transport rate. We also assessed the mean predicted probability of 30 day mortality across quartiles of the instrumental variable. The predicted probability of 30 day mortality for each patient was estimated using a logistic regression model that incorporated age, gender, comorbidities, ISS and severe (AIS $\geq 3$) head, chest and abdominal injuries as covariates.
**Statistical analyses**

Continuous and categorical variables were compared using the standardized difference. Standardized differences of less than 10% represents a negligible imbalance in the covariate across groups\textsuperscript{117, 118}. The instrumental variable analysis was conducted using a full-information maximum likelihood bivariate probit estimation. Separate models were used to estimate the mortality benefit associated with direct transport to trauma center care at 24 hours, 48 hours, 7 days and 30 days. Patient age, gender and comorbidities (defined as a categorical variable based on number of comorbidities) were incorporated into each model. The county-level trauma center transport rate was entered into the model as a continuous variable. Odds ratios were estimated from the parameter estimates produced in each model\textsuperscript{136}. Univariate analyses were conducted in SAS (version 9.2, Cary, NC). Instrumental variable analysis was conducted in STATA (version 9, College Station, TX).

6.4. **Results**

There were 6,341 patients meeting inclusion criteria over the nine years of study. During this interval, 45% (n = 2,857) of severely injured MVC occupants were transported from the scene of injury to a trauma center (Fig 6.1). Of 3,484 patients transported from the scene of injury to a non-trauma center, 57% (n = 2,003) were ultimately transferred to a trauma center after their initial evaluation. Overall, 77% (4,860) of patients received trauma center care following their MVC.

Patients initially triaged to trauma centers and non-trauma centers differed significantly in baseline and injury characteristics (Table 6.1). Compared to patients transported to a non-trauma center, patients triaged directly to a trauma center were younger and had a higher recorded ISS. However, a significantly greater number of patients triaged to a non-trauma center
died early (within 24 hrs of presentation) and thus had a missing or low ($\leq 15$) ISS, as described in *Methods*. The differential in rates of missing/low ISS in non-trauma centers and trauma centers emphasizes the challenge of early identification of injuries in the non-trauma center, and the potential for bias inherent in including ISS or AIS from trauma centers and non-trauma centers in risk adjustment models.

The crude mortality in the cohort was 12% ($n = 761$). There was no significant difference in crude mortality across trauma centers and non-trauma centers at 24 hours, 48 hours, 7 days or 30 days (Table 6.2). However, the ED mortality rate at non-trauma centers was twice that for patients initially transported to a trauma center.

**Patient characteristics**

The instrumental variable ranged from as low as 6% to as high as 90%. Specifically, as few as 6% to as many as 90% of severely injured patients within a county were transported directly to a trauma center. Rates of direct transport of severely injured MVC occupants ranged from as low as 20% ($n = 320$) to as high as 77% ($n = 1,157$) across quartiles of the instrumental variable. When the proportion of patients who received care at a trauma center at any time during their injury episode (including transfers to a trauma center) was calculated, there continued to be a significant difference in the probability of trauma center care across IV quartiles, with as few as 64% ($n = 1,023$) of patients in the lowest quartile receiving trauma center care, compared to 92% ($n = 1,380$) of patients in the highest quartile. Predicted 30 day mortality did not differ significantly across quartiles of county-level trauma center transport rate. There were no significant differences in patient sex, age or comorbidity burden across quartiles of the instrumental variable (Table 6.3). ISS was comparable across quartiles of county-level trauma center transport rate, with the exception of an overrepresentation of patients with very severe injuries ($ISS \geq 47$) among patients in counties with high county-level trauma center transport
rates. Rates of severe injury (AIS ≥ 3) to the head and chest were similar across all quartiles; as with ISS, patients in counties with the highest county-level trauma center transport rates were more likely to have a severe injury to the abdomen. These findings suggest that patient and injury characteristics are similar across counties with highly divergent county-level trauma center transport rates and thus validate the instrumental variable.

**Instrumental variable analysis**

Our adjusted analysis using the instrumental variable approach demonstrated that direct transport to a trauma center was associated with significantly lower mortality at 24 hours and 48 hours following injury (OR 0.58, 95%CI 0.41-0.84 at 24 hours; OR 0.68, 95%CI 0.48-0.96 at 48 hours). In addition, there was a persistent, albeit non-significant, lower mortality at later time points (Figure 6.2).

6.5. Discussion

Trauma centers are the anchor of an organized trauma system and an essential component of injury-related public health policy. Despite the compelling evidence favoring the treatment of severely injured patients at designated trauma centers, a significant proportion of patients continue to receive definitive management of their injuries at non-trauma centers. In prior reports, over a third of severely injured patients receive definitive care at non-trauma centers. These analyses likely underestimated the magnitude of undertriage rates that exist in contemporary trauma systems. Data regarding emergency department deaths are generally unavailable at the population level, and patients undergoing transfer after initial undertriage to a non-trauma center have previously been classified as appropriately triaged in population-based analyses. Given these limitations, accurate, population-based estimates of undertriage
rates and of the mortality cost of undertriage have been lacking. Such data are highly relevant for the purposes of trauma system planning and quality improvement.

In this Chapter, we utilized population-based datasets to capture all severely injured MVC occupants arriving alive to any acute care hospital in our region. Unlike previous analyses, we were able to capture patients who died in the emergency department prior to admission. We were also able to identify the first hospital at which the patient received care, allowing us to accurately classify patients who were initially undertriaged but underwent transfer to trauma center care. We demonstrated that more than half of severely injured MVC occupants experienced undertriage, and were transported from the scene of injury to a non-trauma center. Using an instrumental variable analysis, we identified a 30 to 40% lower mortality at 24 and 48 hours among patient triaged directly to a trauma center, compared to patients who were undertriaged, with a lower, albeit non-significant, difference at 7 days and 30 days following injury.

The use of an instrumental variable approach was based on a number of considerations. Transport of a patient from the scene to a trauma center is not random; more severely injured patients are more likely to be transported to a trauma center. As a result, both measured and unmeasured confounders might bias the analysis of the relationship between trauma center care and mortality. Administrative data may be particularly prone to unmeasured confounding for two reasons. First, administrative data does not capture several common measures used in risk adjustment of injury-related outcomes (e.g. systolic blood pressure, Glasgow Coma Scale scores). In addition, the accuracy of injury scoring is likely to differ significantly across trauma centers and non-trauma centers due to differences in diagnostic resources, particularly among patients who die early in their hospital course. Commonly used means of statistical adjustment, such as logistic regression or propensity score analyses, which adjust only for measured
confounders, are therefore inadequate\textsuperscript{133, 134}. Instrumental variable analysis is an alternative approach that minimizes unmeasured confounding and thus overcomes some of the limitations described above.

Instrumental variable analysis produces estimates of the treatment effect on the “marginal population"\textsuperscript{134, 137}. In this study, this marginal population represents patients whose treatment would change across counties, and excludes those who would always (or never) be directly transported to a trauma center across all counties. As such, our analysis provides an estimate of the reduction in mortality that would result if, due to policy changes, a county transitioned from having a low rate of transport to a trauma center to a high rate of transport to a trauma center. The precise size of the population that would benefit, and therefore the number of lives saved by reducing undertriage in the region, cannot be directly estimated. However, we believe that a large majority of patients who experienced undertriage in the present analysis fall into the marginal population. The county-level trauma center transport rate ranged from as low as 6 (6\% of patients in the county were triaged directly to a trauma center) to 90 (90\% of patients in the county were triaged directly to a trauma center). This range suggests that there is a significant proportion of patients eligible for, but not receiving, direct transport to a trauma center in the study region.

Our data might be interpreted as suggesting that there is no benefit to trauma center care beyond 48 hours. We do not feel our findings support such a conclusion. Trauma center designation emphasizes the human and physical resources required to stabilize and treat the severely injured patients in the period immediately following injury\textsuperscript{18, 19}. Less specific guidance is provided regarding the resources required to care for patients who survive initial resuscitation and care. As such, whereas early trauma center care is likely to be relatively homogeneous across
trauma centers, care provided after initial stabilization may be more heterogeneous. It is likely that the non-significant outcomes at 7 and 30 days are a reflection of this heterogeneity. Nevertheless, the improved survival observed at trauma centers at 24 and 48 hours suggest that there is an opportunity to intervene in that time period.

Our study has several potential limitations. Firstly, we evaluated the similarity of patients across quartiles of our instrumental variable using ISS and AIS, while acknowledging that these scores might not be directly comparable across trauma centers and non-trauma centers due to differences in injury ascertainment. Nevertheless, we felt that evaluating these metrics of injury across quartiles of our county-level trauma center transport rate was important, both to characterize our population and to evaluate the validity of our instrumental variable. An observed imbalance in these measures of injury severity across quartiles, namely, more severe injuries in quartiles with low county-level trauma center transport rates, would lead us to conclude that our chosen instrument is not valid, and biased against non-trauma center care.

Although our analysis captures all patients who arrived alive to the emergency department, our data do not capture patients dying prior to hospital arrival. Approximately half of patients die in the prehospital setting; if more prehospital deaths occurred in areas with a high county-level trauma center transport rate, trauma center care might not offer any benefit at the system level. However, such a distribution of prehospital deaths is unlikely. Prehospital deaths are significantly more likely in rural areas, where geographic barriers to trauma center access exist. As such, a link between high county-level trauma center transport rate (lower probability of undertriage) and high probability of prehospital death is unlikely.

In addition to the distribution of prehospital deaths, it is possible that our analyses might be biased due to the choice of an invalid instrumental variable. Specifically, the accuracy of our instrumental variable analysis is dependent on ensuring that the county-level trauma center
transport rate is not associated directly with any confounders of injury-related death. Due to the use of administrative data, specific physiologic variables, such as blood pressure and Glasgow Coma Scale score, were not available, and could not be compared directly across quartiles of county-level trauma center transport rate. In addition, due to differences in diagnostic resources and injury ascertainment across trauma centers and non-trauma centers, direct comparisons of ISS and AIS across quartiles of county-level trauma center transport rate were potentially biased. If patients in counties with low county-level trauma center transport rates were consistently more severely injured, our findings might be significantly biased. An inverse relationship between county-level trauma center transport rate and injury severity is unlikely, however.

In conclusion, fewer than half of patients sustaining severe injuries as occupants in motor vehicle collisions in the province of Ontario are triaged from the scene of injury to a trauma center. Additionally, only half of undertriaged patients are eventually transferred to trauma center care. Using an instrumental variable analysis, we have demonstrated that, at the population level, undertriage is associated with an up to 40% increase in mortality at 24 hours and 48 hours. These data suggest that current rates of undertriage in Ontario result in a high rate of preventable deaths among patients injured in motor vehicle collisions. Strategies to reduce undertriage need to be implemented and evaluated.
6.6. Tables for Chapter 6

Table 6.1 – Patient baseline and injury characteristics among severely injured motor vehicle collisions occupants

<table>
<thead>
<tr>
<th></th>
<th>Non-trauma center</th>
<th>Trauma center</th>
<th>Standardized difference (%)*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of patients</td>
<td>3,484</td>
<td>2,857</td>
<td></td>
</tr>
<tr>
<td>Male (n, %)</td>
<td>2,226 (64)</td>
<td>1,908 (67)</td>
<td>6</td>
</tr>
<tr>
<td>Age (mean, SD)</td>
<td>45.9 (20)</td>
<td>42.1 (19)</td>
<td>19</td>
</tr>
<tr>
<td>Patients aged ≥ 65 (n,%)</td>
<td>700 (20)</td>
<td>440 (15)</td>
<td>12</td>
</tr>
<tr>
<td>Comorbidities (n, %)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>3,291 (94)</td>
<td>2,702 (95)</td>
<td>&lt;1</td>
</tr>
<tr>
<td>1</td>
<td>136 (4)</td>
<td>110 (4)</td>
<td>&lt;1</td>
</tr>
<tr>
<td>≥2</td>
<td>57 (2)</td>
<td>45 (2)</td>
<td>&lt;1</td>
</tr>
<tr>
<td>ISS (n, %)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>16-25</td>
<td>1,905 (55)</td>
<td>1,263 (44)</td>
<td>21</td>
</tr>
<tr>
<td>26-47</td>
<td>1,321 (38)</td>
<td>1,370 (48)</td>
<td>20</td>
</tr>
<tr>
<td>48-75</td>
<td>122 (3)</td>
<td>170 (6)</td>
<td>12</td>
</tr>
<tr>
<td>Missing/Other**</td>
<td>136 (4)</td>
<td>54 (2)</td>
<td>11</td>
</tr>
</tbody>
</table>

*Standardized difference of <10% represents negligible imbalance in the covariate across groups.

** Patients with Missing/Other Injury Severity Score represent those who died within 24 hours of presentation, where missing or low Injury Severity Scores were attributed to incomplete injury ascertainment.

SD: standard deviation; ISS: Injury Severity Score
Table 6.2 – Unadjusted mortality among severely injured motor vehicle collisions occupants

<table>
<thead>
<tr>
<th>Mortality (n, %)</th>
<th>Non-trauma center</th>
<th>Trauma center</th>
<th>Standardized difference (%)*</th>
</tr>
</thead>
<tbody>
<tr>
<td>ED death</td>
<td>158 (4)</td>
<td>64 (2)</td>
<td>12</td>
</tr>
<tr>
<td>24 hour</td>
<td>248 (7)</td>
<td>185 (6)</td>
<td>2</td>
</tr>
<tr>
<td>48 hour</td>
<td>304 (9)</td>
<td>231 (8)</td>
<td>2</td>
</tr>
<tr>
<td>7 days</td>
<td>361 (10)</td>
<td>291 (10)</td>
<td>1</td>
</tr>
<tr>
<td>30 days</td>
<td>413 (12)</td>
<td>761 (12)</td>
<td>1</td>
</tr>
</tbody>
</table>

*Standardized difference of <10% represents negligible imbalance in the covariate across groups117, 118

ED: emergency department
Table 6.3 — Patient characteristics across quartiles of county-level trauma center transport rate

<table>
<thead>
<tr>
<th></th>
<th>Quartile of county-level trauma center transport rate</th>
<th>Standardized difference (%)*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Number of patients</td>
<td>1,590</td>
<td>1,645</td>
</tr>
<tr>
<td>Number of counties</td>
<td>20</td>
<td>9</td>
</tr>
<tr>
<td>Median county-level trauma center transport rate (IQR)</td>
<td>10 (8-12)</td>
<td>18 (16-18)</td>
</tr>
<tr>
<td>Direct transport to TC from scene (n, %)</td>
<td>320 (20)</td>
<td>595 (36)</td>
</tr>
<tr>
<td>Care at a TC during injury episode (n, %)</td>
<td>1,023 (64)</td>
<td>1,168 (71)</td>
</tr>
<tr>
<td>Male (n, %)</td>
<td>1,041 (65)</td>
<td>1,059 (64)</td>
</tr>
<tr>
<td>Age (mean, SD)</td>
<td>45.2 (20)</td>
<td>43.7 (19)</td>
</tr>
<tr>
<td>Patients aged ≥ 65 (n, %)</td>
<td>297 (19)</td>
<td>271 (16)</td>
</tr>
<tr>
<td>Comorbidities:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>1,490 (94)</td>
<td>1,568 (95)</td>
</tr>
<tr>
<td>1</td>
<td>66 (4)</td>
<td>57 (3)</td>
</tr>
<tr>
<td>≥2</td>
<td>34 (2)</td>
<td>20 (1)</td>
</tr>
<tr>
<td>ISS (n,%):</td>
<td></td>
<td></td>
</tr>
<tr>
<td>16-24</td>
<td>822 (52)</td>
<td>840 (51)</td>
</tr>
<tr>
<td>25-47</td>
<td>655 (41)</td>
<td>672 (41)</td>
</tr>
<tr>
<td>48-75</td>
<td>56 (3)</td>
<td>72 (4)</td>
</tr>
<tr>
<td>Missing/Other**:</td>
<td>57 (4)</td>
<td>61 (4)</td>
</tr>
<tr>
<td>Severe injury, AIS ≥ 3 (n, %):</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Head</td>
<td>559 (36)</td>
<td>575 (36)</td>
</tr>
<tr>
<td>Chest</td>
<td>1,060 (69)</td>
<td>1,074 (68)</td>
</tr>
<tr>
<td>Abdomen</td>
<td>137 (9)</td>
<td>136 (9)</td>
</tr>
<tr>
<td>Mean predicted probability of 30 day mortality (SD)</td>
<td>0.12 (0.19)</td>
<td>0.12 (0.19)</td>
</tr>
</tbody>
</table>
* Standardized difference of <10% represents negligible imbalance in the covariate across groups\textsuperscript{117,118}

**Patients with Missing/Other Injury Severity Score represent those who died within 24 hours of presentation, where missing or low Injury Severity Scores are attributed to incomplete injury ascertainment.

† Proportion of patients with severe injury, excluding patients with Missing/Other Injury Severity Score.

IQR: interquartile range; TC: trauma center; SD: standard deviation; AIS: Abbreviated Injury Scale
6.7. Figures for Chapter 6

Figure 6.1 – Study cohort for Chapter 6

Allocation of patients based on receiving hospital and outcome
**Figure 6.2** – Mortality among undertriaged patients compared to patients triaged directly to a trauma center

<table>
<thead>
<tr>
<th></th>
<th>24 hour mortality</th>
<th>48 hour mortality</th>
<th>7 day mortality</th>
<th>30 day mortality</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Odds ratio</strong></td>
<td>0.58 (0.41-0.84)</td>
<td>0.68 (0.48-0.96)</td>
<td>0.76 (0.55-1.05)</td>
<td>0.79 (0.58-1.08)</td>
</tr>
</tbody>
</table>

*Approximate odds ratio with 95% confidence interval*¹³⁶
Chapter 7  
General Discussion

7.1. Conclusions

Injury remains a leading cause of death and disability, both in Canada and throughout the world. Although primary prevention strategies are paramount to reducing the social and economic burden cause by injuries, the type of care received following severe injury can significantly modify outcomes. Previous work has demonstrated that trauma center care can significantly increase the probability of survival following severe injury. This dissertation explored the relationship between severe injury, direct triage to a trauma center and mortality at a population level.

In Chapter 4, we described the development and validation of an algorithm which can be used to derive ISS from ICD-10 codes. Using the data available in the OTR CDS, we have demonstrated the ability of this algorithm to identify patients with severe injuries in specific body regions, as well as to accurately estimate ISS. Specifically, when examining the crosswalk algorithm’s ability to identify injuries with an AIS ≥ 3, we demonstrated that the crosswalk had good concordance with abstracted AIS scores, and performed particularly well in the head, chest and abdomen regions. When comparing algorithm-derived ISS and abstractor-derived ISS, the algorithm’s accuracy was comparable to that of human abstractors. The difference between ISS scores obtained by crosswalk and abstracted scores was ≤ 10 in 87% of patients. Beyond its use in this dissertation, the ICD-10 to ISS crosswalk algorithm described in this work has other important applications in trauma research. The algorithm can be used in a variety of other population-based analyses to study outcomes among injured patients in Ontario, other provinces or internationally.
In Chapter 5, we performed a study examining the mortality associated with transfer to trauma center care following undertriage. Previous studies examining the mortality associated with transfer were significantly limited by survivor bias. We used a population-based approach to overcome the methodological limitations of previous data. In our analyses, we demonstrated that 50% of deaths that occur among patients eligible for transfer occur in the emergency departments of non-trauma centers, prior to transfer occurring. These deaths have previously not been captured in analyses of outcomes among transferred patients. Our analyses suggest that patients who are undertriaged and require transfer have a 25% higher mortality than patients triaged directly to a trauma center. These findings contradict previous data, which would suggest that transfer patients have outcomes equivalent those of patients triaged directly to a trauma center. As such, our findings suggest that policies to reduce undertriage and to expedite transfers are needed.

Finally, in Chapter 6, we used a population-based approach to evaluate the mortality cost associated with undertriage at the level of a trauma system. We focused on all individuals severely injured in a motor vehicle crash in Ontario between July 1, 2002 and January 31, 2010. We demonstrated that fewer than half of these patients are triaged directly from the scene of injury to a trauma center. Using an instrumental variable analysis, we demonstrated that mortality was significantly lower among patients triaged directly to a trauma center at 24 hours and 48 hours, as compared to patients triaged to a non-trauma center. This mortality benefit did not persist at 7 days or 30 days, however.
7.2. Limitations

The work presented in this dissertation has a number of limitations.

7.2.1. Limitations of available data

Absence of information about prehospital deaths

Although data in this thesis are population-based, it is important to acknowledge that only the population of patients arriving alive to an emergency department are captured. The population of patients dying in the field or en route to the emergency department is excluded. It is acknowledged that a significant proportion of injury-related deaths occur in the field, prior to hospital arrival. As a result, this thesis does not provide a population-based estimate of all injury-related deaths in the study region. The focus of this thesis, however, was to examine the relationship between type of care received following hospital arrival and mortality; deaths occurring at the scene of injury are beyond the scope of this work. In addition, population-based analyses of injury-related field deaths in Ontario have previously been described\textsuperscript{77}.

Absence of information about prehospital care

The studies described in Chapter 5 and Chapters 6 focus on outcomes among severely injured patients, and the relationship between undertriage and mortality. An important potential modifier of outcomes that is not accounted for in these analyses is the type of prehospital care received, and the length of time elapsed between injury and arrival at the emergency department.

Type of care received in the prehospital setting (Advanced Life Support compared to Basic Life Support) has previously been linked to probability of in-hospital death\textsuperscript{138}. In addition, prehospital intubation, prehospital fluid administration and other prehospital procedures have
been shown to modify outcomes among severely injured patients\textsuperscript{138-141}. In Chapter 5, significant differences in prehospital care among patients triaged directly to a trauma center and to a non-trauma center may have led to biased estimates of the relationship between transfer and mortality. Similarly, in Chapter 6, systematic differences in prehospital care across strata of county intensity score may have significantly impacted on the results. Such systematic differences across regions are unlikely, however.

A recent multi-center study examined the effect of the implementation of Advanced Life Support programs in 17 cities within Ontario\textsuperscript{142}. The authors demonstrated that only a minority of patients received interventions in the prehospital setting, even when Advanced Life Support was available: 6.8\% of patients were intubated and 11.7\% of patients received a fluid bolus in the prehospital setting. More importantly, there was no difference in patient mortality when periods prior to and following Advance Life Support program implementation were compared (OR for death 1.2, 95\% CI 0.9-1.7). As such, the type of prehospital care available does not appear to affect outcomes among patients in Ontario.

**Patients not captured by administrative data**

Although NACRS and DAD capture virtually all patients treated in the emergency department and acute care hospitals in the province of Ontario, there are select patient populations that are not captured accurately in this dissertation. Patients included in studies described in Chapter 5 and Chapters 6 were identified and tracked within NACRS and DAD by means of a universal identifier which is derived from the patient’s health card number. As a result, patients who are homeless, patients who are not Ontario residents and First Nations
patients may not be captured. Because these populations are relatively small, their exclusion is unlikely to significantly influence study findings.

**Institutions not captured by administrative data**

In addition to select patient populations, NACRS and DAD cannot capture institutions outside of the province of Ontario. It is possible that a small number of patients who were initially triaged to a non-trauma center were subsequently transferred to an institution in another province, or to an institution in the United States. We are unable to obtain data regarding these patients.

**Outcomes not captured by administrative data**

Although the focus of this dissertation is mortality following severe injury, death is not the only outcome of relevance to patients. Specifically, the severe disability experienced by patients following injury contributes to a significant proportion of its personal and economic costs. A reduction in injury-related disability associated with trauma center care would be highly relevant both to patients and to policy makers. There is previous data to suggest that trauma center care can, in fact, reduce the probability of disability. Specifically, Mackenzie and colleagues have previously demonstrated that patients with severe lower extremity orthopedic injuries treated at trauma centers have better functional outcomes compared to patients treated at non-trauma centers\(^{143}\). However, the authors of this study followed patients up to one year post-discharge; disability cannot specifically be captured using administrative data currently available.
Limited information on hospital-level attributes and process of care

Although we have identified differences in outcomes among patients triaged directly to a trauma center compared to patients who are undertriaged, the data presented in this dissertation provide little guidance regarding the processes of care leading to the observed differences in outcomes. Specifically, although there is considerable information available regarding the structures and processes of care relevant to injured patients at Ontario trauma centers, similar information regarding non-trauma centers is extremely limited. Clearly, there is significant variability in the resource availability at non-trauma centers; the non-trauma centers included in this dissertation ranged from small rural acute care hospitals to highly-resourced, university-affiliated, urban centers. Such a range in resource availability is likely to translate into significant differences in processes of care across the spectrum of included non-trauma centers. However, delineating precisely what resource are available at each center, and how these resources translate into processes of care relevant to severely injured patients, is challenging with administrative data alone.

7.2.2. Limitations of data analysis

The focus of the studies described in this dissertation is treatment at trauma centers and non-trauma centers. As outlined in Chapters 5 and 6, patients triaged to trauma centers and non-trauma centers differed significantly from each other, both in terms of patient characteristics and injury characteristics. Given these differences in patient populations across the two types of centers, risk-adjustment is necessary to produce meaningful estimates of the mortality associated with undertriage.
In Chapter 5 of this dissertation, logistic regression was used for risk adjustment. It is possible that patient or injury characteristics which could not be captured in our dataset might have significantly influenced our findings (residual confounding). Specifically, we did not have access to physiologic variables, such as systolic blood pressure or Glasgow Coma Scale score. However, we believe that our analyses are valid for two reasons. First, measured characteristics were very similar across groups of patients (those transported directly to a trauma center and those transported to a non-trauma center). There is no reason to infer that unmeasured characteristics would differ significantly. In addition, we feel that the variables that were captured explain a significant amount of variation within the model, as evidence by the discrimination and calibration of our model. Finally, we feel that one of the main findings of the analysis in Chapter 5 is the observation that up to 50% of deaths among patients eligible for transfer occur in the emergency departments of non-trauma centers. These patients have not previously been captured in evaluations of trauma system performance, and the important impact these patients have on overall calculations of undertriage does not rely on risk adjustment methods.

In Chapter 6, we argue that the use of an instrumental variable analysis is necessary due to the non-comparability of ISS and AIS across trauma centers and non-trauma centers. Thus, our use of ISS and AIS scores for risk adjustment in Chapter 5 may seem invalid. However, there are important differences in the patient populations in Chapter 5 compared to Chapter 6. In Chapter 5, all included patients were either admitted to a trauma center at some point in their care trajectory, or died in the emergency department of a non-trauma center. Patients admitted to trauma centers would be expected to have equally good injury ascertainment, regardless of whether they arrived directly or were transferred. Among patients that died in the emergency
department, the majority (69%) had a missing or invalid ISS, which was represented in the logistic regression models with a missing indicator. Only 139 patients in the analysis (1.2%) had an ISS derived from diagnoses at a non-trauma center. In this way, the confounding caused by inaccurate injury ascertainment at non-trauma centers was likely to be minimal – virtually all patients who had a valid ISS were assigned this ISS at a trauma center. In contrast, in Chapter 6, patients admitted to non-trauma centers were included in the analysis. Among these patients, 3,348 had an ISS > 15; therefore, 53% of patient in the analysis had an ISS assigned at a non-trauma center, where diagnostic modalities might be limited. As such, there was significant opportunity for residual confounding if ISS were used for risk-adjustment. Concern regarding residual confounding prompted us to select instrumental variable analysis as a means of risk adjustment in Chapter 6.

7.2.3. Limitations of external generalizability

The mortality estimates produced in Chapter 5 and Chapter 6 of this thesis may not be broadly generalizable to all trauma systems. Specifically, Ontario has an exclusive trauma system: only level I and level II centers participate in the system, and there are no specific, injury-related standards at non-trauma centers. Non-trauma centers are not required to have transfer protocols, and staff at non-trauma centers are not required to have specialized training regarding the management of injured patients. As described in Chapter 1, exclusive trauma systems are associated with higher injury-related mortality than inclusive systems. The high rate of mortality in non-trauma center emergency departments observed in Chapter 5, and the higher mortality rates among undertriaged patients observed in Chapter 6, may both be related to inadequate standards of care at non-trauma centers. It is possible that, in inclusive systems, mortality at non-trauma centers would be significantly lower.
We noted that patients dying prior to transfer to trauma center care had prolonged times in the emergency department prior to death (median 2.7 hours). The cause of these delays may be multiple, including failure to recognize the need for transfer, failure to identify an institution willing to accept the patient in transfer and lack of transportation assets. We hypothesize that shorter emergency department length of stays and expedited transfer may have prevented death in a subset of these patients. Given this hypothesis, it is possible that in trauma systems with greater transportation resources or better developed transfer strategies, the mortality associated with undertriage and transfer might be significantly lower than that observed in the analyses in this dissertation.

7.3. Implications

The analyses presented in this dissertation have a number of methodological and policy implications. Firstly, we have demonstrated the significant impact of capturing emergency department deaths on analyses of injury-related mortality. While lack of data regarding these patients is commonly cited as a limitation in many analyses in the trauma literature, our findings convincingly demonstrate that this population is non-negligible. Our analyses of the impact of transfer on mortality demonstrated that the inclusion of emergency department deaths in analyses produced findings completely contradictory to previous studies on this subject. Non-population based analyses in the past led to a significant underestimation of the harmful impact of the transfer process. Future evaluations of trauma system performance (undertriage) and of injury-related mortality at the system level must capture emergency department patients.

Our analyses have also identified that undertriage is a significant problem in Ontario’s trauma system. Among severely injured motor vehicle occupants, only 45% were transported directly to a trauma center. Additionally, among patients that were initially undertriaged, only
half were successfully transferred to a trauma center. Among motor vehicle occupants, 5% of patients triaged to a non-trauma center died in the emergency department – 11% of all deaths at non-trauma centers. Initial undertriage from the scene of injury was associated with significantly increased mortality at 24 hours and 48 hours. Our data suggest that strategies are required to ensure that patients reach appropriate care directly from the scene. Precisely delineating these strategies will require further study; potential approaches to identifying these strategies are described in the next Chapter. More broadly, our data suggest that adopting the Ontario Trauma Expert Panel’s recommendation regarding trauma system organization could be beneficial. Ontario’s exclusive trauma system is not an appropriate trauma system configuration for a system that experiences the degree of undertriage we observed. An inclusive system, which ensures standardized, high quality trauma care at all hospitals, regardless of resources, might help mitigate the excess mortality cause by undertriage in the Ontario trauma system.
Chapter 8
Future directions for research

8.1. Ongoing evaluation of undertriage in Ontario

The findings of the studies described in this dissertation demonstrate that a significant proportion of severely injured patients in the province of Ontario have inadequate access to trauma center care. Although guidelines suggest that, in a well organized system of trauma care, 95% of severely injured patients should be transported directly to a trauma center, this dissertation demonstrates that, in Ontario, fewer than half of patients with severe injuries due to MVC have such access.

Although describing the existing gaps in access to trauma care is important, longitudinally monitoring access to trauma care in the province is essential. The cohorts described in this dissertation can be recreated with new data to monitor the state of trauma center access in the province across time. Indeed, ongoing monitoring and quality assurance are considered essential components of a well developed trauma system\(^{28}\). There has previously been no systematic review of the rates of undertriage in the province. The annual Ontario trauma registry reports produced by CIHI are based on data from the OTR CDS, and therefore do not capture undertriaged patients who are admitted to non-trauma centers for definitive management\(^{82}\). In contrast, the annual report of injury admissions produced by CIHI captures all acute care admissions for injury, regardless of injury severity\(^7\); this data therefore does not provide information regarding the trauma system performance. The methods and crosswalk algorithm described in this dissertation provide the opportunity for future surveillance of undertriage in Ontario, as well as other jurisdictions in Canada.
8.2. Evaluation of field trauma triage protocols in Ontario

Although, in some rural areas, direct transport to a trauma center is not possible due to prohibitive distances, the vast majority of Ontarians live within an hour of a trauma center. It is therefore likely that the high levels of undertriage observed in the analyses in Chapter 5 and 6 are, at least partly, attributable to inappropriate triage decisions in the prehospital setting. At the moment, however, it is unclear whether undertriage in areas in close proximity to a trauma center is attributable to inadequately sensitive prehospital triage protocols, non-adherence to such protocols by EMS personnel, or a combination of both. As described in Chapter 1, prehospital services in the province of Ontario are decentralized, and administered by higher level municipalities. As a result, there is no province-wide standard for prehospital triage of the severely injured. Given the high levels of undertriage described in the dissertation, it is imperative to evaluate the prehospital triage protocols employed by individual EMS agencies, and their implementation.

8.3. Evaluation of the transfer process in Ontario’s trauma system

As we have described in the previous Chapter, a significant proportion of patients who are undertriaged are never transferred to trauma center care; those patients that are transferred experience significant delays in definitive care. How patients are selected for transfer, or the processes involved in executing such a transfer, are poorly understood within Ontario’s trauma system. Expediting the transfer might lead to improved outcomes among patients who are initially undertriaged.
In Chapter 5, we demonstrated that specific patient characteristics differentiated those patients that were successfully transferred, and those patients that died in the emergency department awaiting transfer. Specifically, elderly patients, females and patients with multiple comorbidities were more likely to die in the emergency department of non-trauma centers. These findings imply that selection of patients for transfer may not be based on physiology and injury characteristics alone. Although quantitative analyses of transferred and non-transferred patients are valuable, such data provide little insight into the decision-making that occurs at the level of the providers who select patients for transfer. Given the complexity of such decisions, we feel that qualitative analyses of the transfer process might provide valuable insight into providers’ knowledge and beliefs regarding transfer, the factors that influence their selection of patients for transfer, as well as the barriers they face in executing a transfer.

The potential barriers faced by providers attempting to transfer a patient are multiple, and may explain the prolonged times to death in non-trauma center emergency departments, as well as the relatively low rate of transfer for patients undertriaged to non-trauma centers. Such barriers may include barriers to diagnosis (e.g. inadequate training in the recognition of severe injuries, inadequate access to diagnostic modalities), barriers to identifying a receiving center (e.g. CritiCall’s lack of mandate in directing a center to accept a transfer), barriers to effecting the transfer (e.g. insufficient transportation assets, insufficient personnel to transfer the patient) or other barriers (e.g. refusal of patients’ families to transfer the patient). The factors must be deconstructed in order to identify candidate interventions aimed at expediting the transfer process.
8.4. Evaluation of long term outcomes among severely injured patients in Ontario

Although this dissertation focused on short term outcomes, long term outcomes among severely injured patients who survive their initial hospitalization are of interest, both for prognostication and for system planning purposes.

Ontario’s administrative datasets could be analyzed to examine long-term health care utilization and health outcomes among survivors of severe injury. Of particular interest would be an analysis focusing on differences in these outcomes among patients treated at trauma centers, compared to those treated at non-trauma centers. In addition, these outcomes could be related to other patient-level factors, including socioeconomic status and access to primary healthcare. The identification of a relationship between patient characteristics and increased health care resource utilization or increased risk of adverse outcomes could lead to the development of targeted strategies aimed at these patient subgroups.

Finally, little is known about the psychosocial impact of severe injury in Ontario. Follow-up studies of patients that focus on patient-centered outcomes, such as quality of life, return to work and post-traumatic stress disorder could significantly decrease the impact of severe injury in the province.
References


19. Trauma Association of Canada. Trauma system accreditation guidelines.


## Appendix A

Translation of Abbreviated Injury Scale body regions into Injury Severity Score body regions

<table>
<thead>
<tr>
<th>Abbreviated Injury Scale body regions</th>
<th>Injury Severity Score body regions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Head</td>
<td>1. Head and neck</td>
</tr>
<tr>
<td>2. Neck</td>
<td>2. Face</td>
</tr>
<tr>
<td>3. Face</td>
<td>3. Chest</td>
</tr>
<tr>
<td>4. Thorax</td>
<td>4. Abdomen and pelvis</td>
</tr>
<tr>
<td>5. Abdomen and pelvis</td>
<td>5. Extremities</td>
</tr>
<tr>
<td>7. Lower extremity</td>
<td></td>
</tr>
<tr>
<td>8. External</td>
<td></td>
</tr>
<tr>
<td>9. Spine</td>
<td></td>
</tr>
<tr>
<td>Cervical</td>
<td></td>
</tr>
<tr>
<td>Thorax</td>
<td></td>
</tr>
<tr>
<td>Lumbar</td>
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</table>
# Appendix B

External Cause of Injury Mortality Matrix for ICD-10

<table>
<thead>
<tr>
<th>Mechanism</th>
<th>ICD-10 code</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cut/pierce</td>
<td>W25-W29, W45, X78, X99, Y28, Y35.4</td>
</tr>
<tr>
<td>Fall</td>
<td>W00-W19, X80, Y01, Y3</td>
</tr>
<tr>
<td>Firearm</td>
<td>W32-W34, X72-X74, X93-X95, Y22-Y24, Y35.0, *U01.4</td>
</tr>
<tr>
<td>Machinery</td>
<td>W24, W30-W3</td>
</tr>
<tr>
<td>All transport</td>
<td>V01-V99, X82, Y03, Y32, Y36.1, *U01.</td>
</tr>
</tbody>
</table>

## Motor Vehicle Traffic

<table>
<thead>
<tr>
<th></th>
<th>ICD-10 code</th>
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</thead>
<tbody>
<tr>
<td>Occupant</td>
<td>V30-V39 (.4-.9), V40-V49 (.4-.9), V50-V59 (.4-.9), V60-V69 (.4-.9), V70-V79 (.4-.9), V83-V86 (.0-.3)</td>
</tr>
<tr>
<td>Motorcyclist</td>
<td>V20-V28 (.3-.9), V29 (.4-.9)</td>
</tr>
<tr>
<td>Pedal cyclist</td>
<td>V12-V14 (.3-.9), V19 (.4-.6)</td>
</tr>
<tr>
<td>Pedestrian</td>
<td>V02-V04 (.1, .9), V09.</td>
</tr>
<tr>
<td>Other</td>
<td>V80 (.3-.5), V81.1, V82.1</td>
</tr>
<tr>
<td>Category</td>
<td>Codes</td>
</tr>
<tr>
<td>----------------------------------------------</td>
<td>--------------------------------------------</td>
</tr>
<tr>
<td>Unspecified</td>
<td>V87(.0-.8), V89</td>
</tr>
<tr>
<td>Pedal cyclist, other</td>
<td>V10-V11, V12-V14 (.0-.2), V15-V18, V19 (.0-.3, .8, .9)</td>
</tr>
<tr>
<td>Pedestrian, other</td>
<td>V01, V02-V04 (.0), V05, V06, V09 (.0,.1,.3,.9)</td>
</tr>
<tr>
<td>Other land transport</td>
<td>V20-V28 (.0-.2), V29 (.0-.3), V30-V39 (.0-.3), V40-V49 (.0-.3), V50-V59 (.0-.3), V60-V69 (.0-.3), V70-V79 (.0-.3), V80 (.0-.2,.6-.9), V81-V82 (.0-.2-.9), V83-V86 (.4-.9), V87.9, V88 (.0-.9), V89 (.0,.1,.3,.9), X82, Y03, Y3</td>
</tr>
<tr>
<td>Other transport</td>
<td>V90-V99, Y36.1,*U01.1</td>
</tr>
<tr>
<td>Struck by or against</td>
<td>W20-W22, W50-W52, X79, Y00, Y04, Y29, Y35.3</td>
</tr>
<tr>
<td>Other specified, classifiable</td>
<td>W23, W35-W41, W44, W49, W85-W91,Y85, X75, X81, X96, Y02, Y05-Y07, Y25, Y31, Y35(.1,.5), Y36(.0,2,4-.8), *U01.0, .2, .5, *U03.0</td>
</tr>
<tr>
<td>Other specified, NEC</td>
<td>X58, Y86, X83, Y87.0, Y08, Y87.1, Y33, Y87.2, Y35.6, Y89(.0,.1), *U01.8, *U02</td>
</tr>
<tr>
<td>Unspecified</td>
<td>X59, X84, Y09, Y34, Y89.9, Y35.7, Y36.9,</td>
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### Excluded mechanisms of injury

<table>
<thead>
<tr>
<th>Mechanism</th>
<th>Codes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drowning</td>
<td>W65-W74, X71, X92, Y2</td>
</tr>
<tr>
<td>Fire/hot object or substance</td>
<td>X00-X19, X76-77, X97-X98, Y26-Y27, Y36.3, *U01.3</td>
</tr>
<tr>
<td>Overexertion</td>
<td>X50</td>
</tr>
<tr>
<td>Poisoning</td>
<td>X40-X49, X60-X69, X85-X90, Y10-Y19, Y35.2,*U01(.6-.7)</td>
</tr>
<tr>
<td>Suffocation</td>
<td>W75-W84, X70, X91, Y2</td>
</tr>
<tr>
<td>Adverse effects of medical care</td>
<td>Y40-Y59, Y60-Y84, Y8</td>
</tr>
</tbody>
</table>

Adapted from:
