Geriatric Traumatic Brain Injury: Outcomes, Costs and Quality of Care

By

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Abstract

Observational data from an adult traumatic brain injury (TBI) cohort derived from a Level I Trauma Centre (TC) over an eight-year time horizon were analyzed using descriptive statistics and logistic regression in a series of four studies.

The first study aimed to assess differences between younger and older TBI patients in injury presentation, hospital resource utilization and short-term outcomes. Older adults were found to have reduced odds for TBI in the presence of multisystem injury (TBI+), direct hospital transport, and trauma team activation (TTA). Older age was also associated with increased odds for assisted living disposition and hospital readmission.

The second study sought to assess the impact of different factors related to older and younger patients and factors related to mortality after TBI. It was found that increasing age was associated with increased odds (OR: odds ratio) mortality, as was the presence of comorbidities, severity of injury and receiving surgery.

The third study aimed to assess determinants of hospital length of stay (LOS) and associated costs for acute care medical treatment. It was found that the mean LOS was 6.4 days, with

intensive care unit (ICU) admissions and alternate level of care (ALC) designated patients accounting for 23% and 13% of total hospital days. The six most influential determinants of acute care hospital LOS were discharge destination, hospital acquired complications, ICU management, Geriatric Trauma Consultation Service (GTCS) exposure, physician service, and TBI+ diagnosis. The mean acute care hospital cost for patients in the cohort was $20,148 CAN (SD: $32,800). TBI+ presentation accounted for 20% of all hospital bed-days and 23% of all hospital expenditures, despite its representation in only 10% of the entire cohort.

The fourth study was designed to measure associations between GTCS and hospitalization outcomes for geriatric TBI patients. GTCS patients were matched to those without GTCS (UC: usual care) using propensity scores. GTCS management was significantly associated with increased rate of in-hospital complications, ICU- and ALC-management and prolonged total LOS Among GTCS survivors, there was significant increased disposition to in-patient rehabilitation (IR) (OR 1.37 CI 1.00-1.88), compared to UC patients.

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List of Abbreviations

TBI	Traumatic Brain Injury
GTCS	Geriatric Trauma Consultation Service
TC	Trauma Centre
LOS	Length of Stay
UC	Usual Care
TBI+	Multisystem TBI/TBI with extracranial concomitant traumatic injury
iTBI	Isolated TBI
ISS	Injury Severity Score
WHO	World Health Organization
CT	Computed Tomographic imaging
MRI	Magnetic Resonance Imaging
GCS	Glasgow Coma Scale
HAIS	Head Abbreviated Injury Scale
ICP	Intracranial Pressure monitoring
AIS	Abbreviated Injury Scale
MVC	Motor Vehicle Collision
TTA	Trauma Team Activation
ALC	Alternate Level of Care
OR	Odds Ratio

ICU	Intensive Care Unit
BTF	Brain Trauma Foundation
ACS	American College of Surgeons
AAST	American Association for the Surgery of Trauma
GeriTraC	Geriatric Trauma Coalition
CGA	Comprehensive Geriatric Assessment
SMH	St. Michael’s Hospital
CI	Confidence Interval
CDC	Centers for Disease Control and Prevention
AIS-OBR	Abbreviated Injury Scale for Other Body Regions
SD	Standard Deviation
IR	In-patient Rehabilitation
IQR	Inter Quartile Range
ANOVA	Analysis of Variance
GM	Geometric Mean
GMR	Geometric Mean Ratio
PSM	Propensity Score Matching
d	Absolute Standardized Difference
IRR	Incident Rate Ratio

Chapter 1
General Introduction

1 General Introduction

1.1 Preamble

The proportion of the Canadian population comprised of individuals ≥ 65 years has been reported to be 17.5%. (Statistics Canada, September, 2019). According to demographic projections, this segment of the population is expected to increase rapidly over the coming decade with estimates suggesting a 25% representation within the general population (Statistics Canada, 2012). Although the majority of these individuals are healthy and leading active lifestyles, increased rates of health problems occur with advancing age. Consequently, geriatric-aged individuals are understood to be high users of Canada's health care system. In particular, compared with other age groups, those 65 years and older use a disproportionate amount of hospital services and also stay longer once admitted to hospital (Canadian Institute for Health Information, 2011). Recent estimates suggest approximately 40% of inpatient discharges and 60% of in-patient hospital days are among patients ≥ 65 years, and, on average, their overall acute care LOS is roughly 1.5 times that of younger adults (Canadian Institute for Health Information).

Of equal concern are TBIs, which are the leading cause of death and disability worldwide (Dewan et al., 2019; World Health Organization, 2006). The highest and fastest growing rates of TBI are among the geriatric population (Colantonio et al., 2010; M. Faul, Xu, Wald, Coronado, & Dellinger, 2010). The prevalence of head injury in older patients is alarming. In 2004 the geriatric population comprised 12% of the Canadian population. At the same time, statistics regarding TBI in Canada, collected by the Canadian Institute for Health Information (CIHI) for fiscal year 2003-2004, reported 29% of all head injury hospitalizations in Canada were among elderly individuals (Canadian Institute for Health Information, 2006). More contemporary reports, based on 2011 Canadian data, place geriatric TBI-associated hospitalizations at 38% (T.S Fu, Jing, McFaull, & Cusimano, 2015). Further, trauma-trend analyses support a two-fold increased risk for TBI-associated urgent clinical care resulting in hospital admission among geriatric patients relative to younger age groups (Terence S. Fu, Jing, Fu, & Cusimano, 2016).

Previous work has suggested that hospitalized geriatric-age patients are more likely than younger adults to require greater acute health care resources, have worse outcomes, and need more post-acute care following TBI (Dams-O'Connor et al., 2013; Stein et al., 2018). Based on Canadian data, older adults stayed, on average, 15 days in acute care in 2004. In comparison, those aged 20-39 years stayed for 11 days, and those aged 40-59 years stayed for 13 days (Canadian Institute for Health Information, 2006). Among hospitalized TBI-related fatalities, geriatric patient deaths, reported in the range of 30-50%, are overrepresented relative to younger patients (T.S Fu et al., 2015; R. Gardner, K. Dams-O'Connor, M. Morrissey, & G. Manley, 2018). Among survivors, those of advanced age are less likely to be discharged home following acute care for TBI (Zarshenas et al., 2019). Lifetime cost for treating a TBI among hospitalized geriatric patients in Canada is estimated at approximately CND$145 million per patient, with 52% (CND$49,419 million) attributed to direct medical care (Terence S. Fu, Jing, McFaull, & Cusimano, 2016).

Although risk of hospital admission, costs and poor outcomes with TBI are known to increase with age, the elderly are generally not the focus of specialized case management because resource intense care is understood to be the most appropriate care for this population (Ronksley, McKay, Kobewka, Mulpuru, & Forster, 2015). As a result, prevention efforts aimed at reducing risk of incurring injury in the first place and increasing post-acute care capacities have been at the forefront of health policy initiatives (Canadian Medical Association, September 2016). Despite those efforts, increasing rates of TBI among this vulnerable population continue to overwhelm trauma services (Canadian Institute for Health Information, 2019), and limited availability of appropriate discharge placements contribute to longer LOS which fuels the overall burden on acute care facilities (Canadian Institute for Health Information, 2011). Furthermore, geriatric trauma patients have complex health care needs that pose additional challenges to trauma management teams and which may require additional expertise (Calland et al., 2012; W. Fallon et al., 2006). As specialized care is understood to be the most appropriate care for geriatric patients, there is a need to systematically examine resource utilization in an effort to provide meaningful information in relation to the services provided for these patients, especially in the acute care setting (Ronksley et al., 2015). This necessity is further amplified given the particular vulnerability of the geriatric population to TBI.

1.2 Background

The following text will first discuss the aging population, then traumatic brain injury, and then traumatic brain injury in the aging population. Finally, guidelines for the care of traumatic TBI patients will be discussed.

1.2.1 The Aging Population/Implications for Health Care

1.2.1.1 The Elderly Population is Increasing

Those categorized as elderly (defined as aged ≥65 years) constitute the fastest-growing group in the developed world. Life expectancy among the elderly has increased by approximately 50% in the last century (Crimmins, 2015). Declining rates of mortality from cardiovascular disease, due in part to the introduction of both prevention and effective cardiac treatment programs, have been particularly impactful upon increased longevity among the elderly (Crimmins, 2015; Mensah et al., 2017).

This trend toward an increase in the aging population is expected to continue. The world geriatric population is expected to triple between 2015 and 2050 (World Health, 2019a). In North America, in particular, the elderly age group is expected to double over the next 25 years, growing to 20–25% of the projected population (L. Martel & F.-P. Menard, 2012; "Population Projections: Canada the provinces and territories, 2009-2036," 2010; *U.S. Population Projections, 2008 National Population Projections: Percent Distribution of the Projected Population by Selected Age Groups and Sex for the United States: 2010-2050*, 2009).

This trend is very clear in Canada. According to Statistics Canada, by 2024, Canadians aged 65 and older will constitute more than 20% of the total population. By 2036, they are expected to account for 25% of the population. The very elderly - those aged 85 and older - grew by 127%

between 1993 and 2013, making this group the fastest growing age group in Canada. In Canada, 2015 was the first year in which the proportion of the population over the age of 65 years exceeded the proportion of those younger than 15 (Muratov et al., 2017).

1.2.1.2 The Aging Population Experiences More Trauma

Due to the aging global population, geriatric trauma is an issue of increasing public health concern.

Worldwide, an increasing proportion of trauma patients belong to the elderly population (Adams & Holcomb, 2015). A study from the United Kingdom (UK) found that the average age of those attending emergency departments for trauma increased from 36.1 to 53.8 between 1990 and 2013 (Fisher, Bates, & Banerjee, 2017). A second study found that 26.9% of major trauma reported were seen in those aged >75 years (A. Kehoe, Smith, Edwards, Yates, & Lecky, 2015). In Canada, 29% of all head injury hospitalizations in 2003-2004 occurred in elderly individuals aged 60 years or more (Canadian Institute for Health Information [CIHI], 2006).

1.2.1.3 The Aging Population Has More Disabilities/Comorbidities

The elderly population has specific features that distinguish them from younger patients and that necessitate specialized care from healthcare systems. In particular, the healthcare needs of the elderly are often complicated by the presence of disabilities and pre-existing comorbidities (G. Eamer et al., 2017; Morrissey, 2019).

Approximately 25% of the elderly population in Canada are living with a disability, and this figure increases to 45% among those 75 years and older (Figueiredo, Rosenzveig, Morais, & Mayo, 2017). An exploration of the presence of multi-morbidity in Canada has found that those aged ≥ 85 years had a prevalence of multiple comorbidities of 66.3%, as compared with 7.8% among those aged 40-44 years (Feely, Lix, & Reimer, 2017).

Among the elderly, the presence of comorbidities is associated with poorer health outcomes after trauma (Kirshenbom, Ben-Zaken, Albilya, Niyibizi, & Bala, 2017b). It has also been demonstrated that the presence of six specific pre-existing medical conditions - peripheral arterial occlusive disease (stage IV), heart disease, hepatitis/liver cirrhosis, carcinoma/malignant disease, coagulation disorders, and obesity - are associated with increased post-traumatic mortality among the elderly, independent of injury severity (Wutzler et al., 2015).

Various studies have also observed an independent association between the elderly use of anticoagulation medication and traumatic intracranial hemorrhage, with a two to ten-fold increase in the risk of death among the geriatric patients. Metabolic complications of nutrition support (e.g., hyperglycemia) are also commonly noticed in elderly trauma patients (Hildebrand, Pape, Horst, Andruszkow, Kobbe, Simon, Marx, & Schürholz, 2016).

1.2.1.4 Mortality is Higher in the Aging Population After Trauma

A variety of studies have found evidence that age is significantly correlated with post-traumatic mortality rates (Hollis, Lecky, Yates, & Woodford, 2006; Kairinos, Hayes, Nicol, & Kahn, 2010; Lustenberger, Talving, Schnüriger, Eberle, & Keel, 2012). Partly due to their disabilities and comorbidities, trauma patients older than 55 years have an increased risk of dying after trauma (Pandya, Yelon, Sullivan, & Risucci, 2011). In particular, patients older than 70 years have a significantly higher mortality rate than younger patients (Caterino, Valasek, & Werman, 2010; Grossman, Miller, Scaff, & Arcona, 2002).

1.2.1.5 Elderly Trauma patients Have a Higher Incidence of In-hospital Complications

Elderly trauma patients also have a higher incidence of in-hospital complications, including infections (pneumonia, urinary tract infection), thromboembolic incidents and organ failure, leading to greater resource utilization and increased hospital length of stay (LOS) (Adams et al., 2012; Min et al., 2011; T. S. Richmond, Kauder, Strumpf, & Meredith, 2002).

1.2.1.6 Frailty is Common in the Elderly Population

Frailty plays an important role in the elderly population. Frailty is defined as the inability to withstand illness or injury. It leads to an increased vulnerability to adverse outcomes (Clegg, Young, Iliffe, Rikkert, & Rockwood, 2013; Theou et al., 2018). Frailty in the elderly is caused by impairments in several inter-related systems, resulting in an increased susceptibility to stressors and a decline in reserve and resiliency (Bergman et al., 2007). Frailty is associated with reduced mobility, incident falls, hospitalization (including increased LOS), confusion, and mortality - as well as the inability to carry out the normal activities of daily living (Boyd, Xue, Simpson, Guralnik, & Fried, 2005; Clegg et al., 2013).

In the setting of trauma, the evidence suggests that frailty significantly impacts the occurrence of adverse posttraumatic outcomes among elderly trauma patients (Zhao et al., 2020) . Thus, it is important to determine whether an elderly trauma patient is frail in the acute care setting.

Several tools for measuring frailty exist (Pugh et al., 2018). Generally, researchers have found that performance-based measures (Adamis, Morrison, Treloar, Macdonald, & Martin, 2005; Purser et al., 2006), as well as self-reported function (Alexander et al., 2000), are the most instructive in geriatric acute care patients.

While frailty scales and measures are potentially useful, actual evidence for their utility in determining health outcomes and responses to treatments in the face of acute illness remains limited (Hilmer et al., 2009). Moreover, frailty scales and self-reported data are not as accurate as, and cannot replace, comprehensive geriatric assessments by a multidisciplinary clinical team (Walston, Buta, & Xue, 2018).

1.2.1.7 The Elderly Require More Long-term Care after Trauma

The elderly are more likely to require long-term care following trauma. In terms of disposition, it has been reported that geriatric trauma patients are more likely to be discharged to nursing homes than younger adult patients (Bennett, Scarborough, & Vaslef, 2010).

Even when discharged to home, elderly patients frequently require on-going, home-based care and support to maintain independence. A 2017 study, for example, found high rates of impairment, physical limitation and factors that reduced participation in normal everyday activities among elderly patients (Figueiredo et al., 2017). In this study, 50% of participants reported limitations in their ability to undertake tasks such as climbing stairs and performing routine activities within the home.

1.2.1.8 Financial Implications of the Aging Population for Healthcare Systems

The accelerating growth of the elderly population has challenged and will continue to challenge national healthcare systems (World Health, 2019b). In addition to hospital care, the needs of the elderly for long-term post-hospital care has important resource implications.

In high-income countries, healthcare utilization is highest among those aged 75 years and above (World Health, 2019b). In Canada, for instance, healthcare spending per person has been shown to increase considerably with age (Information, 2011). Compared to younger patients, geriatric trauma patients in the U.S. remain in the hospital twice as long, are twice as likely to die, and have three times greater medical expenses (Zafar, Obirieze, et al., 2015). The financial burden of geriatric trauma is, therefore, quite significant, with continuing increases anticipated in the decades to come (DeLa'O, Kashuk, Rodriguez, Zipf, & Dumire, 2014).

1.2.1.9 Healthcare Planning is required for the Aging Population

In Canada, the Conference Board of Canada has estimated that 2.4 million elderly Canadians will need continuing care by 2026, which is a 71% increase from 2011 (Hermus, 2015). Currently in Ontario, seniors represent only 13% of the total population but they account for the greatest healthcare costs, including 57% of acute inpatient stays and 40% of hospital discharges (Wong, Ryan, & Liu, 2011).

Nonetheless, despite the money already being spent, at present most healthcare systems do not fully meet the needs to the aging population. The Canadian Medical Association, for instance, has estimated that there are only 276 geriatricians and only 166 geriatric psychiatrists nation-wide - far below the 500 geriatricians that experts estimate to be necessary to serve the needs of Canadian seniors ("Health care in Canada, 2011: A focus on seniors and aging," 2011). Also, while most provincial and territorial governments in Canada have strategies to empower seniors to live healthy lifestyles, the Canadian Medical Association has found that elderly-specific considerations for acute and specialty care and long-term care remain lacking ("Health care in Canada, 2011: A focus on seniors and aging," 2011).

1.2.1.10 Plans for Improved Elder Health Care

Several organizations have therefore proposed plans related to improved health care for the aging population. Among them, the World Health Organization (WHO) has developed a plan entitled "Multisectoral action for a life course approach to healthy ageing: global strategy and plan of action on ageing and health" which was agreed on in 2016 at the World Health Assembly (Organization, 2016). WHO's strategy has sought to address five key areas: 1) support for action on healthy aging from every country; 2) the development of environments which are friendly to all ages; 3) the development of health systems which met the needs of the elderly, 4) the development of long-term care for the elderly in diverse settings; and 5) the development of research which could measure and monitor health and aging.

In Canada, 90% of the population believe that it will be necessary to develop a national strategy in this area ("The state of seniors health care in Canada," 2016). The Canadian Medical Association reports that support for healthy aging enables the elderly to lead healthier lives which will, in turn, reduce health care expenditures. For example, in Ontario, five percent of elderly high-cost healthcare users consume 44% of the total elderly public health expenditure within the province (W. P. Wodchis, Austin, & Henry, 2016). Moreover, 60% of high-cost healthcare users in Canada are reported as elderly (Muratov et al., 2017).

A large part of these costs are related to acute hospital care. One study reported that those who use high levels of acute hospital care amounted to 0.5% of the population aged 50-74 and 2.6% of those aged >75. When it comes to days spent in hospital, these groups also accounted for 45.6% and 56.1%, respectively (Rotermann, 2017). As such, the Canadian Medical Association calls for a "focus on initiatives with respect to physical activity, nutrition, mental health and injury prevention, housing and social integration" ("The state of seniors health care in Canada," 2016).

1.2.2 Traumatic Brain Injury (TBI)

1.2.2.1 Definitions Related to TBI

Traumatic brain injury (TBI) is an issue of increasing public health concern. TBI is defined as "an alteration in brain function, or other evidence of brain pathology, caused by an external force" (Menon et al., 2009). Within this definition, an alteration in brain function is regarded as one of the following: a loss of consciousness, a loss of memory for a period of time either immediately before or after the injury, a neurologic deficit (e.g. visual changes, motor weakness, balance problems), or an altered mental state during the time of injury (e.g. confusion) (McKee & Daneshvar, 2015).

1.2.2.2 The Epidemiology of TBI

An estimated 69 million individuals around the world suffer a TBI each year (Dewan et al., 2018). Globally, TBI is the most significant cause of death and disability among all trauma-related injuries (Corrado Iaccarino, Alessandro Carretta, Federico Nicolosi, & Carlotta Morselli, 2018).

In the U.S., there are more than 2 million TBI-related visits to the emergency room annually (R. Gardner et al., 2018). In Canada, the data suggest that the incidence of TBI approaches 155,000 per year, with the year-on-year incidence increasing by ~9% per year (Ho & Hendi, 2018).

In Canada, TBIs result in approximately 25,000 hospitalizations and >10,000 deaths per year (L. Martel & F. P. Menard, 2012). In Europe, a meta-analysis of studies from 23 European countries has suggested that TBI injuries have a hospital admission incidence of 235 per 100,000 people per year (Roozenbeek, Maas, & Menon, 2013). In low- and middle-income countries, there are almost three times as many TBIs as those in high-income countries (Dewan et al., 2018).

These figures may actually underrepresent the occurrence of TBI, since many cases of head injury are either unrecognized by health professionals or unreported by patients - making it a "silent epidemic" with unreliable reporting around the world (Hyder, Wunderlich, Puvanachandra, Gururaj, & Kobusingye, 2007).

1.2.2.3 The Long-Term Consequences of TBI

TBI is associated with "pervasive disruption of behavioral, cognitive, and communicative functions" which result in significant ramifications for quality of life and societal participation (Hammond, Hart, Bushnik, Corrigan, & Sasser, 2004). Following a severe TBI, individuals face long-term neurobehavioral disturbances, such as mental fatigue and poor planning ability (Prins, Greco, Alexander, & Giza, 2013). They often become dependent upon their families for support in the activities of daily living (Hoofien, Gilboa, Vakil, & Donovick, 2001; Marquez de la Plata et al., 2008).

These challenges affect many facets of life and community participation, including, but not limited to, financial management, the use of public transportation, and continued employment (Hammond et al., 2004; Powell, Rich, & Wise, 2016). A 2015 study estimated that 60% of former rehabilitation inpatients face unemployment two years post-TBI, as compared with national averages below 10% in developed countries (J. P. Cuthbert et al., 2011).

1.2.2.4 The Financial Impact of TBI

TBIs have a significant financial impact upon individuals, healthcare systems and the wider economy. The Centers for Disease Control and Prevention estimates that $76.5 billion per year is spent in the U.S. as a consequence of TBIs. This figure includes $11.5 billion for direct medical costs, $64.8 billion in indirect costs, and $1.1 billion dollars related to reduced productivity (Bureau; Hauer, 2019).

1.2.3 Trauma Scoring Systems for the Classification of TBI

1.2.3.1 The Utility of Trauma Scoring Scales

Trauma scoring systems allow physicians to assess the severity of trauma in their TBI patients and to make decisions regarding trauma management with greater ease (Sternbach, 2000). The Marshall computed tomographic (CT) and/or magnetic resonance imaging (MRI) classification, the Glasgow Coma Scale (GCS), and the head abbreviated injury scale (HAIS) and injury severity scores (ISS) are the scales commonly used to classify TBIs.

1.2.3.2 Marshall – CT and MRI Classification

With the increasing use of early sedation, intubation, and ventilation among severe trauma patients, TBI can be classified using morphological criteria from CT and/or MRI evaluations (Zhu, Wang, & Liu, 2009). The Marshall CT classification identifies six TBI patient groups based on the presence or absence of mass lesions, intracranial abnormalities, raised intracranial pressure, and planned evacuation of mass lesions. The six levels are: 1) diffuse injury 1 (no visible intracranial pathology); 2) diffuse injury 2 (lesion densities and/or cisterns present with shift 0.5mm); 3) diffuse injury 3 (cisterns compressed or absent with shift 0-5mm); 4) diffuse injury 4 (shift >5mm); 5) surgically evacuated mass lesion; and 6) non-surgically evacuated mass lesion (high or mixed density lesion >25ml) (Mahadewa, Golden, Saputra, & Ryalino, 2018).

A newer classification, named the "Rotterdam grading system", builds upon the Marshall CT classification by incorporating "subarachnoid/intraventricular hemorrhage, extradural hematoma, and extent of basal cistern compression" as further indicators of TBI. This newer classification, however, has not yet been fully validated (Deepika, Prabhuraj, Saikia, & Shukla, 2015).

1.2.3.3 The Glasgow Coma Scale (GCS)

In the absence of CT and/or MRI scans, the Glasgow Coma Scale (GCS) and the (H)AIS/ISS are the most common scales used to classify TBI.

First published in 1974 at the University of Glasgow by Graham Teasdale and Bryan Jennet, the GCS is a 15-point clinical scale used to assess a patient's level of consciousness at bedside following an acute or traumatic event (Graham Teasdale & Jennett, 1974).

The three neurological components of the GCS relate to the areas of ocular, verbal, and motor responses produced by a patient when receiving standardized stimulation (Heim, Schoettker, & Spahn, 2004). Ocular responses are determined by presence of eye opening, spontaneously or in reaction to a pain stimulus or speech. Verbal responses are assessed based on comprehensibility and discourse level (e.g. moaning, swearing, or confusion versus coherent speech and understanding). Finally, motor responses are determined based on reactions to pain as observed in extensions (e.g. external rotation of shoulder), abnormal flexions (e.g. international rotation of shoulder), withdrawals (e.g. flexion of elbow), and localizations (e.g. “purposeful movements” to painful stimuli), in addition to compliance with physical directions (e.g. sticking out tongue on demand).

Once this assessment has been completed, patients are categorized into three groups based on the total of their best responses to the three components: 1) mild (13-15); 2) moderate (GCS: 9-12) and; 3) severe (3-8). In this calculation, an eye score of 4, a verbal score of 5, and a motor score of 6 would equal 15 (Caterino et al., 2016).

The GCS is recommended in the Brain Trauma Foundation guidelines as a basis for intracranial pressure (ICP) monitoring and in the Canadian CT Head Rule for determining the need for head computerized tomography following TBI. It is one of the most prevalent consciousness scoring systems in the world due to: 1) its ease and speed (thus often being adopted in field triages); 2) its useful distinctions between affected areas of brain function; and 3) its correlation with adverse neurological outcomes including brain injury (Chou et al., 2017). Its emphasis on motor scores is also a reliable measure for short-term prognoses in TBI (Chou et al., 2017; Graham Teasdale & Jennett, 1974).

Nonetheless, the GCS has been criticized for its lack of reliability in patients with moderate symptoms (e.g. moderate GCS of 9-12) and in elderly patients (>65 years) (Kristin Salottolo, Levy, Slone, Mains, & Bar-Or, 2014). One problem is that the same GCS score may actually relate to different mortality risks based on the distribution of the sub-scores within the three individual components of the GCS. Thus, the three individual components are actually more indicative of specific injury than the total GCS that is traditionally used. Moreover, the three categories it assesses fail to provide sufficient information on the “pathophysiological mechanisms and pathoanatomic changes that are at the origin of neurological deficits” (Schumacher, Walder, Delhumeau, & Müri, 2016).

Performing the GCS is also subject to errors when the staff are untrained or if there are language barriers. Also, factors influencing consciousness, such as drugs and sedatives, may misleadingly skew scores. One study, for instance, revealed that assessments calculated by undertrained paramedics on the scene had no prognostic value, as the initial “generalized depression of neurologic status did not necessarily correlate” with the severity of injury or long-term outcomes (Marion & Carlier, 1994).

In addition, there is no scholarly consensus concerning the best time to apply the GCS after TBI. It may be unreliable in the early stages following injury. This is particularly true in the elderly. The elderly often have delayed responses to trauma that lead to GCS scores in the mild range (13-15) despite injuries that later turn out to be serious (A. Kehoe, Rennie, & Smith, 2015). Thus, assigning a GCS score too soon after an injury in the elderly may lead to inaccuracies. Indeed, studies have shown that elderly TBI patients have better GCS scores than younger TBI patients despite similar TBI severities (Kristin Salottolo et al., 2014). As such, the GCS is useful as a measure of functional status in the elderly when recorded 24-72 hours after initial trauma.

Due to its limitations and lack of validation, the GCS should be applied cautiously and in conjunction with other clinical information to guide trauma monitoring and management. The developers of the GCS themselves have stated that they “never recommended using the GCS alone, either as a means of monitoring coma, or to assess the severity of brain damage or predict outcome” (G. Teasdale & Jennett, 1978).

Thus, though the GCS scale is important because so many researchers use it, it is unreliable as an initial measure when taken at the time of hospital admission or in field triage - and this is especially true among the elderly because of their delayed and/or blunted early response to head injury. In the present thesis, we have used the HAIS, in addition to the GCS, to classify TBI severity.

1.2.3.4 The AIS/ISS and HAIS

The Abbreviated Injury Scale (AIS) is an anatomic measure that can be used to score severity of traumatic injury (Chawda, Hildebrand, Pape, & Giannoudis, 2004). The AIS was first developed in 1971 and it undergoes regular revision. The AIS ranks and compares injury nature and severity according to neuroradiologic or operative observations on seven body regions – the “head, face, neck, thorax, abdomen, spine, upper extremities, and lower extremities” – on a 0 to 6 scale (normal to lethal) (Cryer, 2006; Foreman et al., 2007).

The Injury Severity Score (ISS) is a composite measure derived from the AIS, and is defined as the sum of squares of the highest AIS score in the three most severely injured body regions (Greenspan, McLELLAN, & Greig, 1985). It categorizes the body under six regions: thorax, abdomen and visceral pelvis, head and neck, face, bony pelvis and extremities, and external structures (Cryer, 2006). The ISS ranges from 1 to 75, and patients with an AIS score of 6 in any region are automatically given an ISS score of 75 (Baker, o'Neill, Haddon Jr, & Long, 1974; Foreman et al., 2007).

Both the AIS and the ISS are well correlated with morbidity and length of hospital stay, and are consistent risk predictors for post injury multiple-organ failure (Chawda et al., 2004). TBI in the presence of multisystem injuries (TBI+) and isolated TBI (iTBI) can be classified using the ISS (Mosenthal et al., 2002). This is particularly consequential, as the occurrence of multi-trauma versus monotrauma creates significant challenges due to the potential for combined and synergistic pathophysiology between different systems, putting TBI+ patients at greater risk of adverse outcomes (McDonald, Sun, Agoston, & Shultz, 2016).

Nonetheless, both scoring systems fail to account for multiple injuries in the same body region and also weigh injuries in each body region equally, thus neglecting the importance of head injuries in TBI in particular. The AIS also does not consider open or comminuted fractures. Similar to the GCS, the predictive ability of the ISS is impacted by the fact that the same score may be made up of multiple combinations of AIS scores. As such, injuries may be underestimated, particularly in penetrating trauma (Chawda et al., 2004).

Thus, the head AIS (HAIS) score is better used to classify TBI severity. The HAIS is a component of the AIS. A HAIS score of 3 indicates serious TBI, while a score of 4 is severe, 5 is critical, and 6 is fatal.

The HAIS is superior to the GCS for use in scoring TBI. One comparison of the GCS and the HAIS found that, among patients with severe TBIs, the HAIS/ISS predicted death risk at 14 days better than the GCS (Kesmarky, Delhumeau, Zenobi, & Walder, 2017). Ross et al. have also identified HAIS as the more useful classifier in evaluating therapeutic modalities as compared to the GCS (Ross, O'Malley, Stein, Spettell, & Young, 1992). The anatomic measures in the HAIS have actually been observed to outperform GCS in a number of different studies (Foreman et al., 2007).

1.2.4 TBI in the Elderly Population

1.2.4.1 TBI is More Common in the Elderly

TBI is a particular problem in the elderly population. While sport and military-related TBI have received significant attention over the years, the highest incidence of TBI actually occurs in older adults (R. Gardner et al., 2018).

TBI is a highly significant cause of injury-related mortality and morbidity in this population (Coronado et al., 2011; Labib et al., 2011).The significance of this is increased by the fact that the number of older adults is increasing.

The highest incidence of TBI occurs in the people over 65 (R. Gardner et al., 2018), with a lifetime prevalence of up to 40% among this population (Whiteneck, Cuthbert, Corrigan, & Bogner, 2016). Moreover, this problem is increasing. Recent studies show higher and faster-growing rates of TBI in the elderly, amplifying the risk for the older population as compared with younger adults (Colantonio et al., 2010; Coronado et al., 2011; T.S Fu et al., 2015; W. W. Fu, Fu, Jing, McFaull, & Cusimano, 2017; A. Kehoe, Smith, et al., 2015; McIntyre, Mehta, Aubut, Dijkers, & Teasell, 2013).

1.2.4.2 Gender and Racial Disparities in TBI Elderly

Among older adults, the male sex is associated with a higher incidence of TBI. Rates of hospitalization, however, skew more towards women in the elderly trauma population (Albrecht, McCunn, Stein, Simoni-Wastila, & Smith, 2016).

The tendency toward more female hospitalization also seems to be increasing. An analysis by Fu et al. (2015) in Canada has found that, between the years 2006 and 2011, the overall hospitalization rate for TBI remained stable among males, while the rate increased by 14%

among females (T.S Fu et al., 2015). They also found that rates increased by 6.6% and 8.0% each year for males and females, respectively, among elderly individuals.

1.2.4.3 Geographic and Socioeconomic Aspects of TBI in the Elderly

In the United States, more than 1 in 50 older adults aged ≥75 experienced a TBI-related emergency room visit, hospitalization, or death in 2013 (C. A. Taylor, Bell, Breiding, & Xu, 2017). This high incidence has been confirmed in multiple state- and nation-wide studies in the United States (Fletcher, Khalid, & Mallonee, 2007; R. S. Haring et al., 2015; Nwaiwu, Phillips, & Ohsfeldt, 2016).

Similar high instances have been found in other higher-income countries such as the United Kingdom (UK) (Hawley, Sakr, Scapinello, Salvo, & Wrenn, 2017), Scotland (Hamill, Barry, McConnachie, McMillan, & Teasdale, 2015), Spain (Pérez et al., 2012), the Netherlands (Scholten, Haagsma, Panneman, van Beeck, & Polinder, 2014), Austria (Brazinova et al., 2010), Finland (Raj et al., 2018), Australia (Harvey & Close, 2012), and Canada (de Guise et al., 2015).

The incidence of TBI is even higher in low- and middle income countries, but the pattern of injury varies (Maas, Hukkelhoven, Marshall, & Steyerberg, 2005). An analysis by the Medical Research Council CRASH trial found that TBI patients in low-income and middle-income countries were more often younger than their high-income country counterparts, and were usually vulnerable traffic users such as pedestrians and/or motorcyclists (Collaborators et al., 2008).

In high-income countries, improved traffic safety regulations and preventive measures - like the implementation of motorcycle helmet laws in Taiwan which lowered motor vehicle collision (MVC)-related TBIs by 33% - have led to declining rates in traffic-related TBIs (Chiu, Kuo, Hung, & Chen, 2000). Conversely, the increased life expectancy in higher-income countries has led to an increase in absolute TBI incidence among the elderly.

1.2.4.4 Major Causes of TBI in the Elderly

Age-specific mechanisms of TBI are important to consider, as fall-related TBIs result more often in mass lesions - including subdural hemorrhage - while motor vehicle accidents result more often in diffuse axonal injuries (Alberico, Ward, Choi, Marmarou, & Young, 1987).

1.2.4.4.1 Fall-Induced TBI

Falls increase with age and are the single leading cause of trauma among the geriatric population. Thus, this mechanism of injury (MOI) is associated with increased mortality among the elderly as compared to the younger population (El-Menyar, Tilley, Al-Thani, & Latifi, 2019; Spaniolas et al., 2010).

Annually, 8% of geriatric individuals visit the emergency room due to fall-related injuries, with approximately a quarter of these resulting in inpatient admission (H. J. Thompson, McCormick, & Kagan, 2006). The majority of TBIs experienced by older adults are associated with low- or same-level falls from standing height or below, including those necessitating surgical treatment for traumatic intracranial hemorrhage (Harvey & Close, 2012; Herou, Romner, & Tomasevic, 2015).

The rate of fall-related TBI seems to be increasing. Between 2005 and 2013 in Canada, the rate of injuries caused by falls among the elderly increased from 49.4 to 58.8 per 1,000 people (Do, Chang, Kuran, & Thompson, 2015). In 2002, the overall U.S. incidence rate of hospitalization from fall-related TBIs was 29.6 per 100,000 people, a rate that had nearly doubled when considering the geriatric population alone and was more than three times as high among adults 75 years and older (H. J. Thompson et al., 2006). A history of fall-related injuries is a major risk factor for future falls, thus exacerbating the risk of repetitive TBI (Tinetti, 2003).

Disabilities that impede memory, hearing, and vision are key contributors to falls in the elderly, in addition to age-related changes in the musculoskeletal and central nervous systems (H. J. Thompson et al., 2006).

1.2.4.4.2 TBI Due to Motor Vehicle Collisions

Secondary to falls, motor vehicle collisions are the most common cause of geriatric trauma and are associated with a five times greater mortality in the elderly as compared to younger cohorts (R. Gardner et al., 2018). Such accidents among the elderly mostly occur in daylight and close to home. This is opposed to findings in younger adults where causes such as speeding and alcohol are more important (Roozenbeek et al., 2013).

1.2.4.5 Triage is Poor Following TBI in the Elderly

Compared to those who are younger, elderly patients are: 1) more likely to be under-triaged; 2) less likely to be assigned an emergency triage category, and 3) have lower trauma center utilization (El-Menyar et al., 2019; Kirshenbom, Ben-Zaken, Albilya, Niyibizi, & Bala, 2017a).

Under-triage is a particular problem. In elderly victims of trauma, the physiologic response to the traumatic insult is often diminished and altered due to declining physiologic reserve, and to comorbidity and polypharmacy issues. This results in TBI injuries which are seemingly minor, and leads healthcare providers to under-triage the geriatric victims of trauma (Caterino, Raubenolt, & Cudnik, 2011; Sasser et al., 2012). The poor performance of triage protocols for the identification of significant TBI in elderly patients is well known (A. Kehoe, Rennie, et al., 2015; L. J. Scheetz, Horst, & Arbour, 2016).

In particular, the research of Kehoe and colleagues has established that anatomic and physiologic injury scales are unreliable among elderly TBI patients, lending to an underestimation of brain injury severity (A. Kehoe et al., 2016; A. D. Kehoe, Smith, Lecky, & Yates, 2014).

Even when correctly triaged in trauma bay, clinical assessment of a patient's risk profile in determining transfer to other medical units for treatment may be clouded by age-associated physiologic, immunologic and metabolic changes (Hildebrand, Pape, Horst, Andruszkow, Kobbe, Simon, Marx, & Schürholz, 2016; Lukin, Greenslade, Chu, Lang, & Brown, 2015).

Moreover, clinical course decisions for geriatric TBI patients may be influenced by the assumption of futility surrounding their acute management due to perceived poor outcomes including high mortality, morbidity and impaired functional outcomes (Hildebrand, Pape, Horst, Andruszkow, Kobbe, Simon, Marx, & Schürholz, 2016; McIntyre et al., 2013). Based upon all of these factors, multiple studies have demonstrated that elderly victims of TBI are routinely under-triaged, only to be transferred to a higher level of care by their original lower level destination. This high rate of secondary referral may lead to delays in definitive care of already highly time-sensitive neurologic injuries, resulting in poor outcomes for the elderly victims of TBI.

1.2.4.6 Acute Care is Less Aggressive Following TBI in the Elderly

Several studies have reported that older adults undergo less aggressive acute care after traumatic injuries, as compared to their younger counterparts. There is clear evidence of reduced surgery rates and trauma team activation (TTA) in the elderly (Benjamin et al., 2018; Connolly, Woo, Lampron, & Perry, 2018), and of differences in rates of withdrawal of medical support – all factors that are considered influential in TBI-related mortality (R. S. Haring et al., 2015).

Some physicians argue that aggressive care may not be appropriate for the elderly. One therapeutic plan, devised by Joseph and colleagues (BIG project), promotes the concept of managing TBI without specialized neuro-intensive monitoring or neurosurgical intervention (Joseph et al., 2014). They found non-surgical management of moderately severe TBI, in the absence of clear signs of neurological deterioration, posed no undue risk to patients and freed their institution from unnecessary resource diversions. Other studies have questioned the value of aggressive resuscitation and invasive monitoring modalities in improving outcomes for older TBI adults (Callaway & Wolfe, 2007).

Also, the potential benefit of routine ICP monitor placement has been the subject of conflicting reports (Dang et al., 2015; W. You et al., 2016). There have been discussions of the increased risk for the development of potentially life-threatening complications associated with prolonged ICU stays or mechanical ventilation (K. M. Busl, B. Ouyang, T. A. Boland, S. Pollandt, & R. E. Temes, 2015). These considerations suggest the moderate use of these interventions in the elderly. Furthermore, frailty and impaired physiological reserve may render craniotomy or craniectomy intolerable for an elderly TBI patient (Stocchetti, Paternò, Citerio, Beretta, & Colombo, 2012).

1.2.4.7 Hospitalization and Length of Stay Following TBI in the Elderly

Compared to younger age groups, the elderly have the highest and fastest growing rates of TBI-related hospitalizations (Colantonio et al., 2010; M. Faul et al., 2010). In North America, for instance, hospitalizations following TBI in the elderly are much higher than in younger adults (T.S Fu et al., 2015) (Terence S. Fu, Jing, McFaull, et al., 2016) (R. Gardner et al., 2018), and TBI-related hospitalizations among the elderly are increasing at a rate that exceeds population projections (C. A. Taylor et al., 2017)

Hospital length of stay (LOS) has also been reported to be longer in the elderly. LOS is a primary determinant of acute care resource utilization and the costs associated with TBI (Albrecht, Slejko, Stein, & Smith, 2017; Tardif et al., 2016; van Dijck et al., 2019). When those within the geriatric population experience a TBI, it has been reported that they have longer LOSs (Cameron, Purdie, Kliewer, & McClure, 2008; Moore et al., 2018; Tardif et al., 2016), and also that they are more likely to be discharged to lower level of care facilities if they survive (J. Cuthbert et al., 2011; Dams-O'Connor et al., 2013).

It has also been suggested that the protracted hospital LOSs among elderly trauma patients is due to their greater requirements for continuing care and accommodation along the assisted living continuum, and the need for alternate level of care (ALC) involving additional acute care bed days in order to facilitate those placements (E. C. McKevitt et al., 2003; K Salottolo et al., 2009).

1.2.4.8 Elderly TBI Patients Have Slower Recovery Rates

Older TBI patients have slower recovery rates and worse functional outcomes compared to younger adults (Cuthbert et al., 2014; Mosenthal et al., 2004; Stocchetti et al., 2012; H. Thompson et al., 2012; H. J. Thompson et al., 2006). These defining characteristics lead to this age group's increased need for rehabilitation (Cuthbert et al., 2014), extended sub-acute care, and greater requirements along the assisted living continuum (J. Cuthbert et al., 2011; H. Thompson et al., 2012).

1.2.4.9 Elderly TBI Patients Benefit from In-patient Rehabilitation

Among the TBI population, slower recovery trajectories and worse functional outcomes in elderly patients underscore this age groups' need for rehabilitation (Cuthbert et al., 2014). However, reports suggest that elderly TBI patients receive less intensive rehabilitation services as compared to younger individuals (Dijkers, Brandstater, Horn, Ryser, & Barrett, 2013). This is true despite evidence that inpatient rehabilitation (IR) greatly benefits these patients (Uomoto, 2008), and that they show ultimate, functional gains similar (though slower) to younger groups. Frankel et al., for instance, have observed significantly improved scores for cognitive disability, level of independence in performing activities of daily living, and mobility in the elderly group after IR (Frankel et al., 2006). Similarly, measures of physical disability have been observed to be significantly lower after rehabilitation in the elderly (Yap & Chua, 2008).

1.2.4.10 Discharge Placement in Elderly TBI Patients

Not only do elderly victims receive less intensive rehabilitation services in hospital, they are also more likely to be discharged to lower level care facilities - rather than specialized rehabilitation facilities (Zarshenas et al., 2019).

They are not generally discharged to home. The TBI literature demonstrates a lower frequency of home discharge for the elderly and higher rates of discharge to continuing care (Reske-Nielsen & Medzon, 2016).

This is true of elderly trauma patients in general. While ultimately up to 90% of elderly patients will eventually be discharged to home (Gowing & Jain, 2007), initially they are more likely to be discharged to special care settings. One large, retrospective study of over 250,000 elderly individuals found that over 60% of geriatric trauma patients (in general) were discharged to assisted living, long-term acute care, or skilled nursing facilities (Maxwell, Miller, Dietrich, Mion, & Minnick, 2015).

1.2.4.11 TBI is More Frequently Associated with Mortality in the Elderly

TBI is the most frequent cause of death in the geriatric trauma population, with a significant peak in patients older than 75 years (Hildebrand, Pape, Horst, Andruszkow, Kobbe, Simon, Marx, & Schürholz, 2016). Previous research has consistently found increased rates of mortality among elderly TBI patients as compared with the young (Goodmanson et al., 2012), with a year-on-year trend analysis demonstrating that this disparity is continuing to increase (Hashmi et al., 2014). A meta-analysis found that adults ≥75 had an increased odds of TBI-related mortality that was 1.7 times that of those aged 65–74 (Battle, Hutchings, & Evans, 2012). Others reported that the 75+ age group had an increased risk of dying that was nearly three times that of the 65–74 year age group (M. Taylor, Tracy, Meyer, Pasquale, & Napolitano, 2002).

1.2.4.12 Comorbidities Contribute to Increased Mortality after TBI in the Elderly

The causes of this increased mortality in the elderly are complex, and relate to the aforementioned factors such as the increased presence of comorbidities, reduced physical functioning, limited physiologic reserves, increasing injury severity and rates of in-hospital complications among the elderly (Bailey, Davis, Levy, Molinari, & Johnson, 2016).

In particular, pre-existing comorbidities put the elderly TBI patient at greater risk for additional in-hospital complications, which increase hospital LOS and mortality risk (H. J. Thompson et al., 2006). One study found that three prognostic factors - cancer, dementia and a history of antithrombotic therapy - all had a significant impact on mortality risk amongst patients aged 75 years or older with mild TBI (Susman et al., 2002).

Further, pre-existing cognitive impairments may confound the diagnosis of TBI due to challenges in separating impairments associated with pre-existing conditions and those associated with TBI (H. J. Thompson et al., 2006). There is also some evidence that as the brain ages, it has reduced capacity to recover from trauma due to progressive cerebral atrophy (Kojima, Endo, Shiraishi, & Otomo, 2019).

Finally, routine management of chronic conditions common among the elderly often involves aspirin and anticoagulant therapies, which some suggest increases risk of chronic subdural haemorrhage and posttraumatic intracranial lesions after a TBI (Sakr, 2005).

1.2.4.13 Costs of TBI in the Elderly

The costs of treating TBI in the elderly are very high. Results from a large, national sample of older adults with TBI in the United States found that hospital treatment cost averaged USD$73-78,000 per person annually (Mackenzie et al., 2007). An additional study observed that, in the inpatient rehabilitation setting, healthcare expenditures were nearly double among older cohorts when compared to younger groups (Cifu et al., 1996).

These high costs relate to several different factors. In part, they are thought to reflect a high resource use of the elderly in acute care. One study compared older to younger patients, and reported that the elderly TBI patients were three times more likely to receive CT or MRI scans and four times more likely to be admitted to an intensive care unit (ICU) or surgical unit (Pearson, Sugerman, McGuire, & Coronado, 2012). Increased service utilization among the elderly is thus thought to be linked to higher financial costs.

In part the high cost of elder TBI care is also thought to reflect longer hospital stays. The slow rate of recovery and the presence of comorbidities – common in the elderly - are associated with longer hospital stays which are more expensive. These factors also contribute to the requirements of elderly patients for expensive continuing long-term care and assisted living (Adams & Holcomb, 2015).

1.3 Present Guidelines for Geriatric TBI

1.3.1 Health Care Providers Must Address the Needs of Elderly and Elderly TBI Patients

Taken in conjunction, the points discussed above suggest that health care providers need to address the special needs of their elderly populations – and especially their older TBI populations. They must develop plans for elder TBI care that integrate prevention, primary care, specific specialties, chronic disease management, home care, long-term care and end-of-life care.

These plans for future health care will be based on – and evolve from – the current guidelines for healthcare in the elderly.

1.3.2 Guidelines for Elder Care and Elder TBI Care

The importance of specialized care for TBI and elderly TBI patients has been recognized by several institutions, and health care guidelines have been evolved. The Brain Trauma Foundation (BTF) guidelines are protocol-based management strategies focused on intensive care treatment of TBI patients, with particular attention to early identification and airway, oxygenation and hemodynamic support to prevent secondary injuries (Mark Faul, Wald, Rutland-Brown, Sullivent, & Sattin, 2007).

The American College of Surgeons (ACS) also has produced the *ACS TQIP Best Practice Guidelines.* The trauma section of this document outline guidelines for the management of elderly individuals presenting with TBI. Within the guidelines, the ACS calls for the development of geriatric-specific treatment protocols given the overall decreased physiologic reserve, increased presence of medical co-morbidities, and increased likelihood of complications associated with geriatric trauma patients (Surgeons, 2013).

Similarly, the American Association for the Surgery of Trauma (AAST) has funded and facilitated the Geriatric Trauma Coalition (GeriTraC), with a mission to “improve geriatric trauma care through an interdisciplinary approach to injury prevention, transport and triage, initial assessment and hospital management, and transitions of care” (Cooper et al., 2017). The GeriTraC guidelines emphasize attention to geriatric-specific considerations in addition to TBI-specific interventions, with the special needs of the elderly considered early on in transport and triage of patients. Non-trauma-related issues that will influence recovery must be evaluated in initial assessments, including, but not limited to, cognitive decline, frailty, vision problems, osteoporosis, and delirium, in addition to evaluation of current medications. GeriTraC also recommends the establishment of systematic care pathways that incorporative comprehensive geriatric assessment (CGA) and palliative care services (Cooper et al., 2017). Management of post-acute care transitions is also critical in the prevention of TBI readmissions in the elderly. Over 60% of geriatric trauma patients are discharged to assisted living, long-term acute care, and skilled nursing facilities (Maxwell et al., 2015). As such, GeriTraC also recommends the establishment of advanced care planning, discharge medication reconciliation, and access to support networks for trauma centers with large proportions of geriatric patients.

The implementation of these guidelines has already led to improvements in outcomes for several groups. In particular, the institution of a comprehensive geriatric assessment (CGA) - as compared with usual care (US) - has been reported to decrease the odds of mortality and increase discharge to independent living (Ellis, Whitehead, Robinson, O’Neill, & Langhorne, 2011).

One systematic review and meta-analysis found acute geriatric unit care to be associated with reduced rates of falls, delirium, functional decline at discharge, shorter length of stays, discharge to a nursing home and increased discharge to home (Fox et al., 2012). They also found lower costs within program compared with usual care. Despite noting multiple improvements, however, the authors did not find significant differences in overall mortality or hospital re-admission rates associated with the implementation of CGAs (Fox et al., 2012).

1.3.3 The Geriatric Trauma Consultation Service (GTCS)

One version of comprehensive geriatric assessment and care has evolved as the “Geriatric Trauma Consultation Service” (GTCS). The GTCS involves the integration of primary and allied health-care disciplines into a single consultation for the delivery of treatment to meet specialized needs of elderly trauma patients (J. W. F. Fallon et al., 2006).

In the acute care setting, GTCS appears to be an effective implementation of WHO and ACS guidelines to coordinate acute care services around the needs of geriatric trauma patients. It has been suggested that GTCS offers an integrated solution to the care of elderly victims of trauma, potentially not only improving outcomes but reducing overall resource utilization and cost associated with caring for these patients (M. Lenartowicz et al., 2012).

The organization of case-management through geriatricians has, in fact, been reported to enhance compliance with diagnostic and therapeutic recommendations and the implementation of a care plan with demonstrable benefits in terms of patient outcomes (C. L. Wong et al., 2017).

To our knowledge, however, no specific studies have examined the effectiveness of GTCS among TBI patients or whether this therapeutic intervention could improve short-term outcomes within the TBI population.

Nevertheless, studies evaluating GTCS in the general geriatric population have been done. Two studies have reported on the effects of GTCS versus usual care-management (UC) at level I trauma centers. A 2006 study by Fallon, for example, examined the interaction of age, injury severity, and comorbid disease among geriatric trauma patients and reported higher mortality among UC patients, with data specifically suggesting a higher incidence of mortality in UC patients with TBI (W. F. Fallon, Jr. et al., 2006). Among their GTCS patients, increased sub-specialty consults, special care unit management, and attention to in-hospital complications, pain management and polypharmacy complexities occurred. Among survivors, however, those under GTCS management demonstrated significantly longer ICU and overall hospitalization stays and were more likely, albeit non-significantly, to be discharged to in-patient rehabilitation facilities (IRs).

Lenartowicz et al. also evaluated the effects of GTCS in the general elderly population. They reported a trend toward decreased LOS among their GTCS-managed patients (M. Lenartowicz et al., 2012). Compared with UC patients, geriatric-specific complications decreased with GTCS, particularly in the manifestation of delirium. Identification of hospital-acquired complications and sub-specialty consults increased and discharge to long-term care facilities was reduced. Their findings suggested that improved outcomes in elderly trauma patients manifested as a result of specialized care focused on improving the identification and treatment of trauma quality indicators – indicators routinely captured in the general adult-trauma population were identified in the elderly under GTCS management.

1.4 The Need for Further Research

The limited resources available within government health care programs and the increasing expenditures related to the geriatric TBI population suggest that this area should be a key focus of research, evidence-based policy development and health care provision. The latter requires the integration and combination of services from triage through to tertiary care and after-care, as well as services which are able to treat chronic conditions and manage comorbidities when they are present (Gaastra et al., 2016).

As indicated above, there is a need for better plans and guidelines for the care of elderly and elderly TBI patients. The plans and guidelines will need to be evidence based. While a number of relevant studies already exist – as reviewed above – a number of contradictions and gaps still exist in the data. There have been as yet no studies, for example, on the effects of GTSC in the TBI population. There remains a great need for studies to consider the effects of GTCS on resource utilization and acute care management in the geriatric TBI population in particular. Studies focused on this specific subpopulation thus far have primarily evaluated only triage considerations, acute care management, in-patient rehabilitation, and resource utilization.

1.5 Thesis Organization

The international literature discussed above provides a number of general findings about health care in the elderly TBI population. The presence in Toronto of a large, Level I Trauma Centre (TC), with retrospective records on a large population of geriatric and younger adult TBI patients, offers a chance to analyze how these generalizations apply to our local TBI care in Toronto.

Four different studies were done, each designed to explore components of health care utilization and outcomes in the hospitalized geriatric TBI population. In the first two studies, geriatric patients were compared to a younger adult TBI population.

In the course of analyzing these data it became clear that the TBI+ and iTBI cohorts differed in a number of ways. In each study, therefore, data related to these two subtypes of TBI were analyzed separately as well as in combination.

1.5.1 Patient and Cost Data Used in the Present Studies

The current project employed a retrospective cohort study design based on patient data collected from St. Michael's Hospital (SMH) in Toronto, Canada. SMH is a designated Level 1 adult TC for the greater Toronto region. It services over 77,000 emergency room visits and 25,000 inpatient stays annually. Patient data were collected between April 1st, 2008 and March 31st, 2016.

Patient data were drawn from the St. Michael's Hospital Trauma Registry. This registry systematically collects and tracks demographic, injury, and clinical outcomes data of all patients presenting with an ISS of ≥12 in accordance with Ontario Ministry of Health and Long Term Care mandated set of inclusion criteria (Canadian Institutes of Health Information, 2014). Data are coded according to the American College of Surgeons National Trauma Data Bank's National Trauma Data Standard dictionary (American College of Surgeons: Committee on Trauma, 2016) and the Ontario Trauma Registry Comprehensive Data Set (Canadian Institutes of Health Information, 2014). The accuracy and reliability of the hospital's registry data collection are ensured by frequent internal and routine external quality control standards.

Cost data were collected from the St. Michael's Hospital Decision Support department's activity-based costing system for fiscal years 2012 through March 2016. The hospital uses standardized case-costing methodology developed by the Ontario Case Costing Initiative which is based on the Canadian Institute of Health Information's Management Information Systems guidelines (Canadian Institute for Health Information). This method accounts for an individual patient's resource intensity weight and case-mix group, as well as fixed and indirect costs to the hospital based on the patient's location of care and length of stay. It does not include fee-for-service physician billing costs (W. Wodchis, Bushmeneva, Nikitovis, & McKillop, 2013). Total hospital costs included: 1) direct costs associated with staffing (nursing, pharmacy, allied health), ward designation (general, ICU, ALC), imaging, labs, drugs, and other consumable goods (including food); and 2) indirect costs associated with food services, housekeeping, materials management, administration, and patient transport.

The use of these data for the present study was approved by the Research Ethics Board of SMH.

1.5.2 Goal of the Present Project

As stated above, the international literature provides a number of general findings about health care in the elderly TBI population. The present study was designed to analyze how these generalizations apply to our local TBI care in Toronto.

1.5.3 Specific Objectives and Hypotheses

Based on the literature, it is hypothesized: 1) that age-associated characteristics will increase geriatric patients’ vulnerability to TBI; and 2) that TBI+ patients will have worse short-term outcomes than iTBI patients. It is further hypothesized that geriatric patients will receive less aggressive acute care management and show poor short-term outcomes relative to younger adult TBI patients, and also that the TBI+ presentation may lead to a different course of care than the iTBI presentation.

The overall goal of the present project was to advance understanding of geriatric-TBI acute care management at a Canadian Level I TC. Better understanding of factors contributing to and influencing TC care of geriatric TBI patients could improve the process of care and risk stratification in these patients.

The present work was carried out in four separate studies. These constitute Chapters 2, 3, 4, and 5 of the present thesis. Those studies were designed to evaluate different aspects of care and clinical outcomes of geriatric TBI patients admitted to a Level I TC. In studies 1 and 2, geriatric patients were compared to a younger adult population.

The objective and hypothesis of each study is described below.

1.5.3.1 Study 1 – Comparing Younger and Older Adult Traumatic Brain Injury Cohorts: Demographics, Severity, Outcomes and Hospital Resource Utilization

The objective of Study 1 was to describe demographic and hospital course characteristics, processes of acute care, and discharge dispositions of adult TBI patients stratified on the basis of age (adult versus geriatric status) and also TBI sub-type (iTBI and TBI+).

Based on the literature, it was hypothesized that the elderly would have: 1) more fall-induced TBIs; 2) more referral from lower level centres, possibly due to under-triage; 3) more comorbidities; 4) more complications in hospital; 5) less aggressive care; 6) longer lengths of stay; and 6) more disposition along the assisted living continuum.

1.5.3.2 Study 2 – Factors Impacting Mortality Among a Traumatic Brain Injured Cohort: Retrospective Analysis of Data from a Level I Trauma Centre

The objective of Study 2 was to examine the factors associated with in-hospital mortality in our cohort. Younger and older patients were compared, as well as the different TBI sub-type presentations (iTBI and TBI+).

Based on the literature, it was hypothesized that the elderly TBI patients would have increased in-hospital mortality. Other factors expected to increase mortality were severity of injury and the TBI+ sub-type presentation.

1.5.3.3 Study 3 – Determinants of Hospital Length of Stay and Associated Costs in Geriatric Traumatic Brain Injury Patients

In study 1, it had been found that, at St. Michael's Hospital, increased age was not associated with longer lengths of stay (LOS). The objective of Study 3 was to examine the factors that did increase hospital LOS - and also to study the associated acute care costs. The study was done in a smaller cohort of geriatric TBI patients surviving to discharge.

Based on our earlier studies, it was hypothesized that the TBI+ subtype would be associated with increased LOS and increased inpatient costs.

1.5.3.4 Study 4 – Association of Geriatric Trauma Consultation Service with acute Care Outcomes and Resource Use in Traumatic Brain Injured Patients: A Propensity Score Matched Observational Cohort Study

The objective of Study 4 was to evaluate the association of specialized GTCS, relative to Usual Care (UC), on in-hospital resource intensity and short-term outcomes in a matched sample of geriatric TBI patients. The hypothesis was that focused geriatric management by way of GTCS would improve acute outcomes in older TBI patients by enhancing the quality of care those patients received.

Chapter 2
Comparing Younger and Older Adult Traumatic Brain Injury Cohorts: Demographics, Severity, Outcomes and Hospital Resource Utilization

2 Comparing Younger and Older Adult Traumatic Brain Injury Cohorts: Demographics, Severity, Outcomes and Hospital Resource Utilization

2.1 Abstract

TBI occurs with increasing frequency - and presents special challenges - in the elderly population. The current study is a retrospective analysis of data from older (≥ 65 years) and younger (< 65 years) adult TBI patients, collected from a Level I Trauma Centre (TC) in Toronto between 2008 and 2016. Initial analyses indicated that there were important differences between TBI+ and iTBI patients, as well as between older and younger patients. Patients were therefore analyzed both by age (18-64 years versus ≥ 65 years) and by injury pattern (iTBI versus TBI+).

There were 2,883 patients in the whole cohort: 1,618 patients 18-64 years (TBI+: n=551; iTBI: n=1067) and 1,265 patients ≥65 years (TBI+: n=163; iTBI: n=1,102). As compared to younger adult patients, older adult patients had 1) reduced odds for TBI+ (OR: 0.28, CI: 0.23-0.34); 2) less direct hospital transport (OR: 0.45, CI: 0.38-0.52); 3) less severe GCS scores, but also had higher ISS scores; 4) less Trauma Team Activation (OR: 0.21, CI: 0.17-0.25) 5) less ICU management (OR: 0.55, CI: 0.47-0.65); 6) increased odds for assisted living disposition (OR: 1.54, CI: 1.16-2.03); 7) increased odds for hospital readmission (OR: 1.63, CI: 1.07-2.48); and 7) suffered more in-hospital mortality (OR: 1.85, CI: 1.49-2.30).

As compared to the iTBI patients, TBI+ patients: 1) were younger and had less comorbidities, 2) had more TBIs from motor vehicle collisions, 3) had worse GCS and ISS scores, and 4) had more poor outcomes and mortality. At least in the iTBI groups, LOS was not significantly different between older and younger patients despite the older patients’ greater critical head trauma severity (61% versus 27%, $p<0.05$).

In summary, older adults suffered more severe TBIs and had worse clinical outcomes, but less commonly received the clinical care and services that may help improve outcomes.

2.2 Introduction

TBI is a major health concern. It is the leading cause of death and disability due to trauma. Worldwide, 69 million individuals experience a TBI each year (Dewan et al., 2018; James et al., 2019). In the USA alone, 275,000 hospitalizations and more than 52,000 deaths occur annually due to head injury (Kisser, Waldstein, Evans, & Zonderman, 2017). In Canada, 23,000 hospitalizations occur per year due to TBI, with a mortality rate of 8% (T.S Fu et al., 2015), and rates are increasing (Rao, McFaull, Thompson, & Jayaraman, 2017).

TBI is a particularly important in the elderly. Patients aged ≥75 years show a higher incidence of TBI as compared to all other age groups (Canadian Institutes of Health Information, 2014). The elderly population also shows faster-growing rates of TBI (C. A. Taylor et al., 2017). TBI in the elderly is particularly concerning, because the elderly population is the fastest growing segment of the population in the developed world, predicted to reach 1.5 billion by 2050.

The literature suggests that older patients with TBI are likely to have more severe TBIs, worse hospital outcomes, slower recoveries and increased rates of long-term disability. The literature further suggests that the elderly consume more hospital resources than younger patients and have longer hospital stays (Dams-O'Connor et al., 2013; Schönenberger et al., 2012).

The present study was designed to determine how these generalizations from the international literature apply to the TBI population in a large, Canadian TC. It assessed the demographics, mechanism of injury, injury presentation, hospital admission, length of stay, resource utilization, and short-term outcomes in adult TBI patients admitted to St. Michael’s Hospital, a large, urban Level I TC in Toronto, Ontario. Patients were stratified according to age – younger adults versus geriatric status adults – and by TBI sub-type - isolated TBI (iTBI) versus TBI with multisystem injuries (TBI+).

As stated in the Introduction, based on the literature, it was specifically hypothesized that the elderly would have: 1) more fall-induced TBIs; 2) more referral from lower level centres, possibly due to under-triage; 3) more comorbidities; 4) more hospital-acquired complications; 5) less aggressive critical care; 6) more resource use, 7) longer lengths of stay; 8) more in hospital mortality, and 9) greater disposition along the assisted living continuum among survivors.

2.3 Methods

2.3.1 Study Setting and Design

The present study was a retrospective cohort study involving data from TBI patients admitted to St. Michael's Hospital (Toronto, Ontario), a Level I TC providing quaternary trauma services. Patient data were collected between April 1st, 2008 and March 31st, 2016. The St. Michael's Hospital Trauma Registry (SMHTR) database systematically collects and tracks demographic data and clinical outcomes for all patients with an ISS of ≥ 12 in accordance with the Ontario Ministry of Health and Long-Term Care. Data are coded according to the Ontario Trauma Registry Comprehensive Data Set (Canadian Institutes of Health Information, 2014), the American College of Surgeons National Trauma Data Bank, and the National Trauma Data Standard dictionary (American College of Surgeons: Committee on Trauma, 2016). The use of these data for the present study was approved by the Research Ethics Board of St. Michael's Hospital.

2.3.2 Study Population

The present study includes data from all adult (≥ 18 years) TBI (HAIS ≥3) patients admitted to SMH directly from the scene of trauma or transferred from another institution within 12 hours of injury. Participants were identified via chart-validated age information and 2005 AIS scores.

2.3.3 Baseline Data and Cohort Stratification

The following demographic and patient-level clinical data were collected: age, gender, pre-morbid health status, admission GCS score, ISS, HAIS and AIS-OBR, MOI and physician admitting service. Among patients with HAIS scores ≥ 3, ICD-10-CM injury diagnoses codes understood to capture TBI morbidity and mortality were abstracted (5). Hospital admission profiles (e.g., TTA and admission source and physician service), and hospital course parameters (ICU, ALC, and LOS) were also recorded. Alternate level of care (ALC) is a designation for patients who no longer require acute care but are awaiting transfer to a different care level, such as a rehabilitation or long-term care facility.

TBI was defined by HAIS scores of ≥3. For cohort stratification, patients were first stratified into two age groups: younger adult (age ≤64 years) and older adult (≥65 years). Within these age groups, they were further stratified into: 1) iTBI or "isolated TBI" which included patients with serious head injuries without serious injuries to other body regions (iTBI= HAIS ≥3 + AIS-OBR <3), and 2) TBI+ or "multisystem trauma" which included patients with serious head and also serious injuries to other body regions (TBI+= HAIS ≥3 + AIS-OBR ≥3).

2.3.4 Statistical Analyses

Two statistical approaches were used to evaluate the data:

Initially, a large regression analysis was performed to determine how older and young patients differed as a whole, and also how iTBI and TBI+ patients differed (Table 2-1). To do this, logistical regression models were developed to determine associations of age group and TBI type with hospital admission, intervention and outcomes characteristics. Univariable regression was performed to determine plausible variables for inclusion in multivariable models. Predictor variables included: age, gender, number of comorbidities, GCS category, ISS, HAIS score, TBI type, and MOI. Adjusted odds ratios (ORs) were calculated with corresponding 95% CIs. Multicollinearity was assessed with a variance inflation factor greater than 4. Statistical significance was assigned at $p<0.05$. All analyses were performed using Statistical Analysis System software (SAS 9.4: SAS Institute, Inc., Cary, NC, USA). It became clear from this analysis that the iTBI and TBI+ patients were distinct populations, and should be analyzed separately.

Subsequently, clinically significant factors were compared separately for younger and older adult iTBI and TBI+ patients using analyses of variance or non-parametric tests (Table 2-2). Statistics were conducted on demographics, hospital course, and outcome characteristics of the different cohorts. Data consisted of both nominal data (counts) and continuous (interval/ratio) data. The Chi-square (X^2) test was used to examine differences in categorical (nominal) variables. For continuous variables, mean ± standard deviation (SD) or median (including interquartile range, IQR) were calculated. ANOVAs was used to analyze normally distributed continuous data and the signed-rank test was used to analyze non-normally distributed continuous data.

2.4 Results

2.4.1 Demographic Characteristics

The present study included 2,883 patients with a diagnosis of TBI. Ages of patients ranged from 26 to 84 years. The median age of the whole sample was 60 (Interquartile range or IQR: 40-77) years. Injuries to males were more common than injury to females (71% versus 29%) (See Table 2-2).

Stratified by age, there were 1,618 patients in the younger adult group (18-64 years) and 1,265 patients in the older adult group (≥65 years). Thus, the numbers in our sample were roughly similar in the two cohorts. The median age for the younger cohort was 43 (28-54) years and the median age for the older cohort was 78 (72-84) years (Table 2-2).

Stratified by injury type, two-thirds of the patients experienced an iTBI (2,169) and one-third experienced a TBI+ (n=714) (Table 2-2). Comparing the older and younger groups, the number of older patients that had iTBIs was slightly higher than the number of younger patients that had iTBIs. (50.8% of the iTBIs were in older adults; 49.2% of the iTBIs were in younger adults; $p<0.0001$). The number of older patients that had TBI+s, however, was considerably lower than the number of younger patients that had TBI+s. (22.8% of the TBI+s were in the older group; 77.2% of the TBI+s were in the younger group; $p<0.0001$) (Table 2-2). This may have been due to the fact that TBIs resulting from motor vehicle collisions were more common in the younger adults (see MOIs below).

The majority of our patients were living with at least one comorbidity at the time of their TBI. As would be expected, comorbidities were more common in the older adults (84% versus 44.1% in the iTBI group and 79.1% versus 35.4% in the TBI+ group).

2.4.2 Influence of Age and TBI Pattern on Patient Demographics, Injury Characteristics, Hospital Course and Outcomes: Regression Analysis

Our initial approach to these data involved a multivariate regression analysis. The results of the initial regression analysis are presented in Table 2-1. Our first focus was on the effects of age. The middle column of Table 2-1 presents on these data, comparing the whole cohort of older adult patients to the whole cohort of younger adult patients. The younger patients are used as the reference group.

In the course of our first analysis, however, it became clear that TBI type was also crucial factor that needed to be considered. The right hand column of Table 1, therefore, presents an analysis focused on type of TBI, comparing the whole cohort of TBI+ patients to the whole cohort of iTBI patients. The iTBI patients are used as the reference group.

Analysis Based on Age: As indicated by Table 2-1, older adult patients clearly differed from younger adult patients in many ways, including mechanism of injury, severity of injury, hospital course factors and discharge disposition. Compared to younger adults, older patients had increased risk of presenting with pre-existing health conditions, sustaining a fall-induced trauma and presenting with an iTBI.

Despite the older patients' greater odds of sustaining severe global injury (ISS) and critical head injury (HAIS) severity, their odds of presenting with severe admitting GCS score were reduced. The latter finding, may contribute to the older patients association with a greater risk for undertriage both in the field – with reduced odds for direct TC entry, and reduced odds for initiating TTA (Table 2-1).

Older patients also had increased odds for neurosurgical management and surgical procedures. They were less likely, however, to have ICU management or to receive invasive mechanical ventilation or ICP placement. Risk of mortality, discharge to lower-level acute- or home-care, and readmission was also elevated among the older patients (Table 2-1).

Analysis Based on TBI Type: As indicated by the right column of Table 2-1, TBI+ patients also differed from iTBI patients in many important ways. These included mechanism of injury, severity of injury, hospital course factors and discharge disposition. Risk factors associated with TBI+ presentation included severe admitting GCS score, severe ISS, and high-energy collisioninduced traumas (motor vehicle collisions and pedestrian trauma). In addition, TBI+ patients were more likely to be of younger age and have fewer comorbidities.

Despite their severe ISS scores, TBI+ patients had reduced odds of presenting with critical HAIS scores. This suggests that trauma severity in extracranial body regions could be primarily driving higher injury severity (ISS) measures in TBI+ patients (Table 2-1).

TBI+ patients also had increased odds for direct TC transfer, initiating TTA, and trauma service management. In addition, the TBI+ presentation was associated with greater odds for resource-intense management (surgical-, ICU-, and multimodal monitoring). These patients also had a greater risk for developing nosocomial complications requiring additional therapeutic management. The greater resource requirements associated with the TBI+ subtype likely contributed to the increased risk for prolonged hospital LOS recorded for these patients (Table 2-1).

Outcomes were often poor for these patients. Their risk of mortality was more than doubled, and - among survivors - the risks for long-term chronic care and in-patient rehabilitation dispositions were elevated by factors greater than four and two, respectively. Furthermore, their odds for a home disposition, with or without support, was significantly reduced compared to their iTBI counterparts (Table 2-1).

Table 2-1. Adjusted (sex, age and TBI type) Outcomes and Resource Utilization

Variables	**Age[1] (referent: young)**	**TBI+[2] (referent: iTBI)**
TBI+[3]	0.28 (0.23-0.34)*	N/A
Sex[4]	1.21 (1.09-1.87)*	0.80 (0.65-0.97)*
Comorbidity	6.46 (5.38-7.76)*	0.69 (0.57-0.83)*
≥6 comorbidities	7.23 (4.94-10.58)*	1.07 (0.72-1.58)
GCS: Severe (3-8)	0.43 (0.36-0.51)*	2.37 (1.98-2.85)*
ISS: Very severe (≥25)	3.03 (2.55-3.60)*	4.38 (3.54-5.42)*
HAIS: Critical (5)	2.73 (2.33-3.21)*	0.41 (0.34-0.50)*
Fall	6.34 (5.27-7.62)*	0.28 (0.23-0.34)*
Motor vehicle collision	0.28 (0.21-0.37)*	5.74 (4.58-7.20)*
Pedestrian trauma	0.64 (0.48-0.85)*	2.60 (1.99-3.41)*

Bike	0.22 (0.13-0.36)*	0.96 (0.65-1.42)
GSW	0.27 (0.10-0.72)*	0.59 (0.24-1.46)
Stab	-	1.61 (0.66-3.92)
†Other	0.22 (0.13-0.36)*	0.96 (0.65-1.42)
Hospital course		
Hospital arrival from scene	0.45 (0.38-0.52)*	1.23 (1.03-1.47)*
Trauma Team Activation	0.21 (0.17-0.25)*	19.48 (14.66-25.87)*
General Surgery/Trauma admitting service	0.32 (0.27-0.39)*	11.84 (9.51-14.75)*
Neurosurgical admitting service	2.99 (2.50-3.60)*	0.08 (0.06-0.10)*
††Other physician admitting service	1.31 (0.88-1.94)	0.61 (0.36-1.02)
Surgical management	1.92 (1.64-2.26)*	1.52 (1.27-1.82)*
ICU management	0.55 (0.47-0.65)*	4.84 (3.86-6.05)*
ICP management	0.45 (0.35-0.57)*	1.35 (1.07-1.71)*
Mechanical ventilation	0.53 (0.45-0.62)*	4.54 (3.74-5.51)*
In-hospital complications management	0.97 (0.81-1.17)	3.34 (2.76-4.02)*
Alternate level of care designated	0.82 (0.65-1.02)	1.61 (1.28-2.03)*
Hospital length of stay	-0.02 (-0.06-0.02)	10.17 (8.36-11.98)*
ICU length of stay	0.32 (-0.36-1.01)	5.63 (4.89-6.36)*
Discharge disposition		
Home	0.35 (0.30-0.42)*	0.25 (0.20-0.32)*
[a]Home with support	1.54 (1.16-2.03)*	0.59 (0.41-0.86)*
[b]In-patient rehabilitation facility	1.08 (0.90-1.30)	2.26 (1.87-2.74)*
Another acute care facility	1.90 (1.56-2.32)*	0.93 (0.74-1.18)
Chronic care facility	1.39 (0.56-3.45)	4.90 (2.00-11.99)*
[c]Other	0.26 (0.12-0.55)*	0.44 (0.21-0.96)*
Readmission[5]	1.63 (1.07-2.48)*	0.75 (0.44-1.28)
Mortality	1.85 (1.49-2.30)*	2.51 (2.00-3.14)*

GCS=Glasgow Coma Score; ISS=Injury Severity Score; HAIS=head Abbreviated Injury Scale score; GSW=gunshot wound

[1]OR for elderly compared with young

[2]OR for TBI+ compared with iTBI

[3] OR for risk of experiencing TBI+

[4] OR for male compared with female gender

[5]30 day readmission rate

†Recreational other; home or industrial other; legal intervention; assault; unspecified

††Medical services: Internal medicine, cardiology, nephrology, respirology, psychiatry, physiatry, geriatrics; Surgical services: Orthopedic, plastics, cardiovascular, urology, otolaryngology, ophthalmology, vascular

[a]Home with support or nursing home facility

[b]General and special rehabilitation facilities

[c]Left against medical advice; unspecified alive; police custody; psychiatric facility; homeless shelter

*p<0.05

- Not enough data to perform analysis

2.4.3 Comparing Older and Younger Patients *within* TBI Subtypes: Direct Comparisons

The initial regression analyses indicated that there were significant differences between TBI+ and iTBI patients. These initial findings led to subsequent analyses in which older and younger adult TBI patients were compared to each other within distinct TBI subtypes (i.e. older and younger groups of TBI+ patients and older and younger groups of iTBI patients). These comparisons were done using analyses of variance or non-parametric tests.

These data from these analyses are presented in Table 2-2, which compares older and younger patients in each subtype in terms of mechanism of injury, injury characteristics, length of stay, resource use and outcomes and discharge disposition. The left hand column of Table 2-2 presents the data for multi-system TBI+ and the right hand column of Table 2-2 presents the data for iTBI.

Table 2-2. Demographic, Clinical and Hospital Admission Characteristics of TBI Patients by Age Group and TBI Type (n=2,883)

Characteristics	Multi-system +TBI				Isolated TBI			
	714 (24.8%)				2,169 (75.2%)			
	Young (<65 years)	%[1]	Elderly (≥65 years)	%[1]	Young (<65 years)	%[1]	Elderly (≥65 years)	%[1]
Patients, n	551	77.2**	163	22.8	1067	49.2	1102	50.8**
Age, median (IQR)	39	26-52	76	71-83**	45	29-55	79	73-84**
Male, n	407	73.9*	102	62.6	855	80.1**	686	62.3
Comorbidity, n	195	35.4	129	79.1**	470	44.1	926	84**
No. of comorbidities, median (IQR)	1	1-2	3	2-5**	2	1-3	3	2-5**
Admitting GCS, median (IQR)	7	3-14	14	5-15**	13	6-15	14	11-15**
ISS, median (IQR)	34	26-38	29	26-37	21	16-25	25	20-25**
Mechanism of Injury, n								
Fall	138	25	80	49.1*	501	47	965	87.6**
MVC	234	42.5*	34	20.9	127	11.9*	38	3.4
Pedestrian trauma	84	15.2	37	22.7	96	9*	46	4.2
Bicycle	33	6	6	3.7	77	7.2*	14	1.3
GSW	6	1.1	0	0	19	1.8*	5	0.5

Stab	9	1.6	0	0	11	1*	0	0
Other[†]	47	8.5	6	3.7	236	22.1*	34	3.1
Trauma Team Activation, n	512	92.9*	139	85.3	521	48.8**	170	15.4
Admission source, n								
Arrived from referring hospital	258	46.8	88	54	510	47.8	767	69.6*
Direct from scene	293	53.2	75	46	557	52.2*	335	30.4
Admitting Service, n								
Neurosurgery	61	11.1	30	18.4*	619	58	889	80.7*
General Surgery/Trauma	457	82.9*	128	78.5	383	35.9*	149	13.5
Other[††]	16	2.9	2	1.2	36	3.4	60	5.4*
Patients not admitted	17	3.1	3	1.8	30	2.8**	5	0.5
Survival Discharge Disposition, n								
Home	103	23.4*	9	8.8	503	52.6*	257	27.8
Home with support[a]	32	7.3	4	3.9	71	7.4	129	13.9
Inpatient rehabilitation[b]	202	45	58	56.8	204	21.3	243	26.3*
Another acute care facility	86	19.6	27	26.5	142	14.9	282	30.5*
Chronic care centre	10	2.3	3	2.9	3	0.3	6	0.7
Other[c]	7	1.6	1	1	33	3.5*	8	0.9
Readmission, n	14	3.2	4	3.9	29	3	54	5.9*
Overall Mortality, n	111	20.1	61	37.4**	111	10.4	177	16.1**

IQR=interquartile range; GCS=Glasgow Coma Score; ISS=Injury Severity Score; MVC=motor vehicle collision; GSW=gunshot wound

[1]Except where indicated otherwise

[†]Recreational other; home or industrial other; legal intervention; assault; unspecified

[††]Medical services: Internal medicine, cardiology, nephrology, respirology, psychiatry, physiatry, geriatrics; Surgical services: Orthopedic, plastics, cardiovascular, urology, otolaryngology, ophthalmology, vascular

[a]Home with support or nursing home facility

[b]General and special rehabilitation facilities

[c]Left against medical advice; unspecified alive; police custody; psychiatric facility; homeless shelter

* = p<0.05; ** = p<0.0001

2.4.3.1 Mechanism of Injury

As indicated in Table 2-2, there were two major mechanisms of injury: falls and motor vehicle collisions. Falls were particularly common among the older adults.

Falls: Falls were a common cause of injury in both the iTBI and the TBI+ groups, especially in the older adult patients. In the iTBI group, fall-induced injury accounted for 87.6% of older admissions and only 47% of younger admissions. Falls were a less frequent cause for TBI+, but they still accounted for 49.1% of TBI+ admissions in the older adults and 25% of the TBI+ admissions in the younger adults.

Motor Vehicle Collisions (MVC): MVCs were particularly important in the TBI+ patients, and particularly in the younger TBI+ patients. In the iTBI patients, only 3.4% of admissions in the older cohort and 11.9% of admissions in the younger cohort resulted from motor vehicle collisions. In the TBI+ groups, however, motor vehicle collisions accounted for 42.5% of admissions in the younger adults and 20.9% of admissions in the older adults (Table 2-2).

2.4.3.2 Injury Characteristics

Data related to severity of injury are found in Table 2-1 (GCS, ISS and HAIS) and – in more detail – in Tables 2-2 and 2-3.

GCS Scores: At admission, older patients had significantly greater odds for higher GCS scores, suggesting that they showed less severe functional brain injury (Table 2-1). This was true in both the iTBI group and the TBI+ groups (Table 2-2). This suggests that early signs of significant functional brain damage after trauma are delayed in older aged TBI victims compared to younger victims.

ISS, HAIS: Relative to anatomical injury scores, older adults were at significant increased risk for severe injury on both global (ISS) and region-specific (HAIS) scores (Table 2-1). However, age-associated differences were influenced by the type of TBI. In the iTBI group, the older adults actually had higher global severity of injury (ISS) scores (Table 2-2) and a higher percent of critical head injury (HAIS) scores (Table 2-3). These differences in ISS and HAIS scores, however, were not seen in the TBI+ group where the older and younger adults did not differ significantly (Table 2-2 and 2-3).

Head Injury Diagnosis: A greater frequency in diagnosis of intracranial injuries characterized older TBI adults compared to their younger counterparts (Table 2-3). It is possible that identification of significant functional derangement in the older adults could be in response to their delayed or occult injury presentation resulting from an intracranial trauma.

Table 2-3. TBI Classification by Maximum Head Abbreviated Injury Scale and Head Injury Diagnoses

TBI Description	HAIS (Definition)	Young (n=1618)	Elderly (n=1265)
TBI including multisystem trauma (TBI+) (n/%)	3 (serious)	176 (10.9)	49 (3.9)
	4 (severe)	208 (12.9)	68 (5.4)
	5 (critical)	165 (10.2)	46 (3.6)
	6 (fatal)	2 (0.1)	0
Isolated TBI (iTBI) (n/%)	3 (serious)	226 (14.0)*	80 (6.3)
	4 (severe)	396 (24.5)*	246 (19.4)
	5 (critical)	443 (27.4)	776 (61.3)*
	6 (fatal)	2 (0.1)	0
Head Injury Diagnosis			
Intracranial injuries[1]		1,443 (89.2)	1,232 (97.4)**
Open wound of head[2]		161 (10.0)**	46 (3.6)
Fracture of skull		1,009 (62.4)**	291 (23.0)
Fracture of facial bones[3]		297 (18.4)**	79 (6.2)
Unspecified injuries of head[4]		15 (0.9)	5 (0.4)
Crushing injury of head[5]		0	0

HAIS=maximum head abbreviated injury scale score
AIS-OBR=maximum abbreviated injury scale score in other body regions (face; neck; thorax; abdomen; cervical, thoracic, and/or lumbar spine; upper extremities; lower extremities; external; not further specified)
[1] Concussion; epidural hemorrhage; traumatic subdural and subarachnoid hemorrhage; and other/unspecified intracranial injuries (ICD 10 Code: S06.0-S06.9)
[2] Includes multiple open wounds to head; other part of head; and unspecified part of head (ICD 10 Code: S01.7-S01.9)
[3] Skull and/or base of skull. Multiple fractures involving skull and facial bones; other and/or unspecified part of skull and facial bones (ICD 10 Code: S02.0-1 S02.7-S02.9)
[4] Multiple injuries of head; other injuries of head and/or unspecified injuries of head (ICD 10 Code: S09.7-S09.9)
[5] Skull; other part of head; unspecified part of head (ICD 10 Code: S07.1; S07.8; S07.9)
* = p<0.05; ** = p<0.0001

2.4.3.3 Hospital Entry and Admitting Service

As indicated by Table 2-2, there were differences in how older and younger adult patients were admitted to hospital and in the hospital service that admitted them. Once again, this differed by injury subtype.

Hospital Entry: In the iTBI group, younger adults were significantly more likely to be admitted from the scene and older adults were significantly more likely referred from another hospital (Table 2-2). This may reflect the fact that older patients often manifest a blunted/slower injury response to trauma.

Admitting Service: In the iTBI group, the majority of patients were admitted to Neurosurgery - particularly if they were older (80.7% older, 58% younger) – while a minority were admitted to General Surgery/Trauma. In contrast, in the TBI+ group, the majority of patients, both younger (82.9%) and older adult (78.5%), were admitted to General Surgery/Trauma, with a minority going to Neurosurgery. The fact that older iTBI patients were admitted directly to Neurosurgery may reflect the fact that they were often referred from lower level hospitals after the serious nature of their neurological injuries had become evident.

2.4.3.4 Hospital Resource Use

The complex data related to hospital resource use are presented in Table 2.2 and in Figure 2-1.

Trauma Team Activation (TTA): In older patients, TTA was less common than in younger patients in both the iTBI and the TBI+ groups (in the iTBI cohort: 15.4% older versus 48.8% younger; in the TBI+ cohort: 85.3% older versus 92.9% younger) (Table 2-2).

Resource Use: Older patients also received significantly fewer clinical interventions in both TBI groups, including less ICP monitoring and lower rates of mechanical ventilation (Figure 2-1). In the iTBI group, older patients also had less ICU management. In the TBI+ group, but not iTBI, group, older adults were less likely to undergo surgery (Figure 2-1).

These data do not support the suggestions in the literature that elderly patients use more hospital resources. The older patients often used less resources, at least in the cohort sampled here. Resource use will be discussed further in Chapter 4.

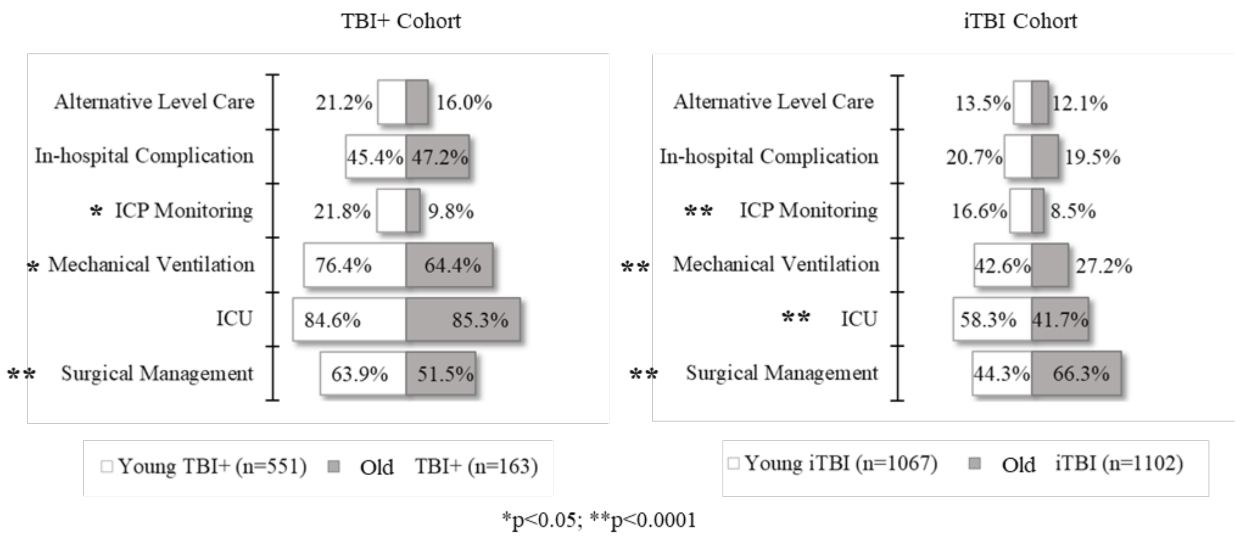


Figure 2-1. Proportional distributions of the acute care clinical management of older (≥ 65 years) and younger adult (18-64 years) TBI patients by TBI injury type.

2.4.3.5 Length of Stay

The data related to length of stay (LOS) are presented in Figures 2-2 and 2-3.

Contrary to expectation, in the present cohort, older patients did not have longer lengths of stay in either TBI subtype. In the iTBI patients, older and younger patients recorded similar median days of hospitalization (5 (3-10) versus 5 (2-12), respectively). In the TBI+ group, older TBI+ patients actually had significantly shorter LOS as compared to younger TBI+ patients, recording 11 (3-21) versus 12 (6-28) median days, respectively. These figures do not appear to agree with the suggestion in the literature that older patients have longer LOS in the hospital. At least in the TC studied here, LOS was not prolonged in the older adult patients (Figure 2-2, upper panels).

Further, the data related to overall hospital LOS did not appear to be influenced by early in-hospital mortality. Median LOS among non-survivors was twice as long in older TBI+ patients compared to younger TBI+ patients (2 (1-10) versus 1 (1-7) days). Among iTBI non-survivors, median LOS was 4 (1-9) and 3 (1-9) days in the older and younger adults patients, respectively, however, this difference failed to reach significance (Figure 2-2, lower panels).

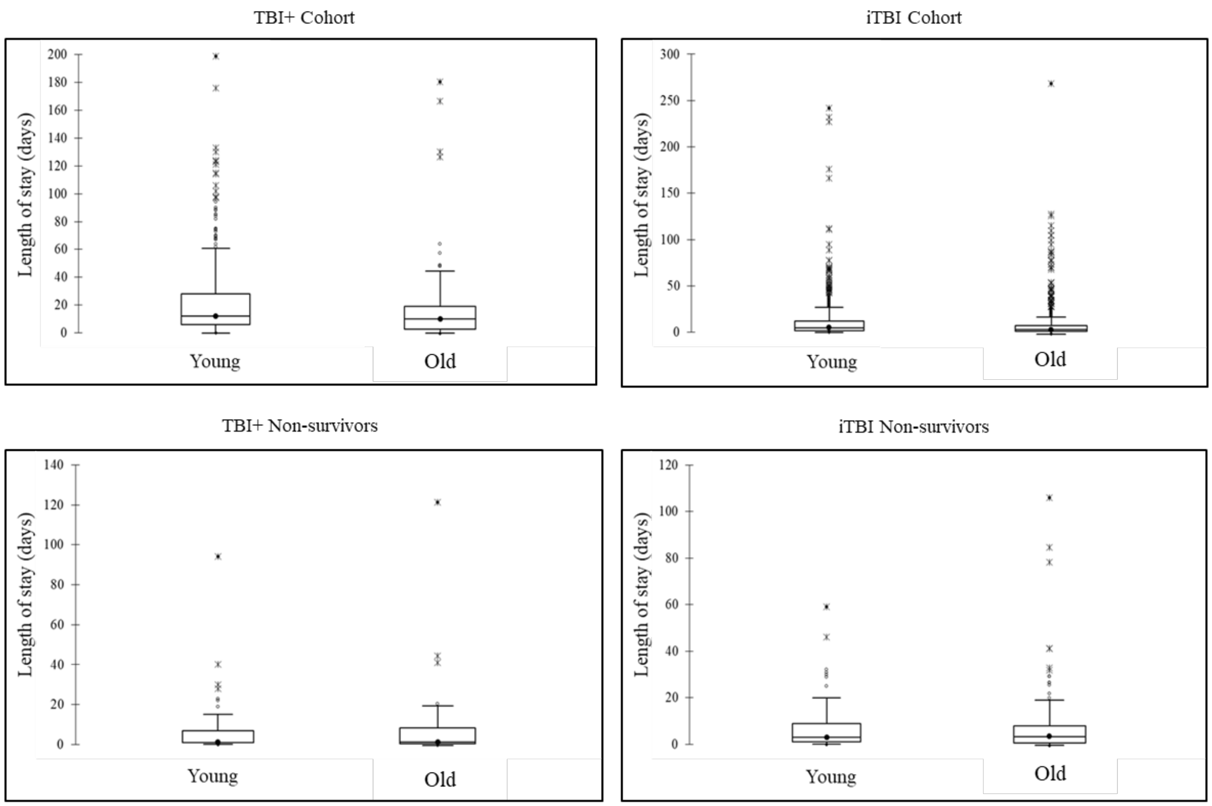
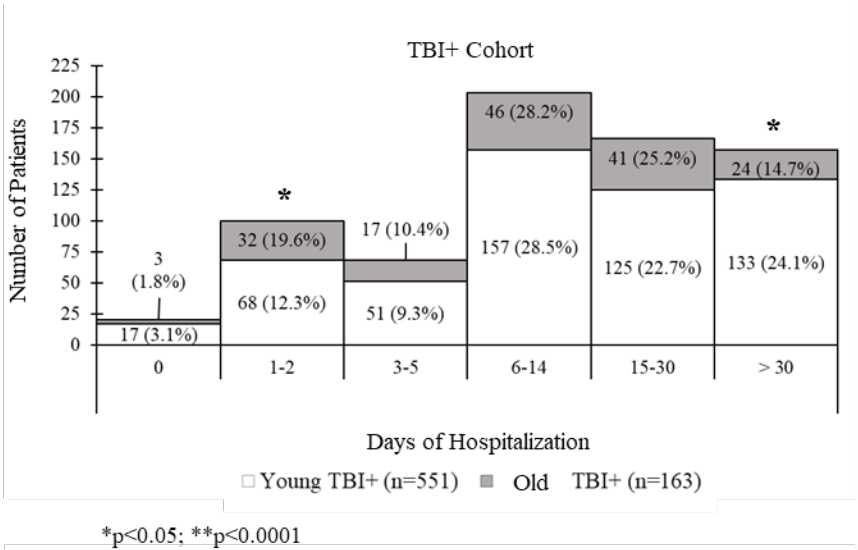


Figure 2-2. Hospital length of stay of surviving and non-surviving TBI patients stratified by TBI type and younger (18-64 years) and older (≥ 65 years) age groups.

Differences between age groups with TBI+ and iTBI in their distribution of LOS by discrete days of hospitalization were evaluated also (Figure 2-3). In the TBI+ cohort, the LOS distribution was equivalent between the age groups except at the extremes in the distribution where significantly more older TBI+ patients had shorter stays of 1-2 days (19.6% older and 12% young), while more young TBI+ patients stayed for more than 30 days (24% young and 15% older). Conversely, in the iTBI cohort, the LOS distribution was more equally distributed at the extremes of stays among the iTBI cohort, however, significant differences between older and younger patients emerged in stays of one to two weeks.



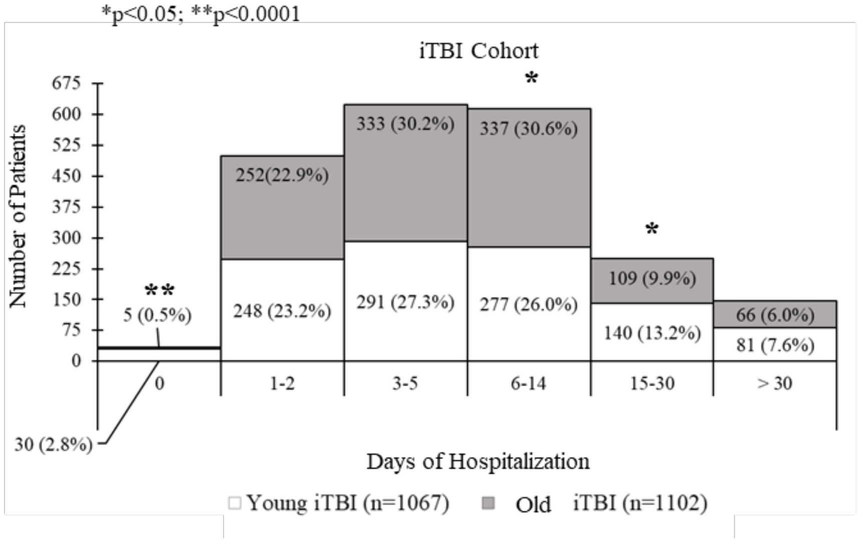


Figure 2-3. Distribution of hospital length of stay among TBI+ and iTBI patients stratified by younger (18-64 years) and older (≥ 65 years) age groups. *p<0.05; **p<0.0001

These findings in conjunction with the observations that early mortality does not influence overall LOS suggests that distinct TBI subtype informs resource intensity as measured by LOS requirements. Indeed, increased LOS was associated with TBI+ diagnosis (OR: 10.17, CI: 8.36-11.98) as compared with iTBI (Table 2-1).

Factors affecting length of stay in the elderly will be discussed in more detail in Chapter 4.

2.4.3.6 Vital Outcomes and Discharge Disposition

Mortality: As suggested by the past literature, overall TBI survival rate was significantly greater among younger adults compared to the older patients. This was true in both TBI+ and iTBI patients (79.1% versus 62.6% in the TBI+ cohort and 89.6% versus 83.9% in the iTBI cohort) (Table 2-2).

Discharge Disposition: Relative to discharge, in both TBI cohorts, older survivors were significantly less likely to be discharged to home than younger survivors (iTBI - 27.8% older versus 52.6% younger; TBI+ - 8.8% older versus 23.4% younger). Instead, older patients were more likely to be sent to inpatient rehabilitation (IR) or to another acute care facility. These findings were seen in both TBI cohorts, but reached significance only in the iTBI group (Table 2-2). These differences in discharge may reflect the greater needs along the continuing care and assisted living continuum among older TBI patients compared to the young.

Readmission: No other significant differences in discharge disposition were seen between the age or injury groups, but older patients in the iTBI group were significantly more likely to require readmission as compared to the younger patients in the iTBI group (5.9% and 3.0%, respectively).

2.5 Discussion

The primary aim of the study was to assess demographics, mechanism of injury, injury presentation, hospital admission, length of stay, resource utilization, and short-term outcomes in younger adult and elderly adult TBI patients admitted to St. Michael's Hospital, a large, urban Level I Trauma Centre in Toronto, Ontario. A secondary objective was to compare and contrast these findings as related to the isolated TBI (iTBI) and multisystem TBI (TBI+), since a preliminary survey indicated that these groups differed in a number of ways.

A number of our findings agree with previously published reports, and with our hypotheses based on the previous reports. As expected, the elderly had: 1) more fall-induced TBIs; 2) more referral from lower level centres, perhaps due to undertriage; 3) more comorbidities; 4) more complications in hospital; 5) less aggressive care; 6) more in hospital mortality and 7) more discharge to lower level care. Unexpectedly, they did not have longer LOSs and they did not use more hospital resources.

These points will be discussed further below.

Falls: As noted in the Introduction, falls are known to be a major cause of TBI in the elderly, with motor vehicle accidents being a secondary cause. This was found to be the case in the present study, where the leading mechanism of injury among the adult TBI population was falls, except among younger TBI+ patients, where MVC prevailed.

Age alone is probably not the only factor contributing to falls and TBI in the elderly. Fu et al. have demonstrated that both increasing age and comorbidity in older adults are independently predictive of fall-induced TBI (W. W. Fu et al., 2017). Friedland et al. have similarly shown that increased rates of falls among middle-aged adults sustaining TBI are associated with pre-existing health conditions (Friedland, Brunton, & Potts, 2014). Roughly 80% of the older patients in the present study were living with comorbidities in both the iTBI and TBI+ groups, which may explain their increased number of TBIs related to falls.

There is a growing awareness of the potential serious impact of falls in older adults (R. Gardner et al., 2018). Preventing falls in the elderly would be an important public health measure.

Undertriage: The literature reviewed in the Introduction also suggests that the elderly are under-triaged, perhaps because of the blunted injury response to TBI seen in older patients. This is consistent with our findings that at admission, GCS scores were significantly higher in the elderly, and that, at least in the iTBI group, the elderly were more likely to be referred from a lower level care centre whereas the younger adults were more likely to enter the TC direct from the scene.

Kehoe and colleagues had previously reported that functional and physiological injury scales are obscured and unreliable among older TBI patients lending to an underestimation of brain injury severity (A. Kehoe et al., 2016; A. D. Kehoe et al., 2014). The poor performance of triage protocols for identification of significant injury in older TBI patients is well described (A. Kehoe, Rennie, et al., 2015; L. J. Scheetz et al., 2016). The insensitivity of triage criteria for identifying latent and/or occult injury among older iTBI patients is thought to contribute to the increased rates of inter-facility transfer to level I TCs (A. Kehoe et al., 2016; L. Scheetz, 2012) – such as the high rates of transfer seen in the present study.

Despite the higher GCS scores at admission in the elderly, when the ISS was applied it became clear that older patients were more severely injured, at least in the iTBI group. An analysis involving HAIS scores (Table 2-3) indicated that older patients in the iTBI group were significantly more likely to have *critical* head injuries as opposed to severe or serious injuries.

In the future, it will be important to understand that older patients with iTBI are often more injured than they appear. They should be triaged appropriately.

Less Aggressive Acute Care: The literature reviewed in the Introduction suggested that older adults are not only under-triaged but that they also undergo less aggressive acute care after traumatic injuries, as compared to their younger counterparts. In agreement with the literature, we found clear differences in the interventions that younger and older adults received in hospital. This was true within both the iTBI and the TBI+ groups. TTA was more frequent in younger adults, while older patients were less likely to be admitted to ICU, had shorter ICU stays, and received less ICP monitoring.

It seems possible that pervasive negative expectations - expectations that older patients will have a bad outcome - infiltrate clinical decisions and lead to decreased resource use in the elderly. This leads to poorer outcomes, which fulfill the negative expectations.

Further research should investigate how such differences in resource utilization impact outcomes in older TBI patients.

Resource Use / LOS: In certain instances, our findings did not agree with the published literature. The published literature suggests that older patients use more hospital resources than younger adult patients. As noted in the preceding paragraph, they actually received less resources than the younger patients.

Previous studies have found longer hospital stays with advanced age among adult TBI populations (Moore et al., 2018; Tardif et al., 2016). In contrast, we found equivalent or reduced LOS among elderly iTBI and TBI+ patients.

Our finding related to resource use and length of stay may be specific to trauma clinic setting studied in the present thesis. As noted above, the factors related to length of stay and resource use in our geriatric cohort will be analyzed in detail in Chapter 4.

Higher Rates of Disposition to Continuing Care / Assisted living: In agreement with the literature, we observed lower frequency of discharge to home and higher rates of discharge to continuing care among older iTBI patients as compared with younger adult iTBI patients. This is consistent with existing literature showing advanced age is a determinant of discharge destination from acute care following TBI (J. Cuthbert et al., 2011; Zarshenas et al., 2019). Slower recovery trajectories, with marked residual functional deficits during the acute clinical course, characterize older TBI survivors and this may render them less fit for discharge to independent living (Karibe et al., 2017).

Readmission: Slower recovery rates in the elderly may relate to our findings on readmission. In the iTBI group, the older patients' rate of readmission was almost twice that of younger adults. A similar trend in the TBI+ patients was not significant. Increased rates of re-hospitalization following TBI have been shown to be influenced by advanced age, mechanism of injury associated with fall, high trauma load, and increased comorbidity (Saverino et al., 2016).

Mortality: Finally, in agreement with the literature, mortality was significantly higher in the older adults both in the iTBI and the TBI+ groups. This result is in agreement with previously published research from North America, Asia, and Europe (Eom, 2019; Mosenthal et al., 2002; Røe et al., 2013). Factors related to mortality in our cohort will be discussed in detail in chapter 3.

2.6 Limitations and Future Studies

The current study was designed to determine how generalizations from the literature would apply to a large Canadian TC. As such, the current study has limitations inherent to the use of data from a single clinical setting. The findings - such as those on LOS and resource use - may not apply generally.

Changes in data collection protocols (diagnostic coding) during the study time period may also have limited access to adequate data to discern patients' pre-existing comorbidities and the complications they developed during their acute care hospital stay. Lack of data concerning rate of mortality and LOS in the pre-index hospital and post-acute phase of care among our patients may underestimate our risk estimates for mortality and total hospitalization LOS. Finally, our decision to use ≥65 years of age may have obscured significant differences within the younger cohort.

Future studies might consider using frailty scales within analysis of the associations between age and TBI. Clinical measures of frailty provide useful means for identify high risk individuals by taking into account individual vulnerabilities and propensity for adverse health outcomes especially in the geriatric population.

2.7 Conclusions

Overall, our study found significant differences between older and younger TBI patients, and those differences may be partially influenced by a TBI in the presence (TBI+) or absence (iTBI) of significant concomitant extracranial injury.

In general, despite similar or more severe injuries, older patients were less likely sent directly to a TC, initiate a TTA, or be admitted to Trauma Service or ICU. In other words, older adults suffered more severe TBIs and had worse clinical outcomes, but less commonly received clinical care and services that may help improve outcomes.

Undertaking further research designed to develop effective treatment programs will be key to improving outcomes in this vulnerable population.

Chapter 3
Factors Associated with Mortality Among a Traumatic Brain Injured Cohort: Retrospective Analysis of Data from a Level I Trauma Centre

3 Factors Associated with Mortality Among a Traumatic Brain Injured Cohort: Retrospective Analysis of Data from a Level I Trauma Centre

3.1 Abstract

TBI is common in the adult trauma population, and it produces the highest rates of mortality of any form of injury. The current study sought to assess the factors associated with in-hospital mortality in an adult Level I trauma centre (TC). Retrospective data were collected from 2,883 adult patients diagnosed with a TBI admitted to St. Michael's Hospital (SMH) in Toronto, Ontario. Clinical data were collected that related to demographic, clinical course and TBI-type diagnosis. A multivariable logistic regression was then performed to evaluate the factors associated with in-hospital mortality. Within our adjusted regression model, mortality was found to be associated with: 1) increasing age; 2) the presence of pre-injury comorbidities; 3) the severity of injury; 4) the presence of concomitant extracranial injury (TBI+); 5) delay to definitive care; and 6) surgical intervention.

The data suggest that older TBI patients are particularly at risk, especially if they have pre-existing comorbidities and extracranial injuries. Special protocols might be developed for the treatment of this particularly vulnerable patient population.

3.2 Introduction

The incidence of traumatic brain injury (TBI) has increased significantly in the last 30 years. It is now the leading cause of death and disability due to trauma (R. Gardner et al., 2018; Shivaji, Lee, Dougall, McMillan, & Stark, 2014). Annually in the United States, 2.5 million individuals visit an emergency department with a suspected TBI. Of these, 282,000 patients are hospitalized with a TBI and, of those, 56,000 die (C. A. Taylor et al., 2017). In Canada, 23,000 hospitalizations occur per year due to TBI, with a mortality rate of 8% (T.S Fu et al., 2015).

Previous research has suggested some of the factors that are associated with mortality among TBI patients. One of the most important is age. A meta-analysis has demonstrated an age-associated increased risk of mortality among those over the age of 65. Even over 65, risk of death increases as age increases, since adults ≥75 years have an odds ratio (OR) of 1.7 (CI = 1.3-2.3) when compared with the 65–74 years age group (McIntyre et al., 2013). Despite this increased mortality in the elderly, research has tended to focus upon improving outcomes within younger, not older, TBI patient populations (Albrecht et al., 2016).

Our own research has also shown that older adults are more likely to die after both isolated TBI (iTBI) and after TBI with multisystem injuries (TBI+). It indicated that TBI+ patients, though younger on average and with less comorbidities, were particularly prone to poor outcomes and mortality (Chapter 2).

The current study sought to further assess the various factors – including age - that were associated with mortality in the TBI patients admitted to St. Michael’s Hospital, a Level I TC, in Toronto, Ontario. Retrospective data were collected from 2,883 adult TBI patients including data related to demographics, clinical course and type of TBI. Multivariable logistic regression was then used to evaluate the factors associated with in-hospital mortality.

Based on the literature - and our past work - it was hypothesized that the elderly TBI patients would have increased in-hospital mortality as compared to younger patients. Other factors expected to increase mortality were severity of injury and the TBI+ sub-type presentation.

3.3 Methods

Study Population: Retrospective data from an inpatient cohort of younger and older adult TBI patients were analyzed. Data were collected from patients treated at St. Michael's Hospital (Toronto, Ontario) between April 1st, 2008 and March 31st, 2016. St. Michael's Hospital is a provider of Level I quaternary trauma services.

Within the St. Michael's Hospital Trauma Registry database, data are systematically collected and tracked to record both demographic data and clinical outcomes for all patients with an ISS of ≥ 12. All data collection and tracking is undertaken in accordance with guidelines of the Ontario Ministry of Health and Long-Term Care. Data were coded based upon the guidelines of the Ontario Trauma Registry Comprehensive Data Set (Canadian Institutes of Health Information, 2014), the American College of Surgeons National Trauma Data Bank, and the National Trauma Data Standard dictionary (American College of Surgeons: Committee on Trauma, 2016). Study approval was granted by the Research Ethics Board within St. Michael's Hospital.

All adults (≥ 18 years) with a TBI (defined as a maximum head AIS ≥3) admitted directly from the scene of the trauma or transferred from another clinical setting within 12 hours of injury were included in our study sample. Identification of participants was by chart-validated age information and 2005 abbreviated injury scale (AIS) scores. The TBI cohort was defined as individuals with head AIS (HAIS) scores of ≥3. The Abbreviated Injury Scale for other body regions (AIS-OBR) scores and HAIS were used to define two TBI sub- types. These were: 1) multisystem trauma with serious intracranial injury (defined as TBI+ = AIS-OBR ≥3) and isolated TBI (defined as iTBI = AIS-OBR <3).

Data Collected: We collected a range of data related to demographic information and clinical presentation. Based upon these data, we were able to measure variables related to age, gender, number of presenting comorbidities, admission Glasgow Coma Scale (GCS) score, Injury Severity Score (ISS), HAIS and AIS-OBR, and mechanism of injury. The cohort of TBI patients was identified as those with HAIS scores ≥ 3 and ICD-10-CM injury diagnoses codes.

Health care utilization was also recorded, and we were able to capture information related to the provision of care such as: trauma center arrival source (direct from scene or via referral center), Trauma Team Activation (TTA), admitting physician service (general surgery/trauma or neurosurgery), Intensive Care Unit (ICU), and Alternate Level of Care (ALC). TTA is a multidisciplinary team that receives at-risk trauma patients in need of higher intensity investigations and interventions (St. Michael's Hospital, 2011). ALC is defined as a designation for patients who no longer require acute care and who are awaiting transfer to a different clinical setting.

Data related to length of stay (LOS) within the TC were also recorded, as were short-term outcomes associated with discharge dispositions and readmission rates - defined as an unplanned hospital stay related to the original trauma admission at St. Michael's Hospital within 30 days of discharge. Data are reported as mean ± standard deviation (SD) or as a proportion of the total cohort and by specific TBI sub-types.

Statistical Analysis: Variables including age, gender, number of comorbidities, GCS category, ISS, HAIS description, and TBI type were then entered into our adjusted logistic regression model to explore their relation to mortality within our TBI population. Statistical significance was assigned at $p<0.05$ and 95% confidence intervals (CI) were computed. All analyses were performed using IBM SPSS Statistics for Windows, version 25 (IBM Corp., Armonk, N.Y., USA).

3.4 Results

3.4.1 Demographics, Mechanism of Injury, Discharge Disposition and Hospital Course

The present chapter examines the same cohort of TBI patients analyzed in Chapter 2. Data related to demographics, mechanism of injury, discharge disposition and hospital course will, therefore, not be discussed here in detail. For reference purposes, they may be found in the Appendix to this chapter.

3.4.2 Mortality

Overall Mortality Overall, in-hospital mortality was 16% in this group of patients. It was higher in the TBI+ patients (24%) than in the iTBI patients (13%) group.

Multivariate Analysis: The results of a multivariate analysis of the factors – including age - associated with mortality among the whole cohort of TBI patients are presented in Table 3-1.

Predominant Effect of Age: Age is considered to be a major factor in TBI mortality. It proved to be a predominant factor in our sample as well.

The important association between age and mortality is indicated by the findings that: 1) all decades of patients over 65 are have higher mortality risks than patients under 65; and 2) that after 65, the risk of mortality increases linearly with each decade (Table 3-1).

Effect of TBI Type: Figure 3-1 presents a graphical breakdown of mortality by age for: 1) all patients; 2) iTBI patients; and 3) TBI+ patients. Mortality increases with age in all groups, with a particularly large increase being seen in the TBI+ group. As indicated by Figure 3-1 and by Table 3-1, patients with multisystem TBI (TBI+) were nearly twice as likely to die as patients with isolated TBI (iTBI).

Preexisting Comorbidities / Severity of Trauma/ Surgery: Other factors associated with increased risk for in-hospital mortality included the presence of pre-existing comorbidities, greater trauma load as measured by increased severity of GCS, ISS and HAIS scores, and surgical management. Those who received surgery had increased odds of mortality compared with those who did not (OR: 5.16, CI: 1.64-2.86).

Delay to Definitive Care: An interesting finding of the present study was that patients admitted directly from the scene of a TBI had a reduced risk of death as compared with those who arrived from a referring hospital (OR: 0.43, CI: 0.33-0.57).

Gender/Mechanism of Injury/ Admitting Service/ In Hospital Complications: We did not find any statistically significant differences in mortality risk related to gender, mechanism of injury, admitting physician service or the presence of in-hospital complications.

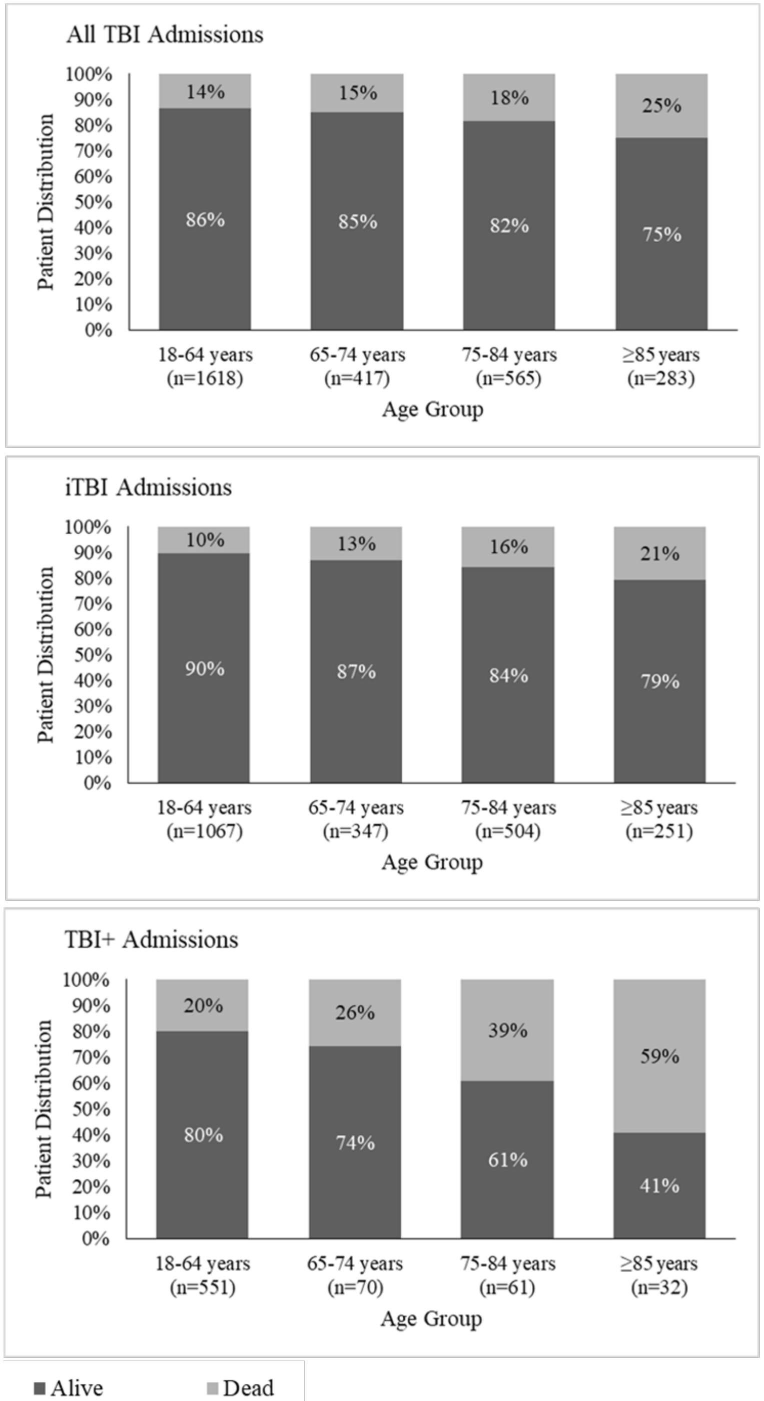


Figure 3-1. Distribution of Survivor and Non-survivor TBI Admissions Stratified by Age Groups and TBI Type. Surviving patients represented in dark grey. Decedents represented in light grey.

Table 3-1. Multivariable Analysis of Factors Associated with Mortality Among TBI Patients

Factor		Odds Ratio	95% Confidence Interval	p-value
Age (years)	Young (18-64)	Referent		
	65-74	2.45	1.64-3.68	<0.0001
	75-84	3.55	2.40-5.23	<0.0001
	85+	5.96	3.74-9.50	<0.0001
Gender	Female	Referent		
	Male	1.12	0.84-1.49	0.432
Comorbidities	0-3	Referent		
	4-6	1.75	1.24-2.48	0.002
	>=7	3.15	1.79-5.53	<0.0001
Admitting GCS	13-15 (mild)	Referent		
	9-12 (moderate)	4.22	2.72-6.56	<0.0001
	3-8 (severe)	18.63	13.22-26.25	<0.0001
ISS	9-15 (serious)	Referent		
	16-24 (severe)	2.97	0.94-9.38	0.063
	≥25 (very severe)	6.50	1.88-22.48	0.003
HAIS	3 (serious)	Referent		
	4 (severe)	1.26	0.71-2.25	0.426
	5-6 (critical/fatal)	3.38	1.70-6.72	0.001
TBI Injury Pattern	Isolated TBI (iTBI)	Referent		
	Multisystem TBI (TBI+)	1.92	1.28-2.86	0.001
Mechanism of Injury	Bike	Referent		
	Fall	1.26	0.21-7.58	0.804
	Gun Shot Wound	1.95	0.36-10.46	0.437
	Motor Vehicle Collision	3.93	0.56-27.61	0.168
	Other[†]	1.33	0.25-7.15	0.737
	Pedestrian	1.12	0.20-6.33	0.895
	Stab	2.34	0.43-12.78	0.325
Admission source	Arrived from referring hospital	Referent		
	Direct from scene	0.43	0.33-0.57	<0.0001
TTA	No	Referent		
	Yes	1.45	0.92-2.30	0.111
Physician service	General Surgery/Trauma	Referent		

	Neurosurgery	0.75	0.53-1.07	0.114
	Other[††]	0.18	0.37-1.77	0.601
Surgery	No	Referent		
	Yes	5.16	1.64-2.86	<0.0001
Hospital Complications	No	Referent		
	Yes	1.01	0.77-1.33	0.929

Note: TBI=traumatic brain injury; GCS=Glasgow Coma Score; ISS=Injury Severity Score; mHAIS=maximum head Abbreviated Injury Scale score

[†]Recreational other; home or industrial other; legal intervention; assault; unspecified

[††]Medical services: Internal medicine, cardiology, nephrology, respirology, psychiatry, physiatry, geriatrics; Surgical services: Orthopedic, plastics, cardiovascular, urology, otolaryngology, ophthalmology, vascular

3.5 Discussion

The current study was designed to assess the impact of different factors related to individual patients and the care that they receive upon mortality. In agreement with our initial hypotheses, we found significant associations between mortality and age, severity of injury and TBI+ presentation. We also found associations with comorbid presentation, surgical management, and with delay to definitive care. We did not find any statistically significant differences in mortality risk related to gender, mechanism of injury, admitting physician service or the presence of in-hospital complications.

Our major finding will be discussed below. The background factors possibly associated with the increased mortality seen in the elderly will then be discussed.

Major Findings

Age: Our first major finding was that age was strongly associated with increased mortality in our cohort, although gender was not. The increase in mortality with age was particularly pronounced in the TBI+ population.

Our findings related to age and mortality are in agreement with the findings of many past studies. Compared with younger patients, those who are elderly consistently experience worse outcomes, following trauma, including disability and mortality, slower recovery, and increased needs for health care related to comorbidities and reduced long-term functioning (R. Gardner et al., 2018).

In terms of mortality specifically related to TBI, several studies have identified increased age as a factor related to mortality following TBI (Mosenthal et al., 2002; Utomo, Gabbe, Simpson, & Cameron, 2009). In our own previous study (Chapter 2), we also found that older aged adults had nearly two times the risk of dying as compared to those aged ≤64 years (OR:1.9, CI =1.5-2.3).

Even after 65, increasing age in an important factor. In the present this study, risk stratification by decile increments of older age was associated with increasing odds of fatal outcome. Compared to the younger adults, mortality was lowest in the 65-74 years group at 15%, 18% among those aged 75-84 years, and 25% amongst the oldest age group more (≥85 years). Those rates corresponded to 2.5, 3.6, and six-fold increases in mortality risk, respectively.

Once again, our findings are in-line with previously reported studies demonstrating the influence of advancing age and mortality among older aged adults. A meta-analysis has reported increased mortality among adults ≥75 (OR: 1.7 (CI = 1.3-2.3)) when compared with the 65–74 age group (McIntyre et al., 2013). A second study found that those over 75 years old had nearly three times the risk of dying as those between the ages of 65-74 years old when they experienced a TBI (Utomo et al., 2009).

Severity of TBI: Our second major finding was that patients with more severe TBIs were more likely to die than patients with less severe TBIs – a result that is hardly surprising. As reported in Chapter 2, older iTBI patients had significantly more severe injuries, as measured by ISS and HAIS. Similar to Schoenberg et al., our analysis yielded increased odds for a fatal course by a factor of 6 with high ISS (>25), and by a factor of 3 with critical HAIS score (≥5) (Schoeneberg et al., 2014). Previous studies have likewise reported comparable associations on these measures among elderly TBI patients (T. S. Richmond et al., 2002; M. Taylor et al., 2002). Advancing age, particularly in the geriatric population, is itself associated with higher mortality following TBI, as we and others have demonstrated (McIntyre et al., 2013; Utomo et al., 2009). Fu et al. showed that increasing age, comorbidities, and injury severity were independent predictors of mortality (W. W. Fu et al., 2017). Thus in our analysis, severity of injury is a probable factor in the increased mortality seen in the elderly.

Type of TBI: Moreover, we found that patients with TBI+ were significantly more likely to die than patients with isolated TBI. The occurrence of polytrauma versus monotrauma creates significant challenges due to the potential for combined and synergistic pathophysiology between different systems, putting TBI+ patients at greater risk of adverse outcomes (McDonald et al., 2016; Watanabe et al., 2018).

Since cause of death was not part of the data collected for the present study, we cannot tell whether these TBI+ deaths were related to TBI itself or to the other injuries incurred. What is clear, however, is that TBI+ patients are about twice as likely to die as patients with iTBI. The cause of death of TBI+ patients might be a topic for a future study.

Comorbidities: We found a significant association between comorbidities and mortality. Patients with 0-3 comorbidities were significantly less likely to die than patients with 4-6 or 7+ comorbidities. Yet again, this finding is in agreement with past reports. One published study exploring nationwide trends in in-hospital mortality following TBI found that patients with five or more comorbid diseases were more than five times as likely to die compared with those without comorbidities (T.S Fu et al., 2015).

Furthermore, in agreement with our findings in Chapter 2, research has consistently reported that there are more pre-existing comorbidities among elderly TBI patients. This, in turn, has been seen as a factor in their increased mortality (W. W. Fu et al., 2017; Hawley et al., 2017; Røe, Skandsen, Manskow, Ader, & Anke, 2015; Schiraldi et al., 2015) (L. J. Scheetz, 2018; Selassie, McCarthy, Ferguson, Tian, & Langlois, 2005) (R. Haring et al., 2015). Pre-existing diseases which predicted greater mortality among the elderly, post-TBI, have been reported to be cancer, kidney disease, liver disease, heart and lung disease, dementia, and a history of antithrombotic therapy (McIntyre et al., 2013). (Kirshenbom et al., 2017b). Unfortunately, we did not evaluate mortality risk based on specific comorbid condition. Future research might assess the question of exactly why comorbidities increase the risk of death following a TBI and which pre-existing health conditions exacerbate a fatal course in this age group.

Surgery: The present study found a significant association between surgery and mortality. This is presumably related to the fact that patients with more severe injuries are more likely to require surgical intervention. Surgical management of severe TBI, with or without severe polytrauma presentation increases mortality risk, particularly among the elderly (Baucher et al., 2019; Gan, Lim, & Ng, 2004; Kinoshita et al., 2016; Petridis et al., 2009).

It should be noted that the present data do not indicate whether these deaths were associated with brain surgery or other surgery. That might be a topic for future studies.

Delayed Definitive Care: In our assessment, we found that mortality was significantly higher in patients referred from other hospitals than in patients referred directly from the scene of trauma. This may reflect the fact that patients referred directly from the scene get more immediate aggressive care at a TC than patients admitted to lower-level care centres (American College of Surgeons, 2014). Previous studies have demonstrated increased mortality among patients who experience a delay to definitive care (Rogers et al., 2013).

It may also reflect the fact that our sample had a predominance of elderly iTBI patients (75%, Chapter 2). In elderly iTBI patients, the seriousness of their injury is often underestimated due to the blunted nature of their response to TBI (A. Kehoe, Rennie, et al., 2015; A. Kehoe et al., 2016). This results in undertriage and a delay to TC care (Pélieu, Kull, & Walder, 2019).

As reported in Chapter 2, older TBI patients tended to be under-triaged, from the scene and also to receive less aggressive care – and less TTA, ICU management, ICP placement, and mechanical ventilation.

Under-triage, among both TBI patients overall and elderly patients, has also been reported in the past literature (Xiang, Wheeler, Groner, Shi, & Haley, 2014). Studies have shown that elderly patients are more likely to be under-triaged and less likely to be assigned an emergency triage category (M. Faul et al., 2010; Lehmann, Beekley, Casey, Salim, & Martin, 2009; Lukin et al., 2015). A 2018 study by Benjamin et al., for instance, found that the importance of age and the presence of comorbidities were often underestimated and that therefore older patients were under-triaged (Benjamin et al., 2018).

Similarly, elderly patients are often treated less aggressively. Studies have shown that elderly patients are not only more likely to be under-triaged, but that they are likely to receive less treatment (M. Faul et al., 2010; Lehmann et al., 2009; Lukin et al., 2015). As discussed in Chapter 2, we also found that older patients received significantly fewer clinical interventions in both TBI groups, including less ICP monitoring and lower rates of mechanical ventilation.

The increased mortality risk found among the older age groups suggests the need for improved care – with better triage and treatment - for this TBI population. Given that previous research demonstrates improved outcomes among older trauma patients when they receive aggressive care regimens and early intervention (Sampalis et al., 2009; Schönenberger et al., 2012), it appears that further efforts should be made to implement better care for older TBI patients.

Complications: An unexpected finding was that we found no significant link between in-hospital complications and mortality. There is a body of evidence suggesting a link between in-hospital complications and the incidence of late mortality - particularly in elderly trauma patients (Schönenberger et al., 2012). No such link was found, however, in the present study.

Although in-hospital complications were not found to be a determinant of mortality in this study, the existing literature does provide a compelling rationale to warrant further investigation of this covariate. For example, in the elderly TBI patient, medical complications can arise from concurrent injuries, co-morbidities, frailty, previous trauma, adverse effects of polypharmacy, immobility, and nosocomial infections (Adams et al., 2012; Jacobs et al., 2003; L. J. Scheetz, 2018). The relation between these factors and mortality is complex, and a fuller understanding of the contribution of each factor is needed to develop a better predictive model for TBI outcomes in older people.

Factors Related to Increased Mortality in the Elderly

Both physiological factors and factors related to health care may relate to the increased mortality seen in aged TBI patients.

Limited Physiological Reserve and Pathological Conditions: The question of how age relates to mortality may be addressed by how an individual ages. As an individual ages, physiological changes occur and pathological conditions develop. In terms of reserve, ageing brings with it progressive changes in musculoskeletal and integumentary structure, alterations of metabolic and haemodynamic rates, cerebral atrophy, cognitive decline, reduced sensory and proprioceptive functioning, and reduced kidney, immune and pulmonary performance (Jacobs et al., 2003; Stein et al., 2018; Tremblay et al., 2019).

In terms of pathology, pathological conditions more likely with age include heart and kidney disease, cancer, diabetes, and pulmonary dysfunction. Nearly 12% of people aged ≥65 years experiencing two or more comorbid conditions concurrently (Seno et al., 2019) (Public Health Agency of Canada (PHAC), 2016), and these may contribute to mortality.

The combination of physiological ageing and pathological conditions is understood to exacerbate the risk of mortality among older adults post-TBI (Krishnamoorthy, Distelhorst, Vavilala, & Thompson, 2015). Further, because of these vulnerabilities, older adults sustaining TBI experience a greater number of medical complications compared to younger individuals (Adams et al., 2012). Scheetz et al. found that 23% of all geriatric TBI admissions to TC experienced one or more in-hospital complication with the most prevalent complications carrying high mortality risk (L. J. Scheetz, 2018). The additional stress from post-traumatic complications may limit the ability of the elderly patient to withstand and recover from serious TBI.

Less Aggressive Care: Another possible factor in mortality in elderly TBI patients may be that the elderly receive less aggressive acute care. It has also been reported in the past literature that elderly patients are not only more likely to be under-triaged, but that they are likely to receive less in-hospital treatment (M. Faul et al., 2010; Lehmann et al., 2009; Lukin et al., 2015).

This was not investigated in the present chapter, but it was investigated in Chapter 2 where we found that older patients were more likely to be undertriaged, and to receive less TTA, ICU management, ICP placement, and mechanical ventilation.

The increased mortality risk found among the older age groups suggests the need for improved care – with better triage and treatment - for this TBI population. Given that previous research demonstrates improved outcomes among older trauma patients when they receive aggressive care regimens and early intervention (Sampalis et al., 2009; Schönenberger et al., 2012), it appears that further efforts should be made to implement better care for older TBI patients.

3.6 Limitations of the Present Study

The results of the present study must be interpreted in light of its limitations. The analyses undertaken in the present report were based on the retrospective collection of data from an administrative database at a single institution. Also, data were not available for those patients dying before admission to the TC or after discharge. Future studies might be done at multiple centres, and might include data on preadmission and post-discharge mortality.

3.7 General Conclusions

We have found key differences in mortality among our TBI cohort based upon demographic factors as well as clinical measures of health care provision. Among the possible contributors to the increased mortality seen in elders are the facts that older TBI patients tend to be under-triaged and also to receive less aggressive care. While there is not much that can be done to improve comorbidities, severity of injury or physiological reserve in the elderly, the problems of under-triage and under treatment must be addressed.

The improvement in outcomes found among this patient population when services such as surgery are provided suggests that improvements in the mortality outcome might be possible with increased provision of acute care and recovery services.

3.8 Appendix to Chapter 3

3.8.1 Demographic Characteristics of the Study Sample

Appendix 3-1. In total, 2,883 participants were included in our study sample. Appendix 3-1 presents the demographic characteristics of the study patients.

Appendix 3-1. Descriptive Characteristics of Study Sample

	Total	%	TBI+	%	iTBI	%
Patients, n (%)	2,883	100	714	25	2,169	75
Age, mean (SD)	57.6 (21.8)	.	47.6 (20.4)	.	60.9 (21.3)	.
Male, n (%)	2050	71	509	71	1,541	71
Female, n (%)	833	29	205	29	628	29
Comorbidity, n (%)	1720	60	324	45	1,396	64
No. of comorbidities, mean (SD)	1.8 (2.1)	.	1.2 (1.9)	.	2.0 (2.2)	.
Admitting GCS, mean (SD)	10.9 (4.7)	.	9.0 (5.2)	.	11.6 (4.4)	.
ISS, mean (SD)	24.8 (9)	.	33.6 (11.2)	.	21.9 (5.7)	.
Mechanism of Injury, n (%)						
Fall	1,684	58	218	31	1,466	68
Motor Vehicle Collision	433	15	268	38	165	8
Pedestrian trauma	263	9	121	17	142	7
Bicycle	130	4	39	5	91	4
Gun Shot Wound	30	1	6	1	24	1
Stab	20	1	9	1	11	1
Other[†]	323	11	53	7	270	12
Discharge Disposition, n (%)						
Home	872	30	112	16	760	35
Home with support[a]	236	8	36	5	200	9
Inpatient rehabilitation[b]	707	24	260	36	447	21
Another acute care facility	537	19	113	16	424	20

Chronic care centre	22	1	13	2	9	0.4
Other[c]	49	2	8	1	41	2
Overall Mortality, n (%)	460	16	172	24	288	13
Readmissions, n (%)	101	4	18	3	83	4

Note: TBI+ = Multisystem Traumatic Brain Injury (TBI); iTBI = Isolated TBI; GCS = Glasgow Coma Scale score; ISS = Injury Severity Score
[†]Recreational other; home or industrial other; legal intervention; assault; unspecified
[a]Home with support or nursing home facility
[b]General and special rehabilitation facilities
[c]Left against medical advice; unspecified alive; police custody; psychiatric facility; homeless shelter

Within this cohort, 714 were diagnosed as having a multi-system TBI+ (25%), while 2,169 had an isolated iTBI (75%). The majority of participants were men (71%) and the mean age was 57.6 (SD: 21.8) years. Those who experienced a TBI+ had a mean age of 47.6 (±SD: 20.4) years, while the iTBI cohort had a mean age of 60.9 (±SD: 21.3) years. Sixty percent of participants were living with a comorbidity at the time of their TBI; 45% of those with a TBI+ and 64% of those with an iTBI – the mean number of comorbidities was 1.7 (±SD: 2.1). Mean GCS was 10.9 (±SD: 4.7) in the sample overall, 9 (±SD: 5.2) in the TBI+ and 11.6 (±SD: 4.4) in the iTBI cohorts, respectively. ISS was 24.7 overall, 33.6 (SD: 11.2) for the TBI+ and 21.8 (SD: 5.7) for the iTBI cohorts.

3.8.2 Mechanism of Injury

Overall, falls were the main mechanism of injury (58%). They were by far the major mechanism among the iTBI group (68%), but MVCs were the main cause among the TBI+ group (38%), followed by falls 31%).

3.8.3 Discharge Disposition

When patients were discharged, we found that the majority were discharged to either home (30%), inpatient rehabilitation (IR) (25%) or another acute facility (19%). Discharge differed when results were stratified by TBI type. TBI+ patients were more likely to be discharged to IR compared with those who experienced an iTBI (36% and 21%, respectively). iTBI patients were more likely to be discharged to their home (35% compared with 16% among TBI+ patients). Rates of readmission were low overall (3-4%) among both TBI types.

3.8.4 Hospital Course

Appendix 3-2. Hospital course and resource utilization characteristics are reported in Appendix 3-2. Over half of our participants were admitted via a referring hospital. TTA occurred among 47% of the overall sample. TTA occurred in 91% of those with a TBI+ and in 32% of those with an iTBI. Neurosurgery was the primary admitting service for more than half of the participants, the majority of which were diagnosed with iTBI. Approximately two-thirds received surgical management and/or received care in the ICU (58% overall, 85% among TBI+ and 50% among iTBI patients, respectively). In terms of invasive monitoring, 44% of the patients in the sample were intubated while only a small percentage had ICP placement. ALC designation occurred in a minority of our sample. LOS was found to be longer among the TBI+ cohort (20.9, ±SD: 26.2) compared with those who experienced an iTBI (10.5, ±SD: 18.5).

Appendix 3-2. Hospital Course and Resource Utilization

n	**Total** 2883	**%**	**TBI+** 714	**%**	**iTBI** 2,169	**%**
Admission source, n (%)						
Arrived from referring hospital	1,623	56	346	49	1,277	59
Direct from scene	1,260	44	368	52	892	41
Physician Service, n (%)						
Trauma Team Activation, n (%)	1,342	47	651	91	691	32
Neurosurgery	1,599	55	91	13	1,508	70
General Surgery/Trauma	1,117	39	585	82	532	25
Other[††]	114	4	18	2	96	4
Patients not admitted, n (%)	53	2	20	3	33	2
Treatment Received						
Surgical management	1,640	57	436	61	1,204	56
Intensive care unit	1,686	58	605	85	1,081	50
Mechanical ventilation	1,281	44	526	74	755	35
Intracranial pressure monitoring	407	14	136	19	271	13

Alternative level of care	421	15	143	20	278	13
Length of Stay, mean (SD)	13.1 (21.1)	.	20.9 (26.0)	.	10.5 (18.5)	.

Note: TBI+ = Multisystem Traumatic Brain Injury (TBI); iTBI = Isolated TBI; GCS = Glasgow Coma Scale score; ISS = Injury Severity Score

[††]Medical services: Internal medicine, cardiology, nephrology, respirology, psychiatry, physiatry, geriatrics; Surgical services: Orthopedic, plastics, cardiovascular, urology, otolaryngology, ophthalmology, vascular

Chapter 4
Determinants of Hospital Length of Stay and Associated Costs in Geriatric Traumatic Brain Injury Patients

4 Determinants of Hospital Length of Stay and Associated Costs in Geriatric Traumatic Brain Injury Patients

4.1 Abstract

The incidence of geriatric traumatic brain injury (TBI) is increasing, resulting in this patient population's greater demands on acute care resources. Consequently, health care systems need to evaluate the quality and efficiency of acute care service provisions for the geriatric TBI population. The present study aimed to evaluate the determinants of hospital length of stay (LOS) in geriatric TBI patients, and to assess the associated costs of acute care medical treatment.

A retrospective cohort study was done using data from 1023 geriatric patients (≥65 yrs.) admitted with TBI between 2008 and 2016 at a Level I trauma centre (TC). Determinants of hospital LOS were identified using multilevel linear regression. LOS was evaluated by: 1) TBI sub-type (isolated TBI or "iTBI" and TBI with extracranial concomitant traumatic injury or "TBI+"); 2) level of hospital care; and 3) use of physician services. Hospital costs were investigated among a sub-sample of the cohort from whom complete cost data were available (n=458).

It was found that the geometric mean (GM) total LOS was 6.4 days (95% CI: 6.3- 6.6), with intensive care unit (ICU admissions) and alternate level of care (ALC) designated patients accounting for 23%and 13% of total hospital days. The six most influential determinants of acute care hospital LOS were discharge destination, hospital acquired complications, ICU management, GTCS exposure, physician service, and TBI+ diagnosis.

Patients with a TBI+ presentation accounted for 20% of all hospital bed-days and 23% of all hospital expenditures, despite their being only 10% of the entire cohort. Total, ICU and ALC LOS for patients presenting with TBI+ were 9.4, 2.1, and 2.8 days longer than for iTBI admissions.

The mean acute care hospital cost for patients in the cohort was $20,148 CAN (SD: $32,800). It varied by TBI presentation, ranging from an average of $46,665 CAN (SD: $43,340) for patients with TBI+ to $17,187 CAN (SD: $29,983) for those with iTBI. Hospital cost per patient/day was $1,944 and $1,616, for TBI+ and iTBI, respectively.

The results of this study suggest that the acute care health burden of geriatric TBI is skewed by a primary diagnosis of TBI+ despite this injury's relatively small representation among all geriatric TBI admissions.

4.2 Introduction

TBI a Major Public Health Concern: TBI is a major public health concern (C. Iaccarino, A. Carretta, F. Nicolosi, & C. Morselli, 2018), with global estimates suggesting 69 million individuals each year experience this neurological disorder (Dewan et al., 2019). TBI is considered a leading cause of trauma-related mortality and morbidity, associated with nearly half of all trauma deaths (World Health Organization, 2006). In the United States, approximately 2.8 million individuals are treated for a TBI each year (C. A. Taylor et al., 2017), resulting in 275,000 hospitalizations, 52,000 deaths (Kisser et al., 2017), and generating USD$21.4 billion in medical charges among admitted patients (Marin, Weaver, & Mannix, 2017). In Canada, 25,000 hospitalizations and 10,000 deaths yearly result from a TBI (T.S Fu et al., 2015).

TBI survivors have long-lasting impairments and their post-discharge care also requires significant health care resources (Cameron et al., 2008). Lifetime direct costs of TBI associated with medical care and lost productivity has been estimated at approximately CND$750 million (Terence S. Fu, Jing, McFaull, et al., 2016). First year, acute care hospitalization costs accounts for 30%-60% of the overall financial burden (Chen et al., 2012; Terence S. Fu, Jing, McFaull, et al., 2016).

TBI in the Elderly: The health-related burden of TBI is particularly urgent considering the burgeoning geriatric population (defined as those ≥65 years of age). Compared to younger age groups, those of geriatric status have the highest and fastest growing rates of TBI-related hospitalizations and deaths (Colantonio et al., 2010; M. Faul et al., 2010). Some evidence suggests that TBI-related hospital encounters among geriatric individuals are increasing at a rate that exceeds population growth projections (C. A. Taylor et al., 2017). Studies investigating Canadian population trends for TBI associated hospitalizations, have reported disproportionate numbers of geriatric admissions (38%) (T.S Fu et al., 2015) and subsequent fatalities (49%), despite this age groups' relatively small representation (14%) in the population (Terence S. Fu, Jing, McFaull, et al., 2016). Similarly, in the U.S., geriatric patients are reported to account for 31% of all TBI-related hospitalizations and 27% of the total number of deaths caused by a TBI (R. Gardner et al., 2018).

When those within the geriatric population experience a TBI, they tend to sustain more severe head injuries, are at increased risk for acquiring in-hospital complications, are thought to have longer LOS, and are more likely to be discharged to lower level of care facilities if they survive to discharge, compared to younger adults (Dams-O'Connor et al., 2013). Even within discreet, geriatric-age stratums, advancing age is associated with increased risk for poor in-hospital and post-acute health outcomes (Dams-O'Connor et al., 2013; R. Haring et al., 2015).

Contributing factors to these worse outcomes appear to relate to advanced age-associated decline in physiologic reserve resulting in diminished capacity to withstand and recover from serious trauma (H. J. Thompson et al., 2006), preexisting comorbidities (Kumar et al., 2018) and accompanying increased rates of polypharmacy (Wang et al., 2018), and frailty (Benjamin et al., 2018). These unique medical complexities pose additional challenges to health care teams, often requiring additional hospital resources to meet the health care needs of this cohort of trauma patients (W. Fallon et al., 2006).

Health Care Costs Related to TBI: Cost estimates for the treatment of TBI-associated geriatric hospital admissions are limited by both the paucity of studies in this age cohort and by the variable methodology among those studies reporting available data (van Dijck et al., 2019). Nonetheless, contemporary reports estimate the lifetime cost for treating a TBI among hospitalized geriatric patients in Canada at approximately CND$145 million per patient, with 52% (CND$49,419 million) attributed to acute medical care costs (Terence S. Fu, Jing, McFaull, et al., 2016). Among geriatric TBI patients admitted to trauma centers, per patient in-hospital cost is estimated at USD$36,075 (Albrecht et al., 2017).

LOS: LOS is a primary determinant of acute care hospitalization costs associated with TBI (van Dijck et al., 2019), and prolonged acute care stays are associated with geriatric status (Cameron et al., 2008; Tardif et al., 2016). However we have limited insight into component resource use, or the intensity of those components, among geriatric TBI admissions.

Given that current and projected TBI admissions are disproportionately represented by geriatric-aged patients (R. Gardner et al., 2018; C. A. Taylor et al., 2017), it is becoming increasingly necessary to develop an understanding of the trauma care experienced by this cohort. While the provision of evidence-based health care programs and protocols, within the trauma setting, have been shown to improve outcomes for geriatric patients in general (Calland et al., 2012; Frederickson, Renner, Swegle, & Sahr, 2013), there is less evidence related to their impact within the TBI sub-population.

Objectives and Hypotheses: The overall aim of this study was to assess the determinants and costs of hospital LOS among geriatric TBI survivors admitted to a Level I TC. The specific objectives were: 1) to identify the major factors associated with LOS in this population; and 2) to describe the costs associated with in-hospital care among a sub-sample of admitted patients.

The first objective was pursued using data from 1023 geriatric patients (≥65 yrs.) admitted with TBI between 2008 and 2016 to Saint Michael's Hospital in Toronto. These patients are the same elderly patients surveyed in Chapter 2, except that study inclusion was limited to those patients with hospital admission of ≥1 day and surviving to discharge.

The second objective was pursued using data from a smaller cohort of 458 of these patients for whom full costing data were available.

4.3 Methods

4.3.1 Study Design and Population

This retrospective cohort study was based on patient data collected from St. Michael’s Hospital in Toronto, Canada. St. Michael’s Hospital is a designated Level I adult TC for the greater Toronto region and services over 77,000 emergency room visits and 25,000 inpatient stays annually. All geriatric-aged (≥65 years) patients admitted for serious TBI (identified by HAIS ≥3), recording hospital LOS ≥1 day, and who were discharged alive, between 2008 and 2016 were included in the study. TBI was identified by ICD-10 injury codes according to the methods of Fu et al. (W. W. Fu et al., 2017).

This study was approved by the Research Ethics Board of St. Michael’s Hospital.

4.3.2 Study Data

Patient data were drawn from the St. Michael’s Hospital Trauma Registry. This registry systematically collects and tracks demographic, injury, and clinical outcomes data for all patients presenting with an ISS of ≥12 in accordance with Ontario Ministry of Health and Long-Term Care mandated set of inclusion criteria (Canadian Institutes of Health Information, 2014). Data are coded according to the ACS National Trauma Data Bank's National Trauma Data Standard dictionary (American College of Surgeons: Committee on Trauma, 2016) and the Ontario Trauma Registry Comprehensive Data Set (Canadian Institutes of Health Information, 2014). The accuracy and reliability of the hospital's registry data collection are ensured by frequent internal and routine external quality control standards.

Cost data were collected from the St. Michael's Hospital Decision Support department's activity-based costing system for fiscal years 2013 through March 2016. The hospital uses standardized case-costing methodology developed by the Ontario Case Costing Initiative which is based on the Canadian Institute for Health Information's Management Information Systems guidelines (Canadian Institute for Health Information). This method accounts for an individual patient's resource intensity weight and case-mix group, as well as fixed and indirect costs to the hospital based on the patient's location of care and LOS, but does not include fee-for-service physician billing costs (W. Wodchis et al., 2013). Total hospital costs included: 1) direct costs associated with staffing (nursing, pharmacy, allied health), ward designation (general, ICU, ALC), imaging, labs, drugs, and other consumable goods (including food); and 2) indirect costs associated with food services, housekeeping, materials management, administration, and patient transport. All costs were standardized to 2016 Canadian dollars using the Health Care Index of the Consumer Price Index (Statistics Canada, Available at: https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=1810000501. (Accessed 2019, Nov. 28)).

Clinical and cost data were linked by corresponding unique-identifying hospital encounter numbers. Alternate level of care (ALC) is a designation for patients no longer requiring acute care management who are awaiting transfer to a lower-level care facility while continuing to occupy an acute care bed.

4.3.3 Length of Stay Determinants Chosen

The current study considered key demographic, injury, hospital course, and outcome factors previously reported to be related to hospital LOS among the adult TBI population (Cameron et al., 2008; Tardif et al., 2016). In agreement with the study advisory committee, the following variables were selected: age, gender, number of pre-existing health conditions, admitting GCS, ISS, HAIS, TBI by sub-type (classified by the presence or absence of multisystem concomitant extracranial injury), MOI, hospital entry source (direct from scene of trauma or referral from lower-level care facility), initiation TTA, admitting physician service, GTCS, surgical intervention, ICU management, invasive mechanical ventilation requirement (MV), ICP placement, hospital-acquired complications, discharge destination, and year of admission. Readmission, though not a determinant of LOS, was also considered.

In this study: 1) TBI in the presence (TBI+=multisystem TBI) or absence (iTBI=isolated TBI) of concomitant extracranial injury was defined by maximum AIS ≥3 or <3, respectively, in any one of the other body regions captured by the AIS coding system; 2) TTA is a multidisciplinary team that receives at-risk trauma patients in need of higher intensity investigations and interventions (St. Michael's Hospital, 2011); 3) GTCS is a mandatory referral service at St. Michael’s Hospital for all geriatric patients with a TTA or hospital admission by the trauma service; and 4) readmission was captured if the patient had an unplanned hospital stay related to the original trauma admission at St. Michael’s Hospital within 30 days of their discharge.

4.3.4 Outcomes

The primary outcome of interest was LOS, calculated as the number of hospital days between admission and discharge. Secondary outcomes were: 1) LOS according to TBI presentation and the level of hospital care (ICU, general ward, ALC physician service); and 2) total hospital costs.

4.3.5 Statistical Analyses

LOS was described and modeled by linear regression using a natural-log transformation and reported using geometric means (GM), which are understood to approximate median values (Daly & Bourke, 2000).

Employing the methods of Tardif et al. (Tardif et al., 2016), the association between patient- and treatment-level characteristics and mean LOS was described by geometric mean ratios (GMR) with 95% CI. The proportional variation in LOS explained by the statistically significant independent variables was assessed by Cohen’s f^2, a local effect size measure used in multilevel regression (Selya, Rose, Dierker, Hedeker, & Mermelstein, 2012). To evaluate the robustness of our results, analyses were repeated with LOS truncated at 95 and 40 days to reduce the impact of outliers. There were no missing data associated with either the patient- or treatment-level variables.

The sum of hospital days across all patients was used to calculate the proportional distributions of physician services and level of care received. Geometric mean hospital LOS was compared between groups of patients stratified by TBI presentation (iTBI and TBI+). Patient- and treatment-level characteristics are reported by their proportional distribution within the cohort or otherwise, when appropriate, by their mean ±SD or median and IQR.

Cost data are reported descriptively using the arithmetic mean ±SD (S. G. Thompson & Barber, 2000). Institutional adoption of standardized case-costing methodology, beginning in fiscal year 2012 (April 1, 2012 through March 31, 2013), rendered questionable the validity and reliability of pre-existing cost data (April 1, 2008-March 31, 2012). As a result, there were a large proportion of missing data which was not partial to simulation techniques designed to generate imputed datasets (Sharath, Zamani, Kougias, & Kim, 2018). Subsequently, resource use and costs were described from among a sub-sample of the cohort – those with a complete dataset.

Statistical tests were two-sided with comparisons deemed significant at $p<0.05$. All analyses were performed using Statistical Analysis System software v9.4 (SAS Institute, Cary, North Carolina).

4.4 Results

Our results are presented in two sections. Our first analysis focuses on factors related to LOS in the whole cohort (Sections 4.4.1-4.4.6). Our second analysis (Section 4.4.7-4.4.9) focuses on resource use and costs in a smaller cohort where complete cost data were available.

Note: To simplify reading, three large tables have been placed in section 4.4.10.

4.4.1 Study Population of the LOS Analysis (Cohort of 1023 Patients)

During the study period, there were 1,883 geriatric (≥65 years) trauma patients recorded in the Hospital's trauma registry, 1,265 (67.2%) of whom presented with serious TBI (HAIS ≥3). Among those, eight (<0.01%) had hospital LOS <1 day (four fatalities prior to admission and four released prior to admission), and 238 (18.8%) died after their hospital admission. As a result, 1,023 patients (80.9% of eligible patients) were included in the study cohort.

The demographics of the study cohort are presented in full in Table 4-1, which has been placed at the end of the Results section (section 4.4.10) due to its size. In brief, the mean age of the study cohort was 78 ±7.7 years (65% of the patients were ≥75 years), 62.2% were male, 84% had at least one pre-existing health condition and, among those, the mean number of comorbidities was 3.5 ±2.1. Falls were the primary MOI related to TBI admissions; 84.2% of patients experienced a fall-induced TBI. The majority of patients (79.6%) presented with mild admitting GCS scores (median: 14, IQR: 13-15), 54.4% had an ISS score of 25 (IQR: 20-25), and critical head injury (HAIS=5) was recorded in 63.4% of the patients. The predominant TBI presentation was an iTBI, with representation in 921 (90%) study patients. Ten percent of the study population (n=102) presented with TBI+ (Table 4-1).

The geometric and arithmetic means of hospital LOS for the cohort were 6.4 (95% CI: 6.3 to 6.6) and 11.7 days (95% CI: 10.5 to 13.0), respectively (Figure 4-2).

4.4.2 Determinants of Hospital LOS

Globally, determinants explained 57% (r^2) of the variation in hospital LOS based on a model including all statistically significant variables ($p<0.05$, Table 4-1). The six most important determinants of LOS were discharge destination (f^2=14.7%), in-hospital complications (11.3%), ICU (2.5%), GTCS exposure (2.2%), physician service (1.6%), and TBI+ sub-type (1.3%) (Figure 4-1).

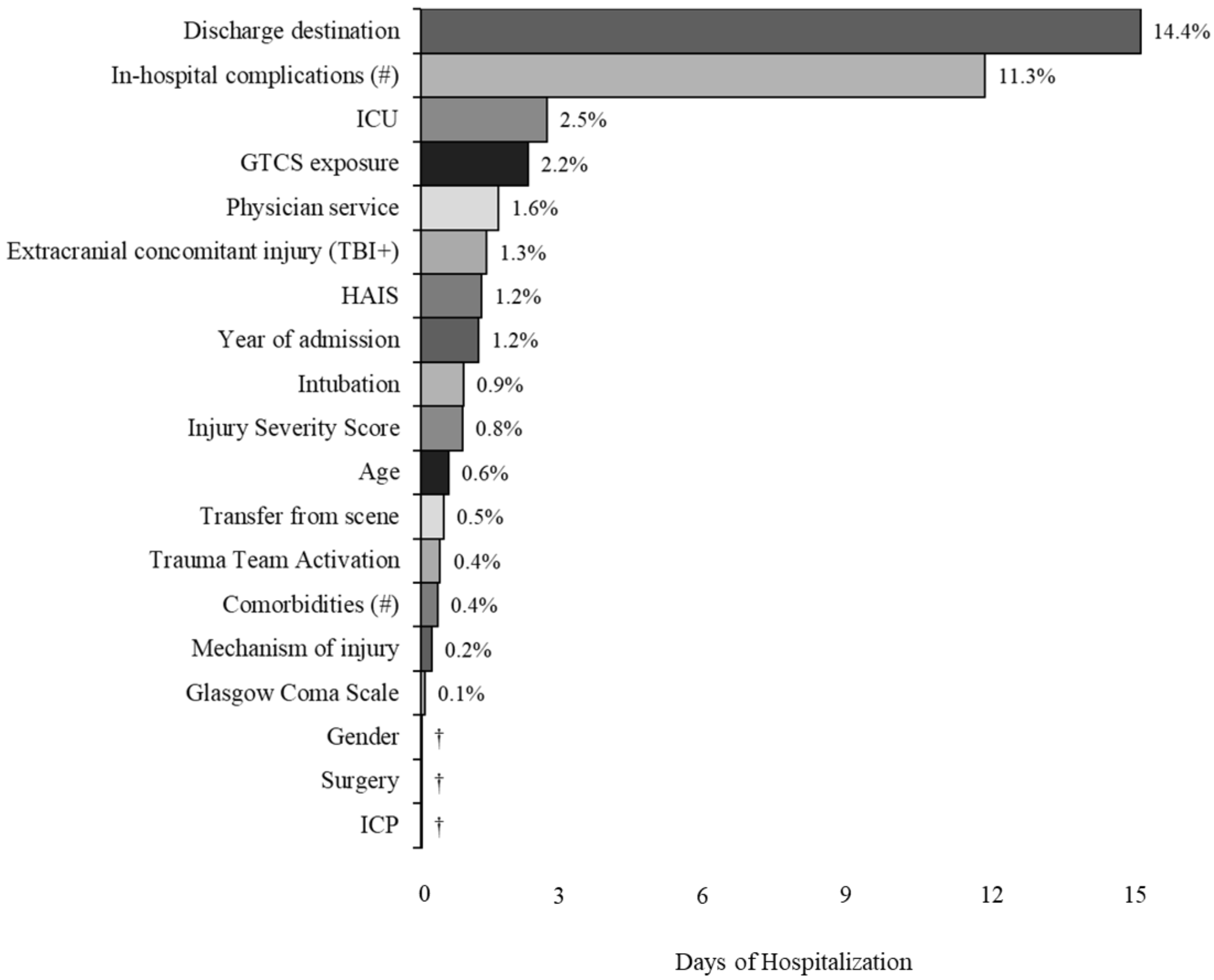


Figure 4-1. Determinants of hospital length of stay among geriatric TBI survivors.

4.4.3 Sensitivity Analyses

Sensitivity analysis, performed by truncating LOS outliers among 99% of the cohort, representing patients with LOS ≤95 days (Appendix 4-1) and 95% of the cohort, representing patients with LOS ≤40 days (Appendix 4-2), did not significantly modify the conclusions.

4.4.4 LOS and TBI Representation

In Chapter 2, it was found that TBI+ and iTBI differed in a number of significant ways. LOS was therefore assessed separately for TBI+ and iTBI patients. Figure 4-2 and Table 4-2 present data relating TBI type and LOS. Table 4-2 - which is lengthy - has been placed at the end of the Results section (section 4.4.10).

On admission, patients experiencing a TBI+ had on average more pre-existing health conditions (3.9 ±2.5 versus 3.4 ±2.0, p=0.011) and a lower mean GSC score (12.7 ±3.7 versus 13.2 ±3.2 p=0.015), compared to those experiencing iTBI. Overall injury severity was higher in TBI+ patients (28.6 ±7.2 versus 22.5 ±4.7, p<0.0001), the majority of whom, in contrast to iTBI patients, had an ISS >25 (66% versus 9%; p<0.0001, 95% CI: 2.1 to 3.8). Although head injury severity was equally distributed among the cohort as a whole, TBI+ patients suffered less critical head injury (HAIS=5) compared to those with iTBI (16% versus 69%; p=0.003, 95% CI: 0.5 to 0.8). Fall-induced TBI was associated with 88% of iTBI admissions, whereas less than 50% of TBI+ was attributed with this MOI (p<0.0001, 95% CI: 1.8 to 3.3) (Table 4-2).

Relative to LOS, an iTBI presentation constituted 80% of hospital days while TBI+ accounted for the remaining 20%. On average, however, hospital LOS was 9.4 days longer among TBI+ patients (GM LOS 15.2, 95% CI: 14.7 to 15.7) as compared to LOS among iTBI patients (GM LOS 5.8 days, 95% CI: 5.7 to 6.0). It was also 8.8 days longer than the total LOS for all patients (Figure 4-2).

Furthermore, the difference between LOS in TBI+ and iTBI patients varied across TBI presentation and HAIS categories. It increased across all levels of severity in the TBI+ patients, with HAIS 5 TBI+ patients having the longest hospital stay (Figure 4-2).

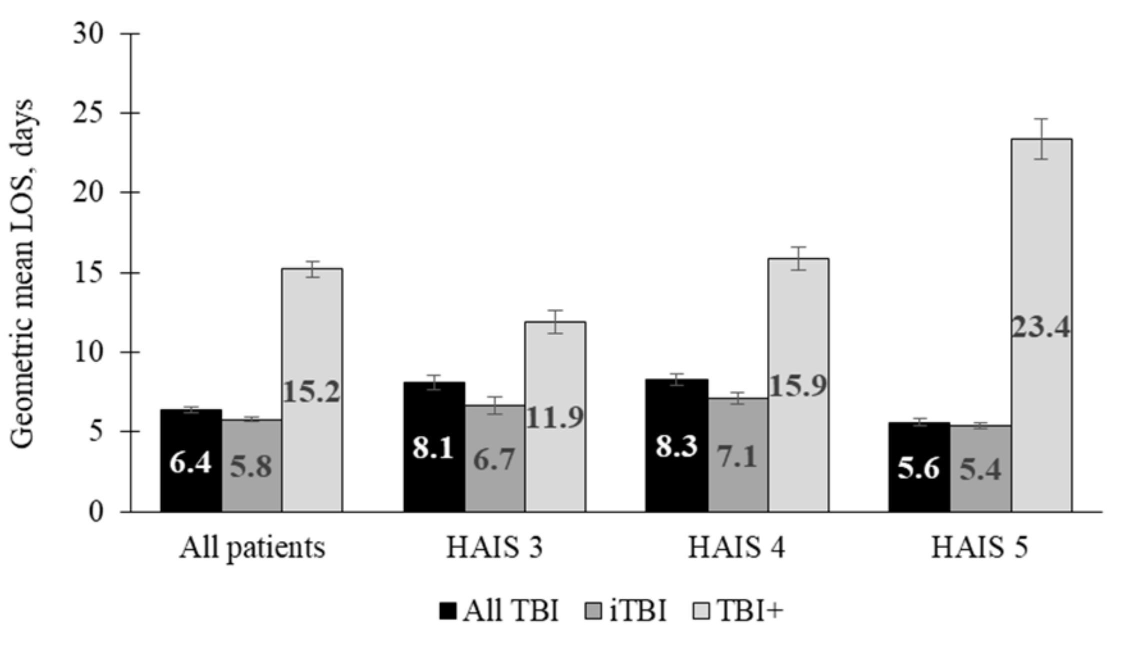


Figure 4-2 Hospital length of stay among geriatric TBI patients stratified by TBI presentation and HAIS severity.

4.4.5 LOS According to Level of Care: ICU, Ward and ALC

Among all patients, 23.2% of hospital days were in the ICU and 63.7% in a general ward and 13.1% under ALC designation (Figure 4-3 a). The geometric mean LOS in the ICU and ALC (among patients admitted to those units) were 3.8 and 3.3 days, respectively.

The proportion of ICU (GM LOS 5.5 days) and ALC days (GM LOS 5.8 days) was greater among patients with a TBI+ presentation than in the whole cohort ("all patients"). In contrast, iTBI patients had a marginal decrease in ICU (GM LOS 3.4 days) and ALC days (GM LOS 3.0 days) than in the whole cohort. Across both TBI presentations, the proportion of ICU days decreased while those attributed with ALC increased, with increasing HAIS severity (Figure 4-3 b).

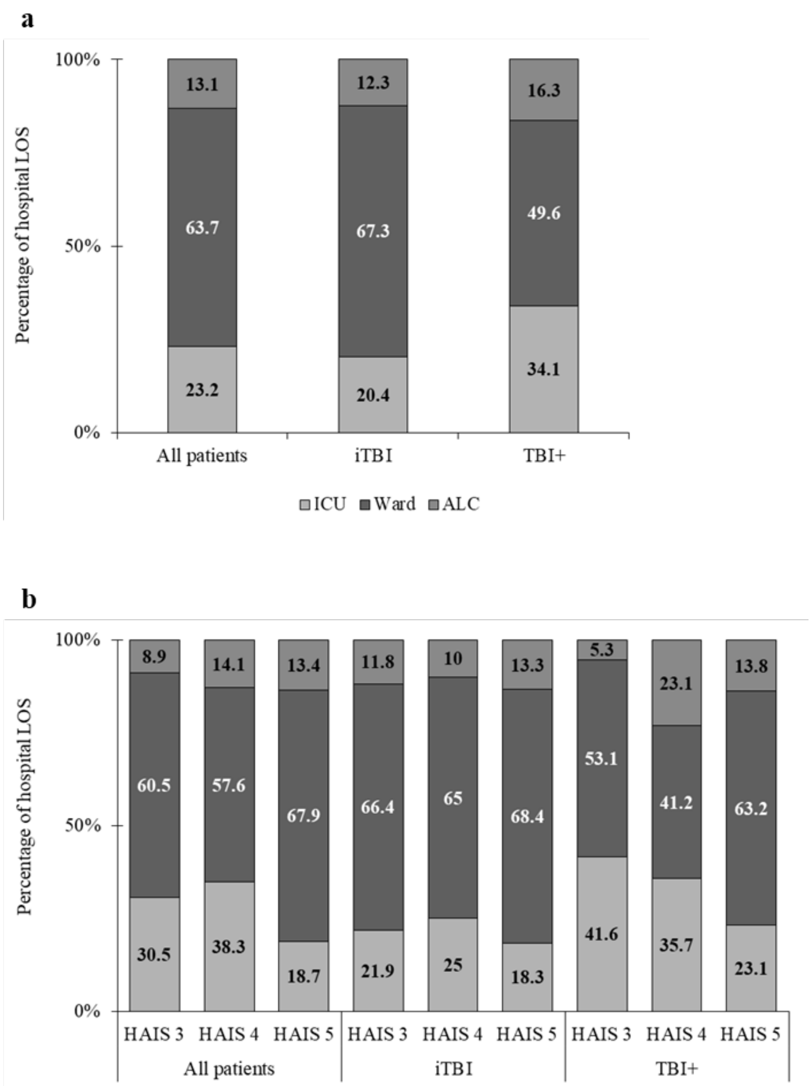


Figure 4-3. Level of in-hospital care as a proportion of length of stay stratified by a) TBI presentation and b) TBI presentation and HAIS severity.

4.4.6 LOS According to Physician Service

As indicated in Figure 4-4 (left column), in the whole cohort, Neurosurgery, General Surgery/Trauma, or another Medical specialty accounted for 61.0% (GM LOS 5.3 days, 95% CI: 5.2 to 5.5), 32.3% (GM LOS 12.4 days, 95% CI: 12.0 to 12.8), and 6.7% (GM LOS 10.6 days, 95% CI: 9.8 to 11.4) of total hospital days, respectively.

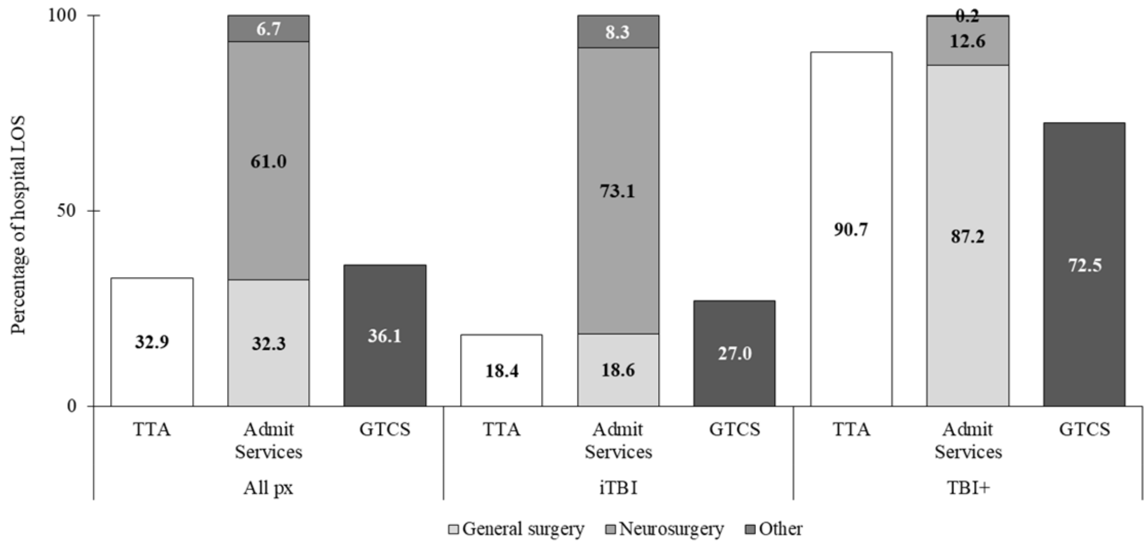


Figure 4-4 Physician services as a proportion of hospital length of stay stratified by TBI presentation.

Further assessment by TBI presentation (Figure 4-4, middle and right columns) showed how the proportion of LOS varied by TBI type and physician services management. iTBI patients spent the majority of their LOS under neurosurgical management, whereas the TBI+ patients spent the majority of their time under general surgery management. This may relate to the finding discussed in Chapter 2 that TBI+ patients are more likely to be admitted direct from the scene and enter general surgery/trauma, whereas the iTBI patients are more likely to be referred from other institutions and enter the hospital through neurosurgical service.

The proportion of total hospital days accounted for by a TTA was 32.9% (GM LOS 11.8 days, 95% CI: 11.4 to 12.2), while those from a secondary referral to GTCS accounted for 36.1% (GM LOS 12.9 days, 95% CI: 12.5 to 13.2) (Figure 4-4, left columns). Among those patients with iTBI (Figure 4-4, middle columns), the proportions of LOS accounted for by TTA (18.4%) and GTCS (27%) were substantially less than those patients with TBI+ (TTA: 90.7%; GTCS: 72.5%) (Figure 4-4, right columns).

Taken together, these findings suggest that certain heterogeneity among geriatric TBI patients informs distinct clinical care pathways that may also influence trauma care services and resource intensity.

Not surprisingly, hospital stays increased linearly with increasing HAIS severity across all physician services and TBI presentation (Figure 4-5). However, among Neurosurgical managed patient, prolonged hospital stays were observed with less severe HAIS score. This may be explained by the proportion of patients managed under Neurosurgery with TBI+. The extra trauma burden of concomitant extracranial injury, rather than HAIS severity, could require additional medical management resulting in prolonged hospital stay.

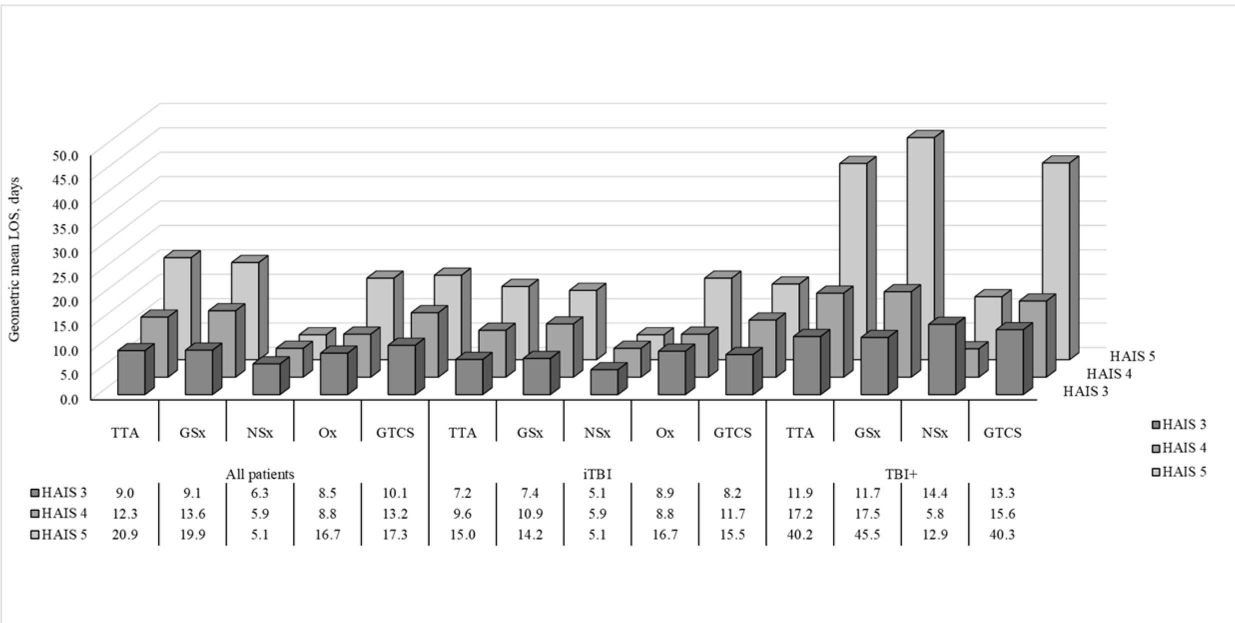


Figure 4-5. HAIS severity and length of stay stratified by TBI presentation and physician service.

4.4.7 Results Related to Resource Intensity and Hospital Costs (Cohort of 458 Patients)

Our second analysis was focused on resource intensity and hospital costs. It was done using a smaller cohort – selected from the total cohort – for whom full costing data were available.

4.4.8 Study Population for the Cost Analysis

There were 458 geriatric TBI patients with complete total hospital cost data. These data were derived from the fiscal years 2012 through 2016. This sub-sample represented 45% of the entire study population.

The demographic, injury, and hospital course characteristics of the cost sub-sample cohort, stratified by TBI presentation are listed in Table 4-3 which appears at the end of the Results section (section 4.4.10). These patients did not differ significantly from patients included in the full study in terms of age, sex, or by injury severity measured by admitting GCS or ISS and HAIS, respectively. Furthermore, TBI representation was the same in both the full and cost cohorts (90% iTBI and 10% TBI+). However, this sub-sample had, on average, less pre-existing health conditions and the proportional distributions of several hospital course characteristics differed.

The geometric mean LOS in the cost sub-sample was similarly distributed to that of the larger study population, although, patients presenting with TBI+ in the cost cohort had, on average 1.5 days longer hospital stay than those in the full cohort (GM LOS 16.8 days, 95% CI: 16.2 to 17.5 versus 15.2 days) (Table 4-3 for cost cohort, Figure 4-2 for full cohort).

Level of care according to hospital days attributed with ICU admission was 26.5% overall, and 34.1%, and 24.6% among TBI+ and iTBI presentations, respectively. The proportion of hospital LOS attributed with ALC designation was reduced in the cost sub-sample compared with the larger study cohort overall (9% versus 13%), and among patients presenting with TBI+ (8% versus 16%) or iTBI (9% versus 12%) (Table 4-4 Figure 4-4a).

Thus, despite some small differences, the sub-cohort used for the cost analysis was fairly representative of the cohort as a whole.

4.4.9 Costs and Resource Use

Data related to costs and resource use are presented in Table 4-4. The left hand column presents mean and SD (plus range) costs for the whole cohort. The middle column presents costs for the subgroup of patients admitted to the ICU and the right hand column presents costs for the subgroup of patients admitted to ALC designation. The ICU and ALC patients are included in the total admissions group, and are not independent from each other (the same patients may be in both the ICU and the ALC groups).

Table 4-4. Resource use and intensity of care among surviving geriatric TBI admissions 2012-2016

Intensity	**Resource**					
	Total admissions		**ICU admissions**		**ALC designated**	
	cost, $		**cost, $**		**cost, $**	
	n	mean (SD) Range	n	mean (SD) range	n	mean (SD) Range
All patients	458	20,148 (32,800) 1,093-322,162	183	39,825 (44,049) 1,859-322,162	76	32,876 (47,522) 3,528-252,913
Crude cost, $		*9,227,624*		*7,288,032*		*2,498,590*
Length of stay, GM (95% CI), days		*6.5 (6.2-6.7)*		*4.4 (3.9-4.8)*		*2.7 (2.0-3.5)*
Bed-days, n (% of all patient bed-days)		*5485 (100.0)*		*1456 (26.5)*		*501 (9.1)*
Per Diem cost, $		*1,682*		*5,005*		*4,987*
TBI+	46	46,665 (43,340) 2,958-201,613	41	50,635 (44,198) 3,422-201,613	14	46,024 (57,085) 9,107-201,613
Crude cost, $		*2,146,594*		*2,076,054*		*644,334*
Length of stay, GM (95% CI), days		*16.8 (16.2-17.5)*		*5.3 (4.3-6.3)*		*4.1 (2.6-5.6)*
Bed-days, n (% of all patient bed-days)		*1104 (20.1)*		*377 (34.1)**		*93 (8.4)**
Per Diem cost, $		*1,944*		*5,507*		*6,928*
iTBI	412	17,187 (29,983) 1,093-322,162	142	36,704 (43,509) 1,859-322,162	62	29,907 (44,549) 3,528-252,913
Crude cost, $		*7,081,030*		*5,211,979*		*1,854,256*
Length of stay, GM (95% CI), days		*5.8 (5.6-6.1)*		*4.1 (3.7-4.6)*		*2.5 (1.6-3.3)*
Bed-days, n (% of all patient bed-days)		*4381 (79.9)*		*1079 (24.6)***		*408 (9.3)***
Per Diem cost, $		*1,616*		*4,830*		*4,545*

*% of TBI+ cohort bed-days

**% of iTBI cohort bed-days

Per Diem = crude cost/total bed-days

Total Costs The mean cost for TBI hospitalization was $20,148 (SD $32,800) for geriatric patients overall. Costs approximately doubled among patients admitted to the ICU ($39,825, SD: $44,049) and increased by more than 60% for those patients designated to ALC ($32,876, SD: $47,522) (Table 4-4).

When the cohort was stratified along TBI type, it was found that although TBI+ represented only 10% of the entire collective, the total costs attributed to this injury presentation encompassed 23% of total hospital costs. On average, the mean total hospital costs for TBI+ patients were 2.7 times higher than the mean total costs for iTBI patients ($46,665, SD: $43,340 versus $17,187, SD: $29,983). Moreover, ICU and ALC costs were 38% and 54%, greater, respectively, among TBI+ patients compared with those presenting with iTBI.

Per Diem Costs The per diem cost of a TBI patient was $1,682, and increased approximately three-fold for patients with ICU admission to $5,005, or ALC requirements to $4,987. Among the differing TBI presentations, a TBI+ patient's per diem cost was $1,944, which was 20% greater than that incurred by an iTBI patient ($1,616). Among patients with ICU requirements, the per diem rate of $5,507 for those with TBI+ was 14% higher than the $4,830 rate for an iTBI-ICU patient. The highest per diem rate was seen among TBI+ patients with ALC requirements. This group of patients incurred a daily cost of $6,928, 52% greater than the $4,545 of those patients with iTBI and ALC requirements.

4.4.10 Results Tables 4-1, 4-2 and 4-3

Table 4-1. The left hand column presents the number of patients in each category, whereas the middle column presents differences as related to a referent group, and the right hand column presents the significance of the differences.

Table 4-1. Determinants of hospital length of stay (LOS) with adjusted geometric mean ratios (GMR) and 95% confidence intervals (CI)

Variables		**N (%)**	**GMR (95% CI)**	**p-value**
All patients		1023	.	

Patient characteristics				
Age	65-69	166 (16.2)	Referent	
	70-74	188 (18.4)	0.82 (0.68-0.99)	0.0346
	75-79	231 (22.6)	0.99 (0.83-1.18)	0.9124
	80-84	227 (22.2)	1.00 (0.84-1.21)	0.9607
	≥85	211 (20.6)	0.91 (0.75-1.10)	0.3176
Gender	Female	387 (37.8)	Referent	
	Male	636 (62.2)	0.96 (0.86-1.08)	0.5368
Number of comorbidities	0	166 (16.2)	Referent	
	1	153 (15.0)	0.97 (0.80-1.18)	0.7681
	2	176 (17.2)	0.89 (0.74-1.07)	0.2242
	3	170 (16.6)	1.05 (0.87-1.26)	0.6292
	4	131 (12.8)	1.14 (0.93-1.40)	0.1928
	≥5	227 (22.2)	1.26 (1.05-1.50)	0.0109
Mechanism of injury	Fall	861 (84.2)	Referent	
	MVA	53 (5.2)	1.05 (0.81-1.35)	0.7306
	Pedes	57 (5.6)	1.08 (0.84-1.38)	0.5575
	Other	52 (5.1)	0.93 (0.72-1.20)	0.5932
Admitting GCS	13-15 (mild)	814 (79.6)	Referent	
	9-12(moderate)	93 (9.1)	1.81 (1.50-2.19)	<0.0001
	3-8(severe)	116 (11.3)	2.13 (1.80-2.53)	<0.0001
ISS	<25	317 (31.0)	Referent	
	25	556 (54.4)	0.48 (0.33-0.71)	0.0002
	>25	150 (14.7)	0.88 (0.61-1.28)	0.5061
HAIS	3	114 (11.14)	Referent	
	4	260 (25.4)	1.21 (0.98-1.49)	0.0714
	5	649 (63.4)	1.73 (1.11-2.70)	0.0152
TBI Type	Isolated TBI (iTBI)	921 (90.0)	Referent	
	Multisystem TBI (TBI+)	102 (10.0)	2.29 (1.72-3.06)	<0.0001
Hospital course characteristics				
Arrival source	Scene	290 (28.4)	Referent	
	Referring hospital	733 (71.6)	0.79 (0.7-0.88)	<0.0001
TTA	No	821 (80.2)	Referent	
	Yes	202 (19.8)	0.73(0.57-0.93)	0.0113
Physician service	Neurosurgery	788 (77.0)	Referent	
	General surgery/trauma	189 (18.5)	1.34 (1.07-1.68)	0.012
	Other	46 (4.5)	1.4 (1.11-1.76)	0.0045
GTCS	No	814 (79.6)	Referent	
	Yes	209 (20.4)	1.47 (1.27-1.7)	<.0001
Surgery	No	318 (31.1)	Referent	
	Yes	705 (68.9)	1.06 (0.94-1.2)	0.3113
ICU	No	635 (62.1)	Referent	

	Yes	388 (37.9)	1.3 (1.14-1.48)	<.0001
Intubation	No	812 (79.4)	Referent	
	Yes	211 (20.6)	1.53 (1.29-1.81)	<.0001
ICP	No	968 (94.6)	Referent	
	Yes	55 (5.4)	1.01 (0.82-1.25)	0.9243
In-hospital complications	No	815 (79.7)	Referent	
	Yes	208 (20.3)	2.07 (1.84-2.33)	<.0001
Discharge destination	Home	266 (26.0)	Referent	
	Home with support	133 (13.0)	1.52 (1.32-1.77)	<.0001
	Inpatient rehabilitation	301 (29.4)	1.98 (1.75-2.24)	<.0001
	Acute care	308 (30.1)	1.56 (1.37-1.79)	<.0001
	Chronic care	9 (0.9)	2.73 (1.72-4.33)	<.0001
	Other	6 (0.6)	0.75 (0.43-1.3)	0.3012
Year of admission	2008-2009	207 (20.2)	Referent	
	2010-2011	219 (21.4)	0.99 (0.86-1.13)	0.842
	2012-2013	282 (27.6)	0.86 (0.76-0.98)	0.0197
	2014-2015	279 (27.3)	1.05 (0.92-1.2)	0.4434
	2016-2017	36 (3.5)	1.03 (0.8-1.31)	0.8369

Note: GCS=Glasgow Coma Scale scores (range 3-15 with mild brain trauma represented by scores 13-15; moderate trauma by 9-12; and severe trauma by 3-8); ISS=Injury Severity Score (range 0-75; higher scores indicate greater global injury with scores >/=20 indicative of severe trauma); HAIS=Maximum Head Abbreviated Injury Scale score (range 1-6 with higher scores indicative of greater head and brain injury severity: HAIS >/=3 represents at least serious trauma; 4=severe; and 5=critical); iTBI=HAIS ≥3 with maximum AIS in any other body region <3; TBI+=HAIS ≥3 with AIS in any other body region ≥3; TTA=trauma team activation; GTCS= Geriatric Trauma Consultation Service; ICU=intensive care unit; ICP=intracranial pressure monitoring.

[*]Variables “age” to “TBI type” are adjusted for all other patient characteristics in the table. Variables “arrival source” to “year of admission” are adjusted for all patient and hospital course related variables.

[†]Recreational other including cycling; home or industrial accident not otherwise specified; assault including gunshot wound and stab with or without legal intervention; unspecified

[††]Medical services: Internal medicine, cardiology, nephrology, respirology, psychiatry, physiatry, geriatrics; Surgical services: Orthopedic, plastics, cardiovascular, urology, otolaryngology, ophthalmology, vascular

[a]Home with support or nursing home facility

[b]General and special rehabilitation facilities

[c]Left against medical advice; unspecified alive; police custody; psychiatric facility; homeless shelter

Table 4-2. Comparison of TBI+ Patients (left column) and iTBI patients (right column), with significances of difference.

Table 4-2. Characteristics of geriatric TBI survivors admitted between 2008-2016

	TBI+		iTBI		
Demographic characteristics	**n***	**%**	**n***	**%**	**p-value**
Patients	102	10.0	921	90.0	<0.0001
Age, mean (SD)	75.1 (7.2)	.	78.3 (7.7)	.	0.433
≥75 years	50	49.0	619	67.2	0.001
Male	62	60.8	574	62.3	0.845
Comorbidity	82	80.4	775	84.1	0.435
No. of comorbidities, mean (SD)	3.9 (2.5)	.	3.4 (2.0)	.	0.011
≥5 comorbid conditions	25	30.5	202	26.1	0.649
Injury characteristics					
Admitting GCS, mean (SD)	12.7 (3.7)	.	13.2 (3.2)	.	0.015
Mild (13-15)	77	75.5	737	80.0	0.284
Moderate (9-12)	9	8.8	84	9.1	0.919
Severe (3-8)	16	15.7	100	10.9	0.253
ISS, mean (SD)	28.6 (7.2)	.	22.5 (4.7)	.	<0.0001
<25	29	28.4	288	31.3	0.627
25	6	5.9	550	59.7	< 0.0001
>25	67	65.7	83	9.0	< 0.0001
HAIS, mean (SD)	3.8 (0.7)	.	4.6 (0.6)	.	0.183
Serious=3	38	37.3	76	8.3	< 0.0001
Severe=4	48	47.1	212	23.0	< 0.0001
Critical=5	16	15.7	633	68.7	< 0.0001
Mechanism of Injury					
Fall	50	49.0	811	88.1	< 0.0001
Motor Vehicle Collision	22	21.6	31	3.4	< 0.0001
Pedestrian trauma	21	20.6	36	3.9	< 0.0001
Other	9	8.8	43	4.7	0.212
Year of admission (fiscal year April 1-March 31)					
2008-2009	15	14.7	192	20.8	0.136
2010-2011	21	20.6	198	21.5	0.931
2012-2013	37	36.3	245	26.6	0.067
2014-2015	27	26.5	252	27.4	0.942
2016-2017	2	2.0	34	3.7	0.431
Hospital course characteristics					
Hospital entry from Scene	42	41.2	248	26.9	0.007
Hospital entry from Referral center	60	58.8	678	73.6	
TTA	86	84.3	116	12.6	<0.0001
Admitting physician service					

General Surgery/Trauma	82	80.4	107	11.6	<0.0001
Neurosurgery	19	18.6	769	83.5	
Other Medical service‡	1	1.0	45	4.9	0.005
Geriatric Trauma Consultation Service	72	70.6	137	14.9	<0.0001
Surgical intervention	55	53.9	650	70.6	0.002
ICU admission	84	82.4	304	33.0	<0.0001
Intubation	49	48.0	162	17.6	<0.0001
ICP placement	2	2.0	53	5.8	0.039
In-hospital complications	46	45.1	162	17.6	<0.0001
Alternate level of care	26	25.5	131	14.2	0.002
Readmission	4	3.9	53	5.8	0.534
Discharge Disposition					
Home	9	8.8	257	27.9	<0.0001
Home with support[a]	4	3.9	129	14.0	<0.0001
Inpatient rehabilitation[b]	58	56.9	243	26.4	<0.0001
Another acute care facility	27	26.5	281	30.5	0.45
Chronic care centre	3	2.9	6	0.7	0.303
Other[c]	1	1.0	5	0.5	1

TBI+ = Multisystem Traumatic Brain Injury (TBI)

iTBI = Isolated TBI

*unless stated otherwise

‡Medical services: Internal medicine, cardiology, nephrology, respirology, psychiatry, physiatry, geriatrics; Surgical services: Orthopedic, plastics, cardiovascular, urology, otolaryngology, ophthalmology, vascular

Table 4-3. Characteristics of Cost Cohort Geriatric TBI survivors and Comparison of TBI+ Patients (left column) and iTBI patients (right column), with significances of difference.

Table 4-3. Characteristics of geriatric TBI survivors admitted between fiscal years 2012-2016

	TBI cost cohort		**TBI+**		**iTBI**		
Demographic characteristics	**n***	**%**	**n***	**%**	**n***	**%**	**p-value**
Patients	458	100.0	46	10	412	90	<0.0001
Age, mean (SD)	77.8 (8.1)	.	75.2 (7.7)	.	78.1 (8.1)	.	0.675
≥75 years	293	64.0	22	47.8	271	65.8	0.030
Male	275	59.6	22	47.8	253	61.4	0.110
Comorbidity	333	72.7	35	76.1	298	72.3	0.702

No. of comorbidities, mean (SD)	2.9 (1.9)	.	2.9 (1.7)		2.9 (1.9)		0.437
≥5 comorbid conditions	59	12.9	5	10.9	54	13.1	0.833
Injury characteristics							
Admitting GCS, mean (SD)	13.1 (3.1)		12.8 (3.4)		13.1	3.2	0.363
Mild (13-15)	357	77.9	36	78.3	321	77.9	0.999
Moderate (9-12)	51	11.1	4	8.7	47	11.4	0.735
Severe (3-8)	50	10.9	6	13.0	44	10.7	0.824
ISS, mean (SD)	23.2 (4.8)		27.2 (6.8)		22.7 (4.4)		<0.0001
<25	142	31.0	18	39.1	124	30.1	0.3
25	251	54.8	3	6.5	248	60.2	<0.0001
>25	67	14.6	27	58.7	40	9.7	<0.0001
HAIS, mean (SD)	4.5 (0.69)		3.7 (0.7)		4.6 (0.6)		0.128
Serious=3	52	11.3	21	45.7	31	7.5	<0.0001
Severe=4	111	24.2	18	39.1	93	22.6	0.04
Critical=5	295	64.4	7	15.2	288	69.9	<0.0001
Mechanism of Injury							
Fall	388	84.7	25	54.3	363	88.1	<0.0001
Motor Vehicle Collision	22	4.8	10	21.7	12	2.9	0.004
Pedestrian trauma	26	5.7	8	17.4	18	4.4	0.037
Other	22	4.8	3	6.5	19	4.6	0.853
Year of admission (fiscal year April 1-March 31)							
2012-2013	144	31.4	17	37.0	127	30.8	0.51
2014-2015	280	61.1	27	58.7	253	61.4	0.844
2016-2017	37	8.1	2	4.3	35	8.5	0.374
Hospital course characteristics							
Arrived from Scene	117	25.5	19	41.3	98	23.8	0.031
Arrived from Referral center	341	74.5	27	58.7	314	76.2	
TTA	104	22.7	41	89.1	63	15.3	<0.0001
Admitting physician service							
General Surgery/Trauma	99	21.6	38	82.6	61	14.8	<0.0001
Neurosurgery	345	75.3	8	17.4	337	81.8	
Other Medical/Surgical service	14	3.1	0	.	14	3.4	<0.0001
Geriatric Trauma Consultation Service	118	25.8	36	78.3	82	19.9	<0.0001
Surgical intervention	312	68.1	25	54.3	287	69.7	0.066
ICU admission	183	40.0	41	89.1	142	34.5	<0.0001
Intubation	103	22.5	23	50.0	80	19.4	<0.0001
ICP placement	21	4.6	0	0.0	21	5.1	<0.0001
In-hospital complications	65	14.2	16	34.8	49	11.9	0.003

Alternate level of care	76	16.6	14	30.4	62	15.0	0.043
Readmission	11	2.4	0	0.0	11	2.7	0.066
Discharge Disposition							
Home	115	25.1	3	6.5	112	27.2	<0.0001
Home with support[a]	50	10.9	3	6.5	47	11.4	0.353
Inpatient rehabilitation[b]	143	31.2	27	58.7	116	28.2	0.041
Another acute care facility	141	30.8	11	23.9	130	31.6	0.337
Chronic care centre	5	1.1	1	2.2	4	1.0	1
Other[c]	4	0.9	1	2.2	3	0.7	0.914

TBI+ = Multisystem Traumatic Brain Injury (TBI)

iTBI = Isolated TBI

*unless stated otherwise

‡Medical services: Internal medicine, cardiology, nephrology, respirology, psychiatry, physiatry, geriatrics; Surgical services: Orthopedic, plastics, cardiovascular, urology, otolaryngology, ophthalmology, vascular

4.5 Discussion

Major Findings The present study aimed to evaluate determinants of hospital LOS in geriatric TBI patients and 2) to evaluate associated costs for their acute care medical treatment.

Relative to determinants of hospital LOS, it was found that the six most influential determinants of acute care hospital LOS were discharge destination, hospital acquired complications, ICU management, GTCS exposure, physician service, and TBI+ diagnosis.

Relative to costs, the mean cost for all geriatric TBI hospitalizations was $20,148. In agreement with our initial hypothesis, it was found that costs varied by TBI presentation, ranging from an average of $46,665 for patients with TBI+ to an average of $17,187 for those experiencing an iTBI. Although TBI+ patients represented only 10% of the population, they accounted for 20% of all hospital bed-days and 23% of all hospital expenditures, having a per diem cost of $1,944. In contrast, the per diem cost for patients experiencing iTBI was $1,616.

LOS in the Present Study This study showed that geriatric TBI patients admitted to our Level 1 TC had a shorter LOS (GM LOS 6.4 days) than those reported in previous assessments of acute care hospital stays from other Provincial Trauma Registries (GM LOS range for TBI index admissions ≥65 years = 12.7-19.8 days) (Tardif et al., 2016). Likewise, LOS was on average 3.3

days shorter than acute care stays for older TBI adults based on nationwide Canadian data (11.7 versus 15 days) (Canadian Institute for Health Information, 2006).

Acute care LOS is highly variable and is dependent upon many factors including, but not limited to, injury severity, age, geographical status, and discharge disposition. The differences in LOS that we observed relative to other jurisdictions may be partly due to the determinants identified in this study, but they are also likely influenced by the differences in the structure of injury care between provincial healthcare systems.

St. Michael's Hospital is a Lead Trauma Hospital, designated by the province of Ontario to provide specialized trauma services to the most severely injured patients and to serve as a referral center for severe head injuries. In our mature, integrated trauma system, acute care hospital resources are optimized by centralizing specialized trauma services, reserving that care for those in need, and - once those needs are met - promoting expeditious discharge to less resource-intense centers (Cadotte, Vachhrajani, & Pirouzmand, 2011).

Among our cohort, more than 25% of patients were transferred to another acute care facility upon discharge. Thus, the shorter LOS we observed may be a reflection of the Level I designated status of our center working cooperatively with lower-level care centers in our health system to improve the efficiency of specialized acute care delivery by promoting expeditious discharge to lower-level care centres.

Important Determinants of LOS in the Present Study

Although research reporting on determinants of acute care LOS among TBI patients is relatively limited, a number of patient-level and hospital course characteristics including age, gender, GCS, injury severity, ICU management, invasive ventilation, hospital-acquired complications, and discharge destination are identified as risk factors for prolonged LOS (Cameron et al., 2008; Tardif et al., 2016). The findings of the present study showed that the influence of TBI LOS determinants differs somewhat from other reports when factors are assessed among a cohort exclusively composed of geriatric status patients. Further, our findings suggest that hospital course characteristics are the most important predictors of acute care hospital LOS, and those may be influenced by the intensity of care provided by distinct clinical care pathways associated with TBI+ and iTBI presentation.

TBI+: Perhaps the most interesting finding was the contribution of TBI+ to hospital stay. The TBI+ presentation accounted for 20% of all hospital bed-days and 23% of all hospital expenditures, despite its representation in only 10% of the entire cohort. The results of this study suggest that the acute care health burden of geriatric TBI is skewed by a primary diagnosis of TBI+ despite this injury's relatively small representation among all geriatric TBI cases.

ICU: ICU care in Canada is largely attributable to urgent medical or surgical admissions. Designated TCs have the highest ICU occupancy rates, and the aging population is suggested as a contributing factor to increased ICU use (Canadian Institute for Health Information, 2016). However, among all general injury admissions and those specific to TBI, advanced age is associated with decreased ICU intensity (Moore et al., 2018; Tardif et al., 2016).

In our geriatric TBI population, ICU LOS (GM = 3.8 days) was shorter than the previously reported 5.4 GM days for all adult general injury admissions (Moore et al., 2018). Yet in our study, days spent in ICU were proportionally greater than in Tardif et al's prior reports concerning TBI in acute care admissions (Tardif et al., 2016).

In Tardif et al.'s assessment, ICU LOS was modified by measures of TBI severity such that lower GCS scores contributed to an increase in overall proportion of hospital days (Tardif et al., 2016). In contrast, we showed the proportion of total LOS attributed to ICU stays decreased with increasing head injury severity (as measured by HAIS). Moreover, we observed a variation in ICU LOS within our TBI cohort with TBI+ patients experiencing approximately 2 days longer stay than patients with iTBI (GM LOS 5.5 versus 3.4 days).

Taken together, our findings suggest that factors associated with extracranial injury (rather than head injury severity), which were associated also with more frequent invasive mechanical ventilation and hospital-acquired complications management (Table 4-2) – risk factors for prolonged ICU management (K. Busl, B. Ouyang, T. Boland, S. Pollandt, & R. Temes, 2015) - may be contributing to our observations.

Increased numbers of pre-existing comorbidities and higher frequency of discharge placement to rehabilitation facilities distinguished our TBI+ and iTBI patients (Table 4-2). The high intensity and complexity of care required by geriatric TBI patients, particularly those presenting with

TBI+, may explain the higher observed burden of ICU use among our geriatric TBI cohort compared with previous reports.

Moreover, perhaps reflecting the contemporary understanding that geriatric patients have poor physiologic reserve to withstand and recover from traumatic insult, especially in the face of multisystem trauma (Jacobs, 2003; Zador, Sperrin, & King, 2016), our results may reflect a conservative medical ICU management approach advised for the geriatric TBI+ patient compared with those experiencing an iTBI (Barry et al., 2019; Rosenfeld & Tee, 2015; Stocchetti et al., 2017).

Hospital-acquired Complications Consistent with past research examining general injury admissions including TBI (Benjamin et al., 2018; Kumar et al., 2018; Moore et al., 2018; Osler, Rogers, & Hosmer, 2013; Tardif et al., 2016), we found hospital-acquired complications to be an important determinant of hospital LOS, accounting for 11% of the explained variation.

Further, it has been suggested that the implementation of quality of care interventions targeting in-hospital complications is central to controlling complication rates and unnecessary hospital days (Farhat et al., 2019).

The data available in the present study did not indicate the nature of the complications themselves, which limited our ability for further analysis. That might be a topic for future studies

Discharge Destination Also consistent with previous studies (J. Cuthbert et al., 2011; Tardif et al., 2016), discharge destination was shown to be highly influential as a predictive factor for determining longer hospital LOS in our TBI population, accounting for more than 14% of the observed variation. Slow recovery trajectories and poor functional outcomes emphasize the geriatric TBI patient’s need for rehabilitation and extended post-acute care (J. Cuthbert et al., 2011; Cuthbert et al., 2014; Stocchetti et al., 2012; H. Thompson et al., 2012; H. J. Thompson et al., 2006). However, limited availability of these resources may aggravate timely discharge and prolong acute care stay. This suggests that efficient discharge planning combined with increasing the availability of extended care facilities to accommodate patients in need could reduce the acute care health burden.

GTCS While the effects of an integrated geriatric trauma service on hospital LOS are the subject of debate, GTCS is believed to be associated with increased identification and clinical management of missed injuries, geriatric specific hospital-acquired complications, and improved discharge placements that address the post-acute care needs of their patients (Dugan, Burns, Baldawi, & Heidt, 2017; W. F. Fallon, Jr. et al., 2006; M Lenartowicz et al., 2012; Southerland, Gure, Ruter, Li, & Evans, 2017; C. Wong et al., 2017).

Our findings suggest that distinct clinical care pathways associated with TBI+ and iTBI presentation influence acute care management and hospital LOS. TBI+ patients are associated with a multidisciplinary approach to trauma case management, incorporating geriatric specialists, as mandated by practice management guidelines (American College of Surgeons Trauma Quality Improvement Program, 2006; Calland et al., 2012; Carney et al., 2017). In our cohort, 70% of TBI+ patients received GTCS compared to 15% of iTBI patients.

In our assessment, exposure to GTCS explained 2.2% of the variation in LOS, suggesting that large-scale efforts aimed at improving acute care for geriatric TBI patients may actually increase the burden of care. Nevertheless, the existing literature indicates that seriously injured geriatric trauma victims benefit from focused treatment at TCs with geriatric trauma experience (Gilgamesh Eamer et al., 2017; W. Fallon et al., 2006; Tessler et al., 2019b; Zafar, Shah, et al., 2015). Thus, improved quality of care provides overall value for health care systems (Group IA, 2014; Mion, Odegard, Resnick, & Segal-Galan, 2006).

GTCS care is considered in detail in the following chapter.

Cost Care Estimates

Cost of TBI The nexus between acute health care utilization and associated hospitalization costs is well known. Among the hospitalized TBI population, injury severity, hospital and ICU LOS, and surgical intervention are considered primary drivers of health care costs (van Dijck et al., 2019). In our sub-cohort - and consistent with prior reports (Albrecht et al., 2017; Davis, Candrilli, Ashish, & Tortella, 2006; Morris, Ridley, Lecky, Munro, & Christensen, 2008) - cost estimates were influenced by longer LOS and increased resource intensity during the hospital course. The increased resource use was associated with ICU requirements, overall injury severity, and the presence of concomitant extracranial injury.

Direct comparison of our results to other studies is complicated by the considerable variation in cost estimates for TBI reported in the literature. This variation is due, in part, to differences in study design, data sources, geographic location, TBI inclusion criteria, costing methodology, and lack of stratification by age group.

To our knowledge, there have been only three Canadian studies of costs associated with TBI, with the only TC-based estimates coming from a study done more than twenty years ago (Snow, Macartney-Filgate, Schwartz, Klonoff, & Ridgley, 1988). In a more recent report, Chen et al (Chen et al., 2012) estimated the average acute care cost for surviving TBI patients hospitalized in Ontario at $19,083 (expressed in 2007 CND, converts to $21,574 2016 CND). However, their cost estimate, abstracted from province-wide administrative data collected for all adult (≥18 years) TBI hospital admissions, did not account for differences between acute care hospital settings (trauma versus non-trauma centers) or distinguish TBI on the basis of age or injury severity. Similarly, Fu et al. (Terence S. Fu, Jing, McFaull, et al., 2016), although comprehensive in their evaluation of lifetime cost estimates by age groupings for TBI patients admitted to an acute care hospital, did not stratify their findings by specific hospital setting or common measures of injury severity, and only reported aggregate annual medical expenditures.

Cost estimates are more readily available from US studies where average acute care hospitalization charges for geriatric TBI, of at least serious severity (HAIS ≥3), are reported in the range of $18,829 (expressed in 2005 USD, converts to $26,701 2016 CND) to $30,651 (expressed in 2012 USD, converts to $31,667 2016 CND) (Albrecht et al., 2017; H. Thompson et al., 2012). The latter figure represents charges specific to TC care inclusive of case mortalities whereas for patients surviving to discharge, average trauma center hospital charges are a reported $27,963 (expressed in 2012 USD, converts to $28,890 2016 CND) (Albrecht et al., 2017).

In comparison to our average patient cost of $20,148 (2016 CND), US estimates are higher. This likely reflects the reported charge versus actual hospital cost, and variations in health care reimbursement structures (a single-payer, publicly insured health care system in Canada versus the private-payer, for-profit reimbursements in the US) between healthcare systems. Nonetheless, assuming access to care and treatment delivery protocols for TBI are relatively uniform among North American Level I TCs, our estimate is in line with figures reported previously and represents a benchmark from which we can evaluate costs associated with at least serious TBI and the high intensity care provided by specialized TCs, particularly those providing geriatric trauma services.

Costs of TBI+ Within our study we found significant differences in healthcare-associated costs between those with an iTBI and those with a TBI+. This result confirms earlier research by Davis (Davis et al., 2006), who found that hospitalization charges incurred by TBI+ patients were more than double those of iTBI patients. This points to a greater need for complex healthcare accommodations for those experiencing a TBI+.

As noted by the Canadian Institute for Health Information, elderly TBI patients require in-patient rehabilitation (IR) and continuing care with the highest frequency among all age groups, a pattern shaped significantly by the severity of elderly injuries in the face of multisystem trauma (Canadian Institute for Health Information, 2006). The related increased ICU and ALC LOS necessary to accommodate these patients contributes to a notable economic burden, with the daily cost of an ICU stay ($3,592) as high as 3 times that cost of a stay in a general hospital ward ($1,135) (Canadian Institute for Health Information, 2016).

4.6 Limitations and Future Studies

This study was conducted at a single urban TC in Ontario, Canada. As such, the results may not be generalizable to all acute care hospitals where TBI is treated or to health care systems without universal access payment structures.

Because resource utilization was evaluated only in terms of the TC hospitalization, the overall health care burden of geriatric TBI is probably underestimated. More than 70% of our study population was transferred to our hospital from another care center and 25% were transferred back to other care centres. Our estimates did not account for resource use related to initial or subsequent hospitalization among transferred patients.

Furthermore, the majority of our patients were discharged to placements along the assisted living continuum. The need for post-acute IR or additional care and assisted living at lower-level care centres among geriatric TBI patients would involve additional resources which would significantly increase the overall health care burden.

Further limitations may relate to a potential estimation error concerning the true burden of resource utilization because we did not include patients who were fatal cases. How this impacts upon care pathways and resource utilization will need to be considered in future research. Further to this, given the time-period of our study, we were unable to report the long-term costs (such as those following discharge) of a TBI among the geriatric population, this needs to be explored in detail in future research. We also did not explore physician billing and how this might impact upon costs for the patient and the wider healthcare system.

Finally, in the present study we only report descriptive results related to the costs of treating a TBI within a subset of our patient population. We did not undertake an analysis of how such costs tie into LOS or how LOS is associated with costs – although it is likely that, as LOS increases, so to do costs. Relatedly, we were unable to collect information on LOS, vital status, and costs after patients were discharged from the hospital or care settings. A future study should explore the distinct clinical care pathways and resource utilization of iTBI versus TBI+ elderly patients, in the context of long-term outcomes.

4.7 Conclusions

Within our study we found significant differences in LOS, costs and resource utilization by TBI sub-type and as well as by injury severity. This suggests that TBI+ and iTBI patients are distinct patient populations who are likely to have distinct clinical pathways and have differing care needs and requirements. Understanding the needs of the two sub-types of TBI in geriatric patients will allows for a systematic and evidence-based approach to be developed.

The factors related to LOS are suggestive of the need for programs which seek to reduce the incidence of in-hospital complications and promote expeditious discharge to post-acute care. There is a significant need for quality-of-care programs, such as GTCS, that may contribute to longer LOS but successfully mitigate unnecessary acute care health delays and enhance resource utilization efficiencies. Further research is needed on how GTCS can comprehensively address the unique needs of different geriatric TBI patients both during and after treatment.

4.8 Appendix to Chapter 4

The following tables (Appendix 4-1 and Appendix 4-2) present the results of sensitivity analyses for the assessment of global determinants of LOS.

To evaluate the robustness of our results, analyses were repeated with LOS truncated at 95 (Appendix 4-1) and 40 (Appendix 4-2) days, representing 99% and 95% of the test sample, respectively.

Appendix 4-1.

Appendix 4-1: Determinants of hospital length of stay (LOS<=95 days) with adjusted geometric mean ratios (GMR) and 95% confidence intervals (CI)

Variables		**N (%)**	**GMR (95% CI)**	**p-value**
All patients		1011		
Patient characteristics				
Age	65-69	161 (15.9)	Referent	
	70-74	187 (18.5)	0.87 (0.73-1.03)	0.1117
	75-79	228 (22.5)	1.02 (0.86-1.22)	0.784
	80-84	225 (22.3)	1.05 (0.88-1.26)	0.5566
	≥85	210 (20.8)	0.97 (0.81-1.16)	0.737
Gender	Female	384 (38.0)	Referent	
	Male	627 (62.0)	0.94 (0.84-1.05)	0.2851
Number of comorbidities	0	164 (16.2)	Referent	
	1	152 (15.0)	0.97 (0.81-1.17)	0.7842
	2	175 (17.3)	0.90 (0.75-1.07)	0.2442
	3	168 (16.6)	1.04 (0.87-1.24)	0.6811
	4	129 (12.8)	1.12 (0.92-1.36)	0.2472
	≥5	223 (22.1)	1.24 (1.05-1.47)	0.0124
Mechanism of injury	Fall	852 (84.3)	Referent	
	MVC	51 (5.0)	0.99 (0.78-1.27)	0.9689
	Pedestrian	57 (5.6)	1.13 (0.89-1.43)	0.3248
	Other	51 (5.0)	0.93 (0.73-1.18)	0.5443
Admitting GCS	13-15 (mild)	808 (79.9)	Referent	
	9-12(moderate)	88 (8.7)	1.59 (1.32-1.91)	<0.0001
	3-8(severe)	115 (11.4)	2.14 (1.81-2.52)	<0.0001
ISS	<25	315 (31.2)	Referent	
	25	551 (54.5)	0.48 (0.33-0.69)	<0.0001
	>25	145 (14.3)	0.84 (0.59-1.20)	0.3315
HAIS	3	113 (11.2)	Referent	

	4	257 (25.4)	1.20 (0.99-1.46)	0.067
	5	641 (63.4)	1.72 (1.12-2.63)	0.0129
TBI Type	Isolated TBI (iTBI)	912 (90.2)	Referent	
	Multisystem TBI (TBI+)	99 (9.8)	2.26 (1.72-2.98)	<0.0001
Hospital course characteristics				
Arrival source	Scene	281 (27.8)	Referent	
	Referring hospital	730 (72.2)	0.82(0.74,0.92)	0.0004
TTA	No	813 (80.4)	Referent	
	Yes	198 (19.6)	0.75(0.6,0.95)	0.0169
Physician service	Neurosurgery	781 (77.3)	Referent	
	General surgery/trauma	185 (18.3)	1.33(1.07,1.65)	0.011
	Other	45 (4.4)	1.41(1.13,1.76)	0.0026
GTCS	No	808 (79.9)	Referent	
	Yes	203 (20.1)	1.41(1.22,1.63)	<.0001
Surgery	No	314 (31.1)	Referent	
	Yes	697 (68.9)	1.07(0.95,1.2)	0.2634
ICU	No	633 (62.6)	Referent	
	Yes	378 (37.4)	1.31(1.16,1.49)	<.0001
Intubation	No	810 (80.1)	Referent	
	Yes	201 (19.9)	1.42(1.2,1.67)	<.0001
ICP	No	960 (95.0)	Referent	
	Yes	51 (5.0)	0.9(0.73,1.11)	0.3229
In-hospital complications	No	812 (80.3)	Referent	
	Yes	199 (19.7)	1.99(1.77,2.23)	<.0001
Discharge destination	Home	266 (26.3)	Referent	
	Home with support	127 (12.6)	1.41(1.22,1.63)	<.0001
	Inpatient rehabilitation	298 (29.5)	2.01(1.78,2.26)	<.0001
	Acute care	306 (30.3)	1.59(1.4,1.81)	<.0001
	Chronic care	8 (0.8)	2.29(1.44,3.67)	0.0005
	Other	6 (0.6)	0.78(0.46,1.32)	0.3519
Year of admission	2008-2009	207 (20.5)	Referent	
	2010-2011	214 (21.2)	0.95(0.84,1.08)	0.4518
	2012-2013	280 (27.7)	0.85(0.76,0.96)	0.0082
	2014-2015	274 (27.1)	1.02(0.9,1.15)	0.784
	2016-2017	36 (3.6)	1.01(0.8,1.27)	0.9632

Note: GCS=Glasgow Coma Scale scores (range 3-15 with mild brain trauma represented by scores 13-15; moderate trauma by 9-12; and severe trauma by 3-8); ISS=Injury Severity Score (range 0-75; higher scores indicate greater global injury with scores >/=20 indicative of severe trauma); HAIS=Maximum Head Abbreviated Injury Scale score (range 1-6 with higher scores indicative of greater head and brain injury severity: HAIS >/=3 represents at least serious trauma; 4=severe; and 5=critical); iTBI=HAIS ≥3 with maximum AIS in any other body region <3; TBI+=HAIS ≥3 with AIS in any other body region ≥3; TTA=trauma team activation; GTCS= Geriatric Trauma Consultation Service; ICU=intensive care unit; ICP=intracranial pressure monitoring.

*Variables “age” to “TBI type” are adjusted for all other patient characteristics in the table. Variables “arrival source” to “year of admission” are adjusted for all patient and hospital course related variables.

†Recreational other including cycling; home or industrial accident not otherwise specified; assault including gunshot wound and stab with or without legal intervention; unspecified

††Medical services: Internal medicine, cardiology, nephrology, respirology, psychiatry, physiatry, geriatrics; Surgical services: Orthopedic, plastics, cardiovascular, urology, otolaryngology, ophthalmology, vascular

[a]Home with support or nursing home facility

[b]General and special rehabilitation facilities

[c]Left against medical advice; unspecified alive; police custody; psychiatric facility; homeless shelter

Appendix 4-2.

Appendix 4-2: Determinants of hospital length of stay (LOS<=40 days) with adjusted geometric mean ratios (GMR) and 95% confidence intervals (CI)

Variables		**N (%)**	**GMR (95% CI)**	**p-value**
All patients		973		
Patient characteristics				
Age	65-69	149 (15.3)	Referent	
	70-74	184 (18.9)	0.97 (0.82-1.15)	0.7311
	75-79	215 (22.1)	1.05 (0.89-1.23)	0.5792
	80-84	220 (22.6)	1.13 (0.96-1.34)	0.1427
	≥85	205 (21.1)	1.05 (0.89-1.25)	0.5325
Gender	Female	371 (38.1)	Referent	
	Male	602 (61.9)	0.91 (0.83-1.01)	0.0931
Number of comorbidities	0	159 (16.3)	Referent	
	1	149 (15.3)	0.98 (0.82-1.16)	0.7819
	2	169 (17.4)	0.91 (0.77-1.07)	0.2488
	3	165 (17.0)	1.06 (0.90-1.26)	0.463
	4	119 (12.2)	1.02 (0.85-1.22)	0.8389
	≥5	169 (17.4)	1.21 (1.03-1.42)	0.0191
Mechanism of injury	Fall	825 (84.8)	Referent	
	MVC	45 (4.6)	0.88 (0.70-1.12)	0.3057
	Pedestrian	53 (5.4)	1.15 (0.92-1.44)	0.2243
	Other	50 (5.2)	1.01 (0.81-1.27)	0.9137
Admitting GCS	13-15 (mild)	790 (81.2)	Referent	
	9-12(moderate)	84 (8.6)	1.53 (1.29-1.83)	<0.0001
	3-8(severe)	99 (10.2)	1.83 (1.56-2.15)	<0.0001
ISS	<25	299 (30.7)	Referent	
	25	546 (56.1)	0.61 (0.42-0.87)	0.0064

	>25	128 (13.2)	0.89 (0.63-1.26)	0.5181
HAIS	3	108 (11.1)	Referent	
	4	242 (24.9)	1.13 (0.94-1.36)	0.2004
	5	623 (64.0)	1.40 (0.93-2.11)	0.1106
TBI Type	Isolated TBI (iTBI)	884 (90.9)	Referent	
	Multisystem TBI (TBI+)	89 (9.1)	2.15 (1.64-2.82)	<0.0001
Hospital course characteristics				
Arrival source	Scene	257 (26.4)	Referent	
	Referring hospital	716 (73.6)	0.88(0.8-0.98)	0.0202
TTA	No	793 (81.5)	Referent	
	Yes	180 (18.5)	0.81(0.64-1.01)	0.0633
Physician service	Neurosurgery	764 (78.5)	Referent	
	General surgery/trauma	166 (17.1)	1.22(0.99-1.51)	0.0659
	Other	43 (4.4)	1.5(1.21-1.86)	0.0002
GTCS	No	790 (81.2)	Referent	
	Yes	183 (18.8)	1.38(1.2-1.59)	<.0001
Surgery	No	302 (31.0)	Referent	
	Yes	671 (69.0)	1.07(0.96-1.2)	0.2075
ICU	No	626 (64.3)	Referent	
	Yes	347 (35.7)	1.37(1.21-1.54)	<.0001
Intubation	No	802 (82.4)	Referent	
	Yes	171 (17.6)	1.25(1.07-1.46)	0.0059
ICP	No	929 (95.5)	Referent	
	Yes	44 (4.5)	0.89(0.72-1.1)	0.2733
In-hospital complications	No	801 (82.3)	Referent	
	Yes	172 (17.7)	1.83(1.64-2.05)	<.0001
Discharge destination	Home	266 (26.0)	Referent	
	Home with support	120 (12.3)	1.3(1.13-1.49)	0.0002
	Inpatient rehabilitation	273 (28.1)	1.92(1.72-2.15)	<.0001
	Acute care	301 (30.9)	1.66(1.47-1.87)	<.0001
	Chronic care	7 (0.7)	2(1.25-3.2)	0.0036
	Other	6 (0.6)	0.8(0.49-1.31)	0.3783
Year of admission	2008-2009	201 (20.7)	Referent	
	2010-2011	205 (21.1)	0.96(0.85-1.08)	0.4783
	2012-2013	269 (27.6)	0.85(0.76-0.95)	0.0039
	2014-2015	263 (27.0)	0.99(0.87-1.11)	0.8072
	2016-2017	35 (3.6)	1(0.8-1.25)	0.9963

Note: GCS=Glasgow Coma Scale scores (range 3-15 with mild brain trauma represented by scores 13-15; moderate trauma by 9-12; and severe trauma by 3-8); ISS=Injury Severity Score (range 0-75; higher scores indicate greater global injury with scores >/=20 indicative of severe trauma); HAIS=Maximum Head Abbreviated Injury Scale score (range 1-6 with higher scores indicative of greater head and brain injury severity: HAIS >/=3 represents at least serious trauma; 4=severe; and 5=critical); iTBI=HAIS ≥3 with maximum AIS in any other body region <3; TBI+=HAIS ≥3 with AIS in any other body region ≥3; TTA=trauma team activation; GTCS= Geriatric Trauma Consultation Service; ICU=intensive care unit; ICP=intracranial pressure monitoring.

[*] Variables “age” to “TBI type” are adjusted for all other patient characteristics in the table. Variables “arrival source” to “year of admission” are adjusted for all patient and hospital course related variables.

[†] Recreational other including cycling; home or industrial accident not otherwise specified; assault including gunshot wound and stab with or without legal intervention; unspecified

[††] Medical services: Internal medicine, cardiology, nephrology, respirology, psychiatry, physiatry, geriatrics; Surgical services: Orthopedic, plastics, cardiovascular, urology, otolaryngology, ophthalmology, vascular

[a] Home with support or nursing home facility

[b] General and special rehabilitation facilities

[c] Left against medical advice; unspecified alive; police custody; psychiatric facility; homeless shelter

Chapter 5
Association of Geriatric Trauma Consultation Service with Acute Care Outcomes and Resource Use in Traumatically Brain Injured Patients: A Propensity Score Matched Observational Cohort Study

5 Association of Geriatric Trauma Consultation Service with Acute Care Outcomes and Resource Use in Traumatically Brain Injured Patients: A Propensity Score Matched Observational Cohort Study

5.1 Abstract

Traumatic Brain Injury (TBI) is a leading cause of hospitalization among geriatric patients, and one which has a poor prognosis. The Geriatric Trauma Consultation Service (GTCS) is known to improve acute care management and survivor disposition in the general geriatric trauma population. The effects of GTCS in a TBI population, however, have, as yet, been poorly described.

The present study was designed to investigate associations between GTCS and hospitalization outcomes in geriatric TBI patients. All geriatric (≥65 yrs.) TBI admissions between 2008 and 2016 at St. Michael's Hospital Level I trauma centre (TC) were identified. Of 1,152 geriatric TBI admissions, 242 were managed with GTCS.

Since an initial survey of the data indicated that there were significant differences between the patient groups that received GTSC and the patients that received usual care (UC), our analysis was done in two ways: 1) first in the whole cohort of GTSC and UC patients, and 2) then in a subgroup of GTSC and UC patients that were matched using propensity score matching (PSM). Between-group comparisons of GTSC and UC patients were made in both the unadjusted and PS matched cohorts using absolute standardized differences (d).

Similar findings were made in both the unadjusted and the PS matched cohorts. As compared to UC patients, GTSC patients showed reduced head injury severity, greater presence of TBI+, increased Trauma Team Activation (TTA), and less neurosurgical management. GTCS management was also significantly associated with an increased rate of in-hospital complications (OR: 1.40 CI 1.03-1.91), ICU-management (OR 1.44 CI 1.21-1.71), alternate level of care (ALC)-management (OR 2.00 CI 1.16-3.44), and prolonged total length of stay (LOS) (incident rate ratio (IRR) 1.88 CI 1.51-2.33). Among GTCS survivors, there was a significantly increased disposition to in-patient rehabilitation (IR) (OR 1.37 CI 1.00-1.88). There was no difference in mortality between the GTSC and the UC groups.

5.2 Introduction

Geriatric TBI: TBI is a major cause of mortality and morbidity within the geriatric population (C. A. Taylor et al., 2017) - and one which has a poor prognosis. When older individuals experience a TBI, they are at an increased risk of experiencing complications, a slower recovery trajectory, long-term disability, and reduced functioning compared with those in younger age groups (R. C. Gardner, K. Dams-O'Connor, M. R. Morrissey, & G. T. Manley, 2018). The complexity of geriatric-specific needs, as well as delays in identifying such needs after a TBI, are associated with poor long-term health outcomes (M. Lenartowicz et al., 2012).

This is a problem which is likely to become more severe over time since the geriatric population is increasing in size. The WHO estimates that there will be an increase from 900 million in 2015 to 2 billion in 2025 in individuals of geriatric status. In the same time period, the proportion of the population in this age group will increase from 12% to 22% (Beard et al., 2016).

In parallel with the increase in age, hospitalizations for geriatric TBI are increasing. Observations at major trauma centres (TC) (Dams-O'Connor et al., 2013; Hawley et al., 2017) and population-based studies have reported high and increasing numbers of hospital admissions for TBI among older adults (T.S Fu et al., 2015; Stocchetti et al., 2012; H. J. Thompson et al., 2006)

Compared with their younger counterparts, the geriatric population has complex and/or chronic medical needs and distinct injury patterns. These needs will demand the development of novel approaches to geriatric health care (Charlesworth, Smit, Lee, Alramadhan, & Odden, 2015).Understanding how best to meet the needs of geriatric trauma patients is an increasingly important area of public health research.

Costs of Geriatric TBI: The aging TBI population presents economic as well as medical challenges. There is an increased utilization of health care and allied services among the geriatric TBI group. For example, the cost of treating TBIs incrementally increases with age and is highest among the geriatric patient population at approximately $2.2 billion per year in the U.S (H. Thompson et al., 2012; X. You et al., 2018).

Guidelines for Elder Care: To address the problems associated with geriatric health management, the WHO has introduced a set of guidelines designed to provide integrated and specialized geriatric health care (World Health Organization (WHO), Geneva; 2017). The American College of Surgeons (ACS) also recognizes the importance of intersecting geriatric and trauma specialists in the care of elderly patients and supports a multidisciplinary approach with geriatric-specific protocols (American College of Surgeons, 2014).

The GTCS Approach: Research has demonstrated that adherence to ACS' Trauma Quality Improvement Program Geriatric Trauma Management Guidelines is increased when the consultation is provided at an early stage of the patients' care pathway (Southerland et al., 2017). This has led to the development of the Geriatric Trauma Consultation Service (GTSC) approach.

Specialized, GTCS programs implement an interdisciplinary approach, based on comprehensive geriatric assessment, which integrates primary and allied healthcare disciplines into a single consultation for the delivery of treatment. Under GTCS management, geriatric specialists advance recommendations designed to proactively address the complex and specialized needs of elderly trauma patients and inform the specialists charged with their critical care (Dugan et al., 2017).

GTCS at St. Michael's Hospital: Since 2007, St. Michael's Hospital (SMH) has incorporated mandatory GTCS and its multidisciplinary management approach for all elderly trauma patients admitted through trauma service. This service is also available to other admitting specialties by referral.

Since the introduction of GTCS, SMH has observed demonstrable improvements in identification, management, and discharge planning among geriatric patients (M Lenartowicz et al., 2012). However, while studies have observed improved outcomes in their GTCS cohorts (Ellis et al., 2011; Landefeld, Palmer, Kresevic, Fortinsky, & Kowal, 1995), there have been no assessments of this approach specifically within the geriatric TBI population.

Objectives: The present study, therefore, aimed to examine the effects of GTCS management for geriatric TBI patients on hospital resource utilization and short-term discharge dispositions, including in-hospital mortality. Our specific objectives were to compare patient-level demographic, injury, and admission profile characteristics of GTCS- and UC-managed TBI patients admitted into a Level I TC, and to evaluate the relative associations of GTCS management with outcome measures of interest.

Since an initial survey of the data indicated that there were significant differences between the patient groups that received GTSC and the patients that received usual care (UC), propensity score matching (PSM) was used to assemble a sub-group of UC patients that more closely matched the GTSC patients. Between-group comparisons of GTSC and UC patients were then made in both the unadjusted and PS matched cohorts using absolute standardized differences (d).

Our initial hypothesis was that focused geriatric management by way of GTSC would decrease LOS and improve acute, short-term outcomes in geriatric TBI patients by enhancing the quality of care those patients received.

5.3 Methods

5.3.1 Study Design and Setting

A retrospective cohort study was performed on geriatric TBI patients admitted to St. Michael's Hospital (SMH) in Toronto, Ontario between 2008 and 2016. SMH is a 459 acute inpatient-bed, academic health sciences institution providing tertiary and quaternary services in neurosurgery, cardiovascular surgery, inner city health and therapeutic endoscopy. As a level I adult TC for the greater Toronto region, SMH services over 77,000 emergency room visits and 25,000 inpatient stays annually. This study was approved by the Research Ethics Board at SMH.

5.3.2 Study Population

All geriatric trauma patients (≥ 65 years) presenting with a serious TBI (defined by HAIS) ≥ 3), evaluated at SMH within 12 hours of their injury, and recording hospital LOS > 2 days were identified. Patients with primary trauma attributed to major burns, drowning and/or asphyxia (described by their ICD-10 external injury codes) were excluded.

5.3.3 Data Collection

All patient data meeting the study's inclusion and exclusion criteria were abstracted from the St. Michael's Hospital Trauma Registry (SMHTR) and electronic medical records. SMHTR systematically collects and tracks demographic data and clinical outcomes of all patients presenting to the hospital with ISS of ≥ 12 in accordance with Ontario Ministry of Health and Long Term Care mandated set of inclusion criteria (*Ontario Trauma Registry Comprehensive Data Set Data Dictionary*, 2014). Data are coded according to the American College of Surgeons National Trauma Data Bank's (ACS NTDB) National Trauma Data Standard dictionary as well as the Ontario Trauma Registry Comprehensive Data Set (Duran, Mazzurco, & Palmer, 2018; *Ontario Trauma Registry Comprehensive Data Set Data Dictionary*, 2014; Tessler et al., 2019a). The accuracy and reliability of the registry's data collection are ensured by frequent internal and routine external quality control standards. In accordance with this study's protocol guidelines, the data collection was validated by designated study personnel (A.W.M. and G.S.).

5.3.4 Exposure and Cohort Selection / Propensity Score Matching

The exposure studied was GTCS intervention. At SMH, GTCS is an automatic referral for geriatric patients with Trauma Team Activation (TTA) and/or admitted through trauma service within 72 hours of presentation. In Chapter 2, we observed that a subset of geriatric TBI patients were less likely to be admitted through trauma service, evaluated in trauma bay, and have reduced TTA frequency. Consequently, GTCS exposure through automatic referral was diminished in these patients. As a result,7 direct comparison between GTCS and UC geriatric TBI patients is problematic due to the potential selection bias introduced by way of GTCS referral.

Due to the meaningful clinical management differences between patient groups that received GTCS and the patients that received usual care (UC), as noted above, we worked not only with the data as a whole, but also with a subset of data where we matched GTCS patients with UC patients using propensity score matching (PSM).

To account for and reduce a potential biased estimate of the intervention effect in our geriatric TBI population, we matched GTCS patients with UC patients using PSM to select a study cohort with hospital LOS > 2 days.

Patient-level characteristics (age, gender, comorbidity, ISS, and MOI), identified *a priori,* guided by literature review and in agreement with the study steering committee, served as covariables in our PS model. No exposure data were missing.

5.3.5 Outcomes

The primary outcome was to measure the associations between GTCS management and the following variables: 1) short-term survivor dispositions; 2) in-hospital mortality; 3) in-hospital resource intensity, as measured by LOS requirements - total, ICU, and ALC - and by clinical care treatment domains understood to inform acute care resource intensity including surgical management; 4) ICP and intubation requirements; and 5) prevalence of in-hospital complications. Alternate level of care (ALC) is a designation for patients no longer requiring acute care management while occupying an acute care bed pending transfer to lower-level care facilities.

5.3.6 Parameters of Interest

Patient level demographics and injury and hospital course characteristics were recorded. Trauma load was assessed by ISS, HAIS, and admission GCS score. Patients' hospital admission profiles were recorded by admission source (arrived directly from trauma scene or transferred from a referral centre), TTA, and admitting service (trauma, neurosurgery, or other admitting physician services). Hospital course parameters were distinguished by level of care requirements including: ICU admissions, surgical management, invasive mechanical ventilation, ICP, in-hospital complications, transfer to ALC, total LOS, and ICU and ALC LOS.

5.3.7 Statistical Analyses

Patient-level injury characteristics and hospital admission profiles between treatment groups were assessed using standardized differences (d), where differences > 0.1 were considered important correlations. The primary analyses consisted of unadjusted and PS-matched analyses to measure the associations between GTCS management and in-hospital mortality, hospital resource intensity parameters, and survivor discharge dispositions.

A multivariable logistic regression model was used to estimate propensity for GTCS intervention among TBI patients. Seven variables believed to act as confounders between GTCS and UC management were included in the model (See Appendix 5-1 for full model details).

The greedy match strategy with PS caliper set at 0.1 was applied to match patients, 1:1 without replacement (Austin, 2008, 2011; Austin & Laupacis, 2011). Model quality was determined by the covariable balanced ratio between exposure groups and a high proportion of matched exposed patients (Ali et al., 2015).

We calculated the absolute risk differences between GTCS and UC patients on outcomes of interest and described associations between GTCS and categorical outcome variables with the Pearson Chi-square test (X^2) or the Wilcoxon signed-rank test for nonparametric continuous outcome variables. Relative associations were calculated using generalized linear models and recorded as odds ratio (OR) or incidence rate ratio (IRR) with 95% CI for categorical or continuous data, respectively.

To evaluate the robustness of our primary analyses we conducted prespecified sensitivity analysis. We calculated the average treatment effects in our unmatched patient population by using the propensity scores to assign inverse probability of treatment weights according to the methods of Austin et al. (2015) (Austin & Stuart, 2015).

Patient data were recorded as proportions of the study population or with mean ± SD. Statistical tests were two-sided with significance assigned at $p < 0.05$. All analyses were performed using Statistical Analysis System software (SAS 9.4: SAS Institute, Inc., Cary, NC, USA).

5.4 Results

5.4.1 Cohort Selection

A total of 1,265 geriatric TBI patients were identified as being admitted during the period of the study. There were 113 patients excluded because their hospital LOS was ≤ 2 days. Of the 1,152 patients that fulfilled the study's inclusion criteria, 21% (n=242) received GTCS intervention and 79% (n=910) were managed with UC (Figure 5-1).

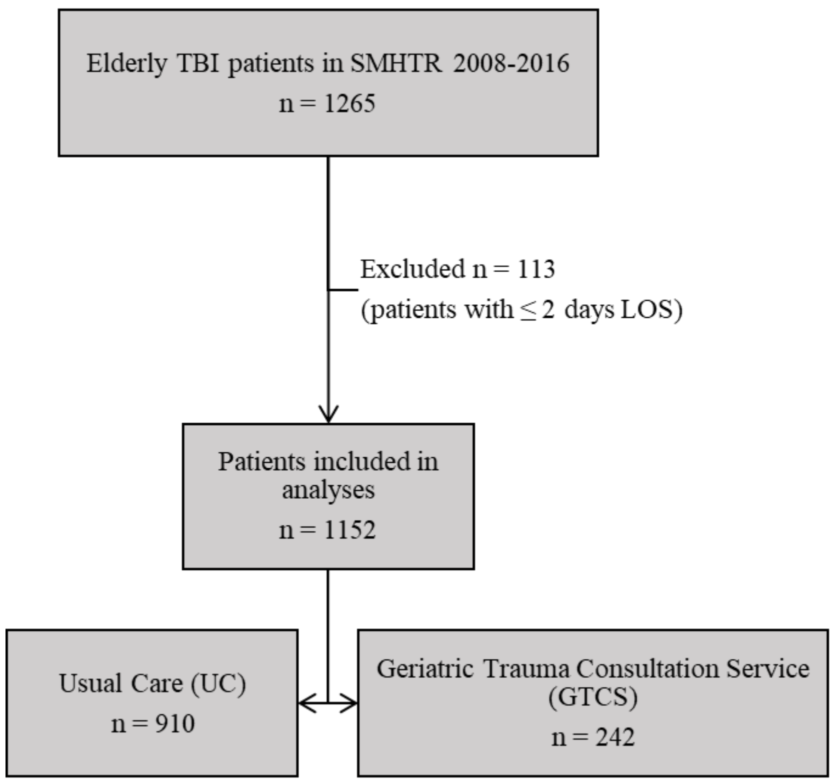


Figure 5-1. Study flow diagram

5.4.2 Propensity Score Matching

In order to minimize clinically meaningful differences among groups of patients, PSM was used. Using the PSM algorithm, 72% (n=174) of GTCS patients were matched with 19% (n=174) of the UC patients. The PSM resulted in a satisfactory balance of covariables having a balanced ratio of 3.71 (Appendix 5-2 and 5-3).

5.4.3 Demographic, Injury and Admission Characteristics of the Cohort Before and After Propensity Score Matching

Demographics: Patient demographics are shown in Table 5-1 with unmatched data presented in the left-hand columns, and PSM-matched data presented in the right-hand columns. On measures of demographic and injury-related characteristics, clinically meaningful correlations with treatment exposure were reduced among the matched patients.

In the cohort as a whole, TBI severity by admitting GCS score was reduced among GTCS patients who were characterized also by serious to severe head trauma along the head-injury severity continuum (HAIS). These differences were reduced in the PSM-matched patients.

Table 5-1. Demographic characteristics of Full cohort and PSM cohort

	% entire cohort*			**% propensity score-matched cohort***		
	UC n=910	**GTCS n=242**	**Absolute standardized difference†**	**UC n=174**	**GTCS n=174**	**Absolute standardized difference†**
Age, years, mean ±SD	78.5 ± 7.6	77.1 ± 7.9	0.2	77.23 ± 8.8	77.12 ± 8.0	0
Gender, Female:	35.3	44.6	0.2	22.4	38.5	0.3
Comorbidities (ICD-10)	85.1	81.8	0.1	84.5	82.2	0.1
# comorbidities, mean ±SD	3.0 ± 2.3	2.9 ± 2.3	0.1	3.1 ± 2.4	3 ± 2.4	0
Admitting GCS score, mean ±SD	12.6 ± 3.7	11.9 ± 4.2	0.2	12.3 ± 4.0	11.9 ± 4.2	0.1
GCS severity:						
Mild	74.8	66.5	0.2	71.3	64.9	0.1
Moderate	10.3	10.7	0	9.8	13.2	0.1
Severe	14.5	22.7	0.2	18.4	21.8	0.1
ISS, mean ±SD	23.6 ± 5.3	23.9 ± 8.5	0	22.3 ± 9.6	23.5 ± 8.2	0.1
HAIS score, mean ±SD	4.7 ± 0.6	4.0 ± 0.8	1.1	4.1 ± 0.8	4.1 ± 0.8	0
mHAIS score Serious - 3	22.4	30.2	0.7	25.3	21.8	0.1
mHAIS score Severe - 4	40.8	41.7	0.5	38.5	42.0	0.1
mHAIS score Critical - 5	44.1	28.1	1.0	36.2	36.2	0
Mechanism of Injury:						
Fall	89.2	62.4	0.7	77.6	71.8	0.1
MVC	3.6	12.4	0.3	6.3	11.5	0.2
Pedestrian trauma	2.5	17.8	0.5	10.9	11.5	0
[α]Other	4.6	7.4	0.1	5.2	5.2	0

Note: GTCS=Geriatric Trauma Consultation Service; UC=usual care follows standard hospital evaluation and service provision standards; ICD-10=International Classification of Disease, Tenth Revision, Canadian Modification; GCS=Glasgow Coma Scale scores (range 3-15 with mild brain trauma represented by scores 13-15; moderate trauma by 9-12; and severe trauma by 3-8); ISS=Injury Severity Score (range 0-75; higher scores indicate greater global injury with scores >/=20 indicative of severe trauma); mHAIS=Maximum Head Abbreviated Injury

Scale score (range 1-6 with higher scores indicative of greater head and brain injury severity; HAIS >/=3 represents at least serious head trauma); SD=standard deviation.

*Except where indicated otherwise

†Absolute standardized differences > 0.1 represent important differences

[α] Recreational other including cycling; home or industrial accident not otherwise specified; assault including gunshot wound and stab with or without legal intervention; unspecified

Type of Injury The distribution of TBI type also differed in the unmatched GTSC and UC patients (Figure 5-2 A). Although iTBI was prominent among both GTCS and UC patients (63% and 95%, respectively), TBI in the presence of extracranial concomitant injury (TBI+) was more frequent in the GTCS patients (37%) than in UC patients (5%).

Following PS matching, this difference in injury type was largely corrected (Figure 5-2 B). An equal distribution of TBI injury type between GTCS and UC patients was achieved with approximately ¾ of the matched cohort presenting with iTBI (78% and 76%, respectively) and 1/4 presenting with TBI+ (22% and 24% respectively).

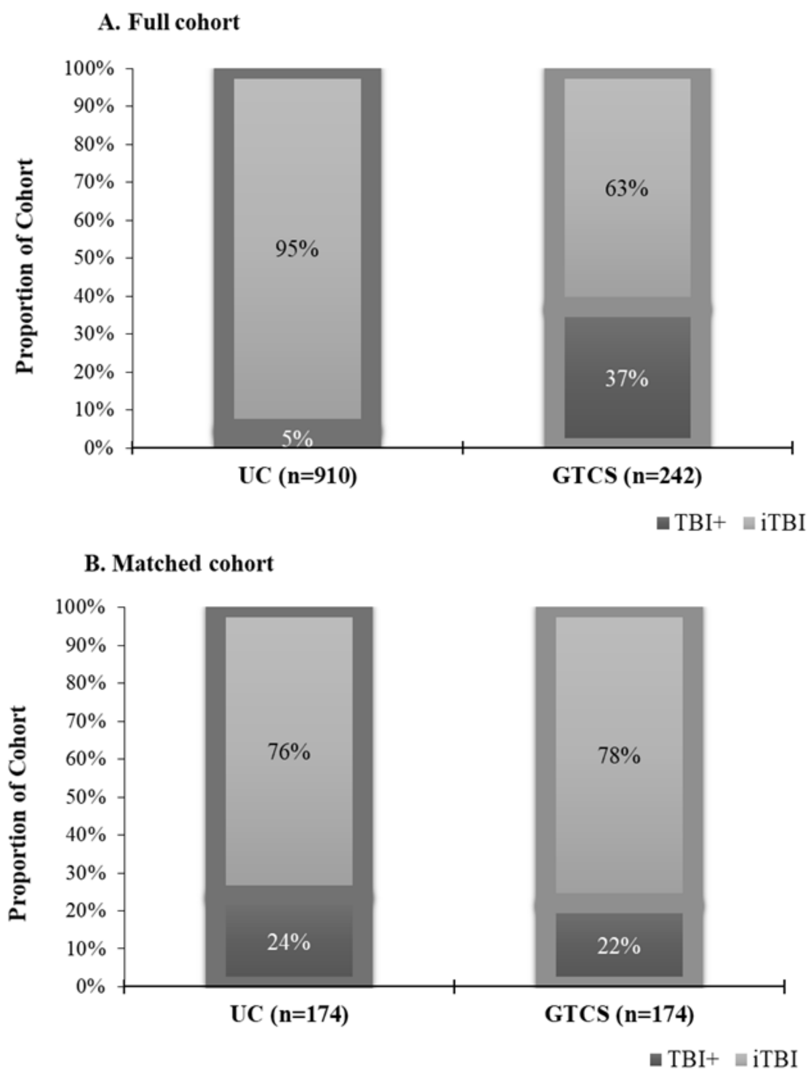


Figure 5-2. Distribution of TBI type among GTCS and UC managed patients. (A) Full cohort. (B) PS-matched cohort. d=absolute standardized difference.

Hospital Admission Admitting characteristics were strongly correlated within and between the groups of patients, even following PS matching (Table 5-2). GTCS patients were strongly correlated with direct entry, TTA and General Surgical service. In contrast, the majority of UC patients were referred from lower-level care centres, they did not have a TTA, and they were predominantly admitted through Neurosurgery. It should be noted, however, our PS matching did not include matching for hospital entry route, TTA initiation or physician service of record. These differences will have to be kept in mind when the data are analyzed.

Table 5-2. Admission characteristics of the entire and PSM cohort

	% entire cohort (n)			% propensity score-matched cohort (n)		
	UC n=910	**GTCS n=242**	**Absolute standardized difference†**	**UC n=174**	**GTCS n=174**	**Absolute standardized difference†**
Hospital entry direct from scene	26.8	47.1	0.4	38.5	47.7	0.2
Hospital Admission with TTA	8.6	75.6	1.9	23.0	67.2	1.0
Physician service of record:						
Neurosurgery	87.1	27.3	1.5	71.3	33.3	0.8
General surgery/Trauma	8.0	67.8	1.6	23.6	60.9	0.8
[β]Other	4.8	5.0	0	5.2	5.8	0

Note: GTCS=Geriatric Trauma Consultation Service; UC=usual care follows standard hospital evaluation and service provision standards; TTA=trauma team activation.

†Absolute standardized differences > 0.1 represent important differences

[β]Medical services: Internal medicine, cardiology, nephrology, respirology, psychiatry, physiatry, geriatrics; Surgical services: Orthopedic, plastics, cardiovascular, urology, otolaryngology, ophthalmology, vascular

5.4.4 Outcome Associations

Outcome associations are reported in Table 5-3. Both unadjusted and PSM matched data are presented.

Unadjusted Cohort In the unadjusted cohort, the risk of mortality did not differ between GTCS- and UC-managed patients. GTCS management was significantly associated with longer total hospitalization LOS (IRR: 2.05, CI: 1.77-2.37), increased in-hospital complication rates (OR: 1.81, CI: 1.47-2.23), increased ICU (OR: 1.98, CI: 1.78-2.21) with invasive intubation (45% GTCS versus 25% UC) and ALC management (OR: 1.81, CI: 1.34-2.44), and reduced surgical management (OR: 0.58, CI: 0.50-0.68). Disposition to IR favoured GTCS survivors (OR: 1.78, CI: 1.48-2.15), while home (OR: 0.49, CI: 0.34-0.69) or home setting with support (OR: 0.52, CI: 0.32-0.86) was lower among GTCS patients compared to the UC group.

Adjusted Cohort Within the matched (PSM) cohort, the findings were very similar. Crude mortality rate also did not differ and GTCS management was significantly associated with longer total hospitalization LOS (IRR: 1.88, CI: 1.51-2.33), increased in-hospital complication rates (OR: 1.40, CI: 1.03-1.91), increased ICU- (OR: 1.44, CI: 1.21-1.71) and ALC management (OR: 2.00, CI: 1.16-3.44), and reduced surgical management (OR: 0.73, CI: 0.59-0.90). Disposition to

IR was higher among GTCS survivors (OR: 1.37, CI: 1.0-1.88), while more UC survivors were discharged to home (OR: 0.57, CI: 0.36-0.89).

Table 5-3. Study outcomes

Outcome **Unadjusted**	**UC** **n=910**	**GTCS** **n=242**	**Absolute difference**	**Relative association* (95% CI)**	**p-value**
In-hospital death, n (%)	128 (14.1)	33 (13.6)	0.5	0.97(0.68-1.38)	0.864
LOS, days, mean ±SD	9.9 ± 17.7	20.3 ± 26.0	10.4	2.05(1.77-2.37)	< 0.0001
Surgery, n (%)	673 (74.0)	104 (43.0)	31.0	0.58(0.50-0.68)	< 0.0001
ICU management, n (%)	345 (37.9)	182 (75.2)	37.3	1.98(1.78-2.21)	< 0.0001
ICU LOS, days, mean ±SD	7.3 ± 12.7	8.6 ± 8.6	1.3	1.18(.98-1.43)	0.2067
Multimodal monitoring, n (%):					
Mechanical ventilation	224 (24.6)	109 (45.0)	20.4	1.83(1.53-2.19)	< 0.0001
ICP	85 (9.3)	17 (7.0)	2.3	0.75(0.46-1.24)	0.260
In-hospital complications, n (%)	187 (20.6)	90 (37.2)	16.6	1.81(1.47-2.23)	< 0.0001
No. Complications, mean ±SD	2.0 ± 1.6	2.2 ± 1.6	0.2	1.09(0.80-1.48)	0.3608
ALC designated %(n)	108 (11.9)	52 (21.5)	9.6	1.81(1.34-2.44)	0.0001
ALC LOS, days, mean ±SD	9.6 ± 27.0	11.3 ± 17.2	1.7	1.18(0.83-1.67)	0.6777
Survivor discharge disposition, $n_{survivors}$ (%survivors):	**n=782**	**n=209**			
Home	223 (28.5)	29 (13.9)	14.6	0.49(0.34-0.69)	<.0001
Home with support	115 (14.7)	16 (7.7)	7.1	0.52(0.32-0.86)	0.0075
In-patient rehabilitation	204 (26.1)	97 (46.4)	20.3	1.78(1.48-2.15)	<.0001
Acute care facility	231 (29.5)	61 (29.2)	0.3	0.99(0.78-1.25)	0.9208
Chronic Care facility	4 (0.5)	5 (2.4)	1.9	4.68(1.27-17.26)	0.0239
$^{\alpha}$ Other	5 (0.6)	1 (0.5)	0.1	0.75(0.09-6.37)	1.0000
Readmission, $n_{survivors}$ (%survivors)	49(6.3)	6(2.9)	3.4	0.46(0.20-1.05)	0.0569
Propensity score match adjusted	**n=174**	**n=174**	**Absolute difference**	**Relative association* (95% CI)**	**p-value**
In-hospital death, n (%)	28 (16.1)	23 (13.2)	2.9	0.82(0.49-1.37)	0.4485
LOS, days, mean ±SD	11.7 ± 17.8	21.9 ± 29.6	10.2	1.88(1.51-2.33)	<.0001
Surgery, n (%)	102 (58.6)	74 (42.5)	16.1	0.73(0.59-0.9)	0.0027
ICU management, n (%)	87 (50.0)	125 (71.8)	21.8	1.44(1.21-1.71)	<.0001
ICU LOS, days, mean ±SD	9.7 ± 17.9	8.7 ± 8.4	1.0	0.90(0.68-1.2)	0.6029
Multimodal monitoring, n (%):					
Mechanical ventilation	58 (33.3)	74 (42.5)	9.2	1.28(.97-1.67)	0.0771
ICP	17 (9.8)	13 (7.5)	2.3	0.76(0.38-1.53)	0.4449
In-hospital complications, n (%)	47 (27.0)	66 (37.9)	10.9	1.40(1.03-1.91)	0.0296
No. Complications, mean ±SD	2.4 ± 2.0	2.1 ± 1.5	0.3	0.89(0.57-1.39)	0.4268

ALC designated, n (%)	17 (9.8)	34 (19.5)	9.8	2.00(1.16-3.44)	0.0100
ALC LOS, days, mean ±SD	12.5 ± 23.6	14.1 ± 20.1	1.6	1.13(.62-2.07)	0.7996
Survivor discharge disposition, $n_{survivors}$ (%survivors):	**n=146**	**n=151**			
Home	41 (28.1)	24 (15.9)	12.2	0.57(0.36-0.89)	0.0111
Home with support	16 (11.0)	14 (9.3)	1.7	0.85(0.43-1.67)	0.6295
In-patient rehabilitation	43 (29.5)	61 (40.4)	11.0	1.37(1.0-1.88)	0.0481
Acute care facility	45 (30.8)	47 (31.1)	0.3	1.01(0.72-1.42)	0.9548
Chronic Care facility	0	4 (2.7)	2.7	-	0.0477
$^{\alpha}$ Other	1 (0.7)	1 (0.7)	0	0.97(0.06-15.31)	0.9809
Readmission, $n_{survivors}$ (%survivors)	4(2.7)	5(3.3)	0.6	0.990(.96-1.03)	0.7739

Note: GTCS=Geriatric Trauma Consultation Service; UC=usual care follows standard hospital evaluation and service provision standards; LOS=hospital length of stay; ICU=intensive care unit; ALC=alternative level of care; ICP=intracranial pressure monitoring; CI=confidence interval; SD=standard deviation

$^{\alpha}$ Left against medical advice; police custody; psychiatric facility; homeless shelter

*For in-hospital death, relative association is odds ratio; for LOS outcome characteristics and number of complications, relative associations is the incidence rate ratio.

5.4.5 Sensitivity Analysis

Inverse probability of treatment weight analysis resulted in clinically meaningful differences in demographic and admitting characteristics among patients managed with and without GTCS intervention despite achieving a balance across covariables (Appendix 5-4). The average treatment effects of GTCS intervention in the entire cohort were congruent with the average treatment effects in the treated patients (matched cohort). In both analyses, GTCS patients were more likely to experience: longer total hospital LOS (IRR: 1.48, 95% CI: 1.14-1.92); more ICU management (OR: 1.59, 95% CI: 1.31-1.94) with invasive intubation (OR: 1.53, 95% CI: 1.09-2.05); greater rate of in-hospital complications (OR: 1.55, 95% CI: 1.08-2.24); more ALC management (OR: 1.76, 95% CI: 0.99-3.12); and reduced surgical intervention (OR: 0.71, 95% CI: 0.55-0.92). GTCS management was also associated with increased relative odds for discharge to IR (OR: 1.74, 95% CI: 1.21-2.39).

5.5 Discussion

Major Findings: The present study, to our knowledge, is the first study to specifically explore the impact of GTCS management upon short-term outcomes and resource utilization among geriatric TBI patients.

Contrary to our initial hypothesis, we did not find that GTCS would decrease LOS, although it may have improved the quality of patient care. In our assessment, GTCS management was significantly associated with increased hospital LOS, increased ICU, increased in-hospital complications, increased ALC management, and less surgical intervention. We also found disposition to IR to be higher among GTCS survivors compared with those under UC management. These findings will be discussed in the following sections.

ICU Admissions: Previous studies in non-TBI patients have reported GTCS to be associated with higher rates of ICU admission (Barry et al., 2019; M Lenartowicz et al., 2012). Our findings similarly show that in TBI patients GTCS is associated with increased ICU management

It is important to note, however, that, in this study, ICU admission took place directly from trauma resuscitation bay and, therefore, occurred before exposure to GTCS. There was no causal relationship between GTCS and ICU admission. This higher prevalence of direct ICU placements and durations of may be related to patients with greater severity of injuries.

Surgical Management: We also found decreased surgical intervention in GTCS patients relative to UC patients. As with ICU, there is probably no causal relationship here. Decisions concerning surgical intervention would have been made by neurosurgeons solely on the basis of whether injuries could be corrected surgically (e.g. epidural hematoma). No major role was played by GTCS teams.

GTCS and In-hospital Complications: It has previously been reported that identification and therapeutic management of post-traumatic complications - such as referral for cognitive evaluation - were associated with GTCS in the non-TBI geriatric population (W. F. Fallon, Jr. et al., 2006; M. Lenartowicz et al., 2012; Olufajo et al., 2016).

In our assessment, GTCS TBI patients also had higher rates of in-hospital complications relative to UC patients. This was found in both our un-matched and matched cohorts.

It should be noted, however, that this does not mean that GTCS care causes in-hospital complications. Rather, it is possible that the addition of geriatric-focused care improves vigilance for – and the treatment of – complications that might otherwise be missed.

In-patient Rehabilitation, ALC and LOS It has been reported that intensive IR significantly improves the long-term prognosis of geriatric TBI victims, with the majority being shown to achieve functional gains equivalent to those seen in younger patients (R. C. Gardner et al., 2018; Mosenthal et al., 2004).

In the present study, GTCS was associated with increased referral to IR. The increased referral to IR - instead of placement along the assisted living continuum – is suggestive of a better quality of care received.

The increased disposition to IR in our GTCS cohort occurred in conjunction with increased LOS and ALC management. Earlier work in non-TBI patients (M Lenartowicz et al., 2012) had reported decreased LOS among their GTCS cohort. This was not the finding in the present TBI cohort.

In agreement with the findings of the present study, however, others have found that discharge disposition, specifically to IR, has the potential to increase overall patient LOS (W. F. Fallon, Jr. et al., 2006; Elaine C. McKevitt et al., 2003). This phenomenon is particularly well established for patients who require neuro-rehabilitation services following TBI, with increased LOS due to neuro-rehabilitation disposition demonstrated across numerous studies (J. P. Cuthbert et al., 2011; Tardif et al., 2016).

In our study, transitions to ALC - while awaiting IR placement – perhaps contributed to the prolonged LOS observed in GTCS patients (Elaine C. McKevitt et al., 2003; K Salottolo et al., 2009).

Mortality We also found that GTCS management was not associated with a significant difference in in-hospital mortality in TBI patients. Dugan et al. have similarly reported no difference in mortality with the introduction of GTCS in non-TBI patients (Dugan et al., 2017).

In contrast, a substantial Cochrane Review (Eamer et al., 2018) found that comprehensive geriatric assessment could improve mortality outcomes in patients with hip fracture, but with limited evidence related as to how it might improve the health of patients with other traumas. Fallon et al. (W. F. Fallon, Jr. et al., 2006) also observed a statistically higher mortality rate among patients in UC, but did not categorize by trauma injury type, and based those conclusions on prospective data without a control group.

Thus, it is possible that - while GTCS may lead to an improved level of care for geriatric TBI patients - these results may not translate into significant changes in short-term mortality rates.

It should be noted, however, that the present data only apply to short-term mortality. Future studies might investigate whether GTSC may have an effect on long-term mortality.

5.6 Limitations and Future Studies

A number of factors may have impacted upon our study results.

First, the use of retrospective data adds to the potential for selection bias that is inherent to this type of analysis. Because our sample is observational in nature and taken from a single Level I TC, our results may not be generalizable to the wider patient population. Future research could explore the impact of GTCS upon patient outcomes and service utilization using a multi-center, randomized approach.

Importantly, due to the operational guidelines of GTCS at St Michael's, elderly patients that arrive off hours or during the weekend may be exposed to surgery and/or mechanical ventilation before receiving GTCS. Moreover, patients that are admitted to the ICU may not be exposed to GTCS at all (*Trauma Services Annual Report 2011*, 2011). The trauma team at St. Michael's uses a two tiered response to respond to patients' arrival, with tier 1 activations used to prepare for critically injured patients requiring immediate surgical interventions (*Trauma Services Annual Report 2011*, 2011). While we controlled for this by excluding patients with hospital LOS < 2 days, our findings that geriatric TBI patients exposed to GTCS face increased ICU and decreased surgical intervention when compared to their UC counterparts should nonetheless be reconsidered in the context of differing TBI sub-type presentations and how GTCS operates at St. Michael's.

Secondly, we had a limited sample size, which hampered our ability to PSM match. A larger sample size could have enabled us to match patients with their triage and admitting physician characteristics, therefore adjusting for differences in clinical decisions. For example, future work should modify the present analysis to compare elderly TBI patients admitted to neurosurgery (iTBI) with those admitted to trauma care (TBI+), as only the latter integrates GTCS. Relatedly, the parameter of analysis for surgical interventions should also differentiate betweeen orthopedic versus neurosurgical interventions.

In addition, future studies could employ better matching of brain injury types, i.e. on the basis of Marshall Score classifications, by incorporating frailty measures, and/or only on the basis of TBI sub-type. Indeed, our observational cohort study demonstrated distinct injury traits among TBI geriatric patients that distinguished GTCS referral and management compared to those without GTCS. Importantly, those differences in TBI characteristics at the patient-level likely contributed to our outcome measures on clinical and resource utilization effects, and confounded our determination of quality improvements with GTCS intervention compared to UC. This further highlights the importance of controlling for distinct TBI injury patterns when assessing quality improvements of GTCS in future work.

Thirdly, our results may have been shaped by the covariables chosen for matching as parameters. Different matching methods may create different estimates for matched populations than the PSM used in this study. This may lead to differences in the outcomes reported (Pirracchio, Resche-Rigon, & Chevret, 2012; Wells et al., 2013). These limitations are associated with the PSM matching in general, rather than our particular methodology. As recommended in the literature, we conducted sensitivity analysis based on inverse probability weighting to alleviate these shortcomings (Austin & Stuart, 2015; Thoemmes & Ong, 2016). Nonetheless, our results may have been shaped by our decision to use the covariables chosen for matching as parameters.

Finally, this study did not account for all outcome measures that can be impacted by GTCS, such as patient and family satisfaction, decision to continue care, and decreases in delirium, depression, and pain.

The present study represents a first attempt to PSM match in assessing the effects of GTCS in geriatric TBI. Further work, however, is needed to understand the clinical course characteristics of patients exposed to GTCS and the role of GTCS specifically in distinct clinical pathways pathways associated with specific TBI sub-types.

5.7 Conclusions

The present study is the first to directly address the impact of GTCS management on resource utilization and short-term outcomes within the geriatric TBI population. Our present findings suggest that patients under GTCS management received more resources and were more likely to be referred for IR, all of which may contribute to better quality of care, but also a prolonged LOS.

In a sub-cohort, we attempted to control for differences between GTSC patients and UC patients using PSM. Our findings were similar to the findings in the unmatched cohort. Even in our PS matched groups, however, there were still important differences between GTSC and UC group which may have influenced the results. These included differences in hospital admission (direct versus scene) and clinical management pathways (physician services). The limited number of patients in the present sample limited further analysis, however. Better matching might be accomplished in future multisite studies with larger patient populations.

5.8 Appendix to Chapter 5

Appendix 5-1.PSM Model Characteristics

Appendix 5-1. Propensity score model for full cohort

Covariate	Representation	OR (95%CI)
Age	65-69	Referent (NA)
	70-74	0.77(0.43-1.37)
	75-79	1.39(0.81-2.38)
	80-84	0.87(0.49-1.57)
	≥ 85	1.40(0.79-2.47)
Male	versus Female	0.79(0.55-1.12)
Comorbidities (ICD-10) (number at admission)	0	Referent (NA)
	1-2	0.72(0.43-1.23)
	3-4	0.77(0.45-1.33)
	≥ 5	0.87(0.50-1.53)
ISS	< 25	Referent (NA)
	25	0.40(0.16-0.96)*
	> 25	1.06(0.44-2.55)
HAIS	3	Referent (NA)
	4	0.36(0.22-0.60)**
	5	.17(0.07-0.45)**
Extracranial multisystem injury (TBI+)	versus Isolated TBI (iTBI)	3.99(2.08-7.68)**
Mechanism of injury	Fall	Referent (NA)
	MVA	2.3(1.17-4.53)*
	Pedestrian trauma	4.40(2.38-8.14)**
	Other	2.00(0.99-4.05)

*p<0.05; **p<0.0001

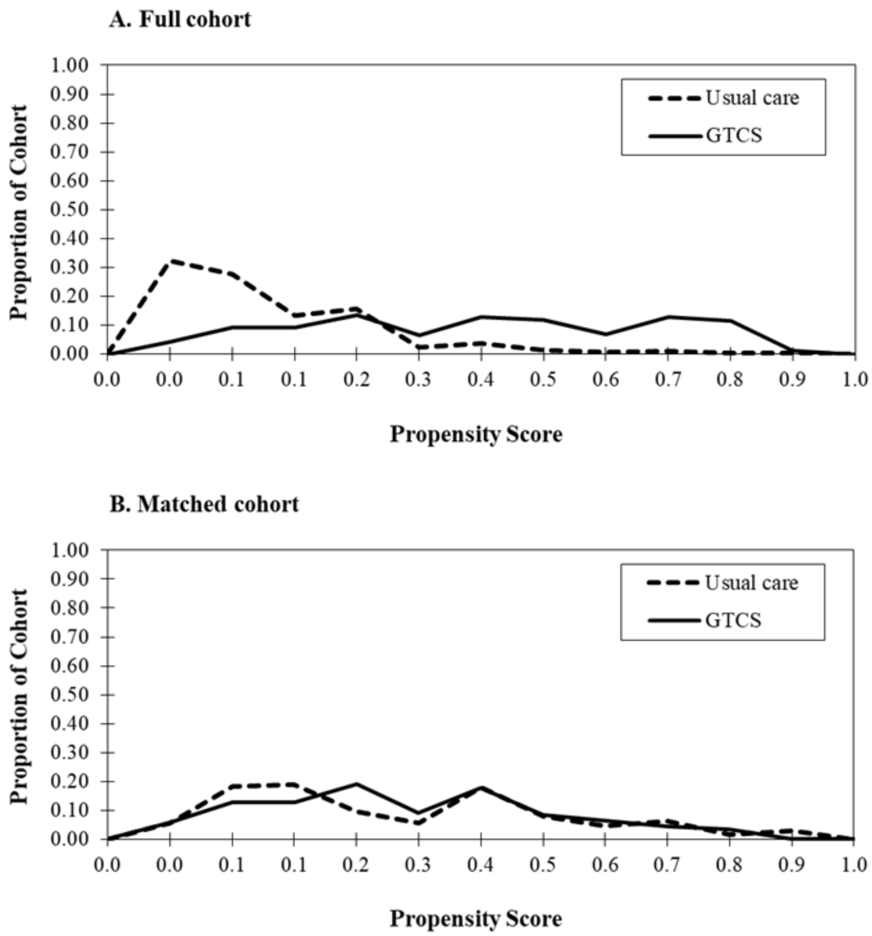
Appendix 5-2. PSM Covariate Balance

Appendix 5-2. Propensity score model characteristics

Criterion	**Full Cohort**	**Matched Cohort**
Sample size (%)	1152 (100%)	348 (30.2%)
Balanced ratio	1.00	3.71
Absolute Standardized differences, d	∑d = 8.4152	∑d = 2.2690
Age, years		
65-69	0.1836	0.0241
70-74	0	0.2239
75-79	0.0705	0.3801
80-84	0.2017	0.0856
≥ 85	0.0488	0.1644
Male	0.2040	0.3725
Comorbidities (ICD-10), number at admission		
0	0.0799	0.0540
1-2	0.0645	0.1290
3-4	0	0.1136
≥ 5	0	0
ISS		
< 25	0.5790	0.0200
25	1.0699	0.0714
> 25	0.4523	0.0898
HAIS		
3	0.6934	0.0705
4	0.4648	0.0612
5	1.0336	0
Isolated TBI (iTBI)	0.8571	0.0471
Mechanism of injury		
Fall	0.6585	0.1378
MVA	0.2971	0.1768
Pedestrian trauma	0.5145	0
[α]Other	0.0846	0

Note: Balanced ratio = ∑d full cohort/∑d matched cohort; ICD-10=International Classification of Disease, Tenth Revision, Canadian Modification; ISS= Injury Severity Score (range 0-75; higher scores indicate greater global injury with scores >/=20 indicative of severe trauma); HAIS=Head Abbreviated Injury Scale score (range 1-6 with higher scores indicative of greater head and brain injury severity).
[α] Recreational other including cycling; home or industrial accident not otherwise specified; assault including gunshot wound and stab with or without legal intervention; unspecified

Appendix 5-3. Distribution of Propensity Scores This figure shows the distribution of propensity scores before and after matching. A closer overlap in the PSM cohort was indicative of an improved balance in the measured covariables.



Appendix 5-3. Distribution of propensity score by clinical management status (usual care or GTCS). (A) Full cohort. (B) After propensity score matching. Closer overlap in the propensity score-matched cohort supports improved balance of the measured covariables.

Appendix 5-4. Inverse Probability of Treatment Weight Analysis

Appendix 5-4. Demographic and admission characteristics for inverse probability of treatment weight analysis

	% weighted cohort*		
	UC n=910	**GTCS n=242**	**Absolute standardized difference†**
Age, years, mean ±SD	78.0 ± 3.0	76.5 ± 5.2	0.3
Gender, Female:	41.6	48.3	0.3
Comorbidities (ICD-10)	81.7	81.9	0
# comorbidities, mean ±SD	2.9 ± 0.9	2.9 ± 1.6	0
Admitting GCS score, mean ±SD	12.2 ± 1.5	12.1 ± 2.8	0
GCS severity:			
Mild	70.0	70.3	0
Moderate	11.2	8.3	0.2
Severe	18.4	21.5	0.1
ISS, mean ±SD	22.9 ± 3.4	24.2 ± 6.1	0.3
HAIS score, mean ±SD	4.2 ± 0.3	3.7 ± 0.5	1.4
mHAIS score Serious – 3	19.3	43.3	0.9
mHAIS score Severe – 4	39.8	44.1	0.2
mHAIS score Critical – 5	40.9	12.6	1.4
Isolated TBI	94.7	62.8	0.9
Mechanism of Injury:			
Fall	75.5	46.5	1.1
MVC	7.8	17.9	0.5
Pedestrian trauma	10.2	27.0	0.7
[α]Other	6.5	8.6	0.1
Hospital entry direct from scene	36.6	50.0	0.5
Hospital Admission with TTA	23.1	90.6	3.8
Physician service of record:			
Neurosurgery	69.5	14.0	2.7
General surgery/Trauma	23.1	81.7	2.7
[β]Other	7.4	4.3	0.3

Note: GTCS=Geriatric Trauma Consultation Service; UC=usual care follows standard hospital evaluation and service provision standards; ICD-10=International Classification of Disease, Tenth Revision, Canadian Modification; GCS=Glasgow Coma Scale scores (range 3-15 with mild brain trauma represented by scores 13-15; moderate trauma by 9-12; and severe trauma by 3-8); ISS=Injury Severity Score (range 0-75; higher scores indicate greater global injury with scores >/=20 indicative of severe trauma); mHAIS=Maximum Head Abbreviated Injury Scale score (range 1-6 with higher scores indicative of greater head and brain injury severity; HAIS >/=3 represents at least serious trauma); TTA=trauma team activation; SD=standard deviation.

*Except where indicated otherwise

†Absolute standardized differences > 0.1 represent important differences

[α] Recreational other including cycling; home or industrial accident not otherwise specified; assault including gunshot wound and stab with or without legal intervention; unspecified

[β]Medical services: Internal medicine, cardiology, nephrology, respirology, psychiatry, physiatry, geriatrics; Surgical services: Orthopedic, plastics, cardiovascular, urology, otolaryngology, ophthalmology, vascular

Chapter 6
General discussion and Future Directions

6 General Discussion and Future Directions

6.1 Overview

This thesis showed that geriatric TBI patients – in comparison to younger adults - are particularly likely to experience: 1) delays in definitive care via field and trauma bay triage mechanisms; and 2) less aggressive acute care management once at the TC. These may lead to poorer short-term outcomes, including greater in-hospital mortality. These observations suggest that there may exist implicit bias in the delivery of health care for geriatric TBI patients.

One factor associated with delay to definitive care may be the blunted response to TBI seen particularly in the iTBI patients. This would suggest that there should be a lower GCS threshold for referral of geriatric patients to a level 1 TC.

A factor associated with less aggressive care may be the expectation of less good outcomes in older patients, and less willingness to expend resources in their care. This would suggest a need for education in the fact that elderly patients do well when they receive proper care.

A further factor affecting the less aggressive care seen in elderly iTBI patients is the fact that - compared to TBI+ patients - they are less likely to enter the hospital through general surgery/ trauma, and thus less likely to receive TTA and referral to GTCS care. This would suggest that all geriatric patients should be referred to geriacentric management, regardless of their course of care.

Thus, underlying age-associated complexities and institutional protocols may lead to clinical bias in the observed care patterns between older and younger TBI+ and iTBI patients Health care systems, particularly trauma systems, need to promote early and aggressive management of vulnerable older-aged TBI patients and to increase sensitivity to geriatric-specific needs in an effort to deliver efficient and effective acute health care.

With some exceptions, the findings of the four research studies in this thesis (Chapters 2-5) were consistent with the past literature and with our hypotheses based on the past literature. Both advancing age and the presence or absence of significant extracranial injuries had a pronounced effect on patients suffering from TBI.

The following sections will first briefly discuss the general findings among our TBI cohort, and then some of the clinically significant findings from Chapters 2-5.

General Findings

6.1.1 TBIs are Common in the Adult Trauma Population

Over a nine-year time-horizon, 41% of adult trauma presentations at St. Michael's Hospital involved serious TBIs (mHAIS $\geq$3), and 44% of those were reported among patients 65 years and older. These rates are comparable to those observed in other major trauma centers (Dams-O'Connor et al., 2013; Hawley et al., 2017). They are also consistent with previous population-based studies reporting high rates and increasing numbers of hospital admissions for TBI among older adults (T.S Fu et al., 2015; Stocchetti et al., 2012; H. J. Thompson et al., 2006).

6.1.2 Distinct TBI Subtype Presentations

We also observed distinct injury pattern distributions within our TBI cohort. About 75% had iTBI and about 25% had TBI+. Geriatric patients presented more frequently with TBI in isolation (iTBI) and less frequently with TBI and concomitant multisystem injuries (TBI+), as compared to younger adult patients.

Others have reported similar discriminate injury patterns among their adult TBI populations (Brown et al., 2016; Dams-O'Connor et al., 2013; Schönenberger et al., 2012). TBI in the presence of concomitant extracranial injuries (TBI+) is capable of modifying patient outcomes - in addition to creating significant challenges for trauma teams - as compared with iTBI (McDonald et al., 2016).

6.1.3 Falls are the Leading Mechanism of Injury in TBI

In our assessment, the leading MOI was falls. Falls accounted for 83% of admissions among geriatric patients and 40% of admissions among younger adult patients. MVCs and pedestrian trauma were the second and third most common MOIs in both age groups. MVCs were more common in the younger than in the geriatric population.

Our findings are consistent with the reports of others demonstrating the predominance of fall-induced adult TBI (de Vries et al., 2018; Friedland et al., 2014; A. Kehoe, Smith, et al., 2015; Røe et al., 2013), and also with studies reporting a shift from MVCs to falls with advancing age (Harrison-Felix et al., 2012; C. A. Taylor et al., 2017).

Falls, which are the top MOI for elderly TBI patients, often result in severe yet isolated TBI (iTBI) (Krishnamoorthy et al., 2015). MVCs, which are a top MOI in younger adults, often result in TBI+.

6.1.4 Pre-existing Health Conditions are Common in Geriatric TBI Patients

Among our TBI cohort, there was a doubling in the incidence of comorbid conditions among our older patients as compared to the younger adults.

Our data agree with previous studies that have shown the incidence of pre-existing comorbidity to be 90% or more among hospitalized elderly TBI patients (Hawley et al., 2017; Røe et al., 2013). In comparison to younger TBI patients, the elderly have a three- to six-fold increase in pre-morbid health conditions (Mosenthal et al., 2002; Mosenthal et al., 2004), and a substantial proportion of those patients present with multiple pre-existing conditions (R. Haring et al., 2015; Røe et al., 2013).

6.1.5 TBI Severity May Be Obscured in Geriatric Patients

We observed higher GCS scores (indicative of lower TBI severity) in the face of significant anatomical derangement (as measured by higher HAIS) among the older patients as compared to the younger adults.

Our data agree with a number of past studies. The seriousness of significant TBI in geriatric patients is often underestimated by traditional injury severity scales due this age group's delayed and altered physiological response to traumatic injury (Caterino et al., 2011; A. Kehoe, Rennie, et al., 2015; Sasser et al., 2012; L. J. Scheetz et al., 2016). The research of Kehoe and colleagues, in particular, has established that anatomic and physiologic injury scales are unreliable among elderly TBI patients, lending to an underestimation of brain injury severity (A. Kehoe et al., 2016; A. D. Kehoe et al., 2014).

Findings Related to Specific Studies

6.1.6 Age and Injury Characteristics Influence Acute Care Resource Use and Discharge Placement in Adult TBI Patients (Study 1)

The primary objective of Study 1 (Chapter 2) was to describe demographic and hospital course characteristics, processes of acute care, and discharge dispositions of adult TBI patients stratified on the basis of age (adult versus geriatric status) and TBI sub-type (iTBI and TBI+). It was hypothesized that advancing age would be associated with greater acute care resource intensity, LOS and disposition to on-going clinical care and assisted living. Further, it was expected that hospital resource intensity and disposition along the assisted living continuum would increase in patients presenting with a TBI and concomitant extracranial injuries (TBI+).

The findings of Study 1 elucidated significant differences between older and younger TBI patients. Further, it demonstrated how age-associated differences may be impacted by the presentation of TBI in the presence (TBI+) or absence (iTBI) of significant concomitant extracranial injury.

Consistent with past reports, this study showed that older patients were less likely sent directly to TC, initiate TTA, be admitted to Trauma Service and the ICU, or have ICP monitoring compared to their younger counterparts (Carney et al., 2017; R. Gardner et al., 2018).

Also consistent with previous research, compared to younger adult patients, older TBI patients had higher mortality (Eom, 2019; Mosenthal et al., 2002). Among survivors, discharge to home was less likely among the elderly, the majority of whom required continuing care at lower-level treatment facilities compared to younger adults (J. Cuthbert et al., 2011; Karibe et al., 2017).

Although others have reported that older patients with TBI may have worse hospital outcomes, slower recovery, increased rates of long-term disability and reduced function, they do so in the context of these older patients also consuming more hospital resources compared to younger patients (Dams-O'Connor et al., 2013; Schönenberger et al., 2012). In contrast, and contrary to the hypothesis, this study showed that, despite suffering more severe TBIs, older patients did not consume more hospital resources compared to their younger counterparts. Furthermore, notwithstanding a trend toward delayed mortality among our elderly patients, our observed LOS was not different between the age groups (Tardif et al., 2016).

An assessment of this study's findings in the context of distinct TBI sub-types found a pattern of increasing head injury severity among older iTBI patients. These patients had also different processes and management of acute care compared to their TBI+ counterparts. They were predominantly referred to TC and primarily managed through the neurosurgical service.

Studies have shown that delays to definitive care can negatively impact outcomes associated with highly time-sensitive neurological injuries (Pélieu et al., 2019). The high referral rate, in addition to this patient population's reduced frequency of TTA is suggestive of their particular vulnerability for under-triage both in the field and at this TC (Calland et al., 2012; Connolly et al., 2018; Flottemesch et al., 2017; Jacobs et al., 2003).

Furthermore, we observed that older adults presenting with iTBI were more likely to undergo surgery. These findings may reflect increased frequency of neurosurgical referral among older iTBI patients relative to their TBI+ counterparts. These finding are consistent with previous studies suggesting that less invasive, non-operative treatment are common among older TBI+ adults (Barry et al., 2019; Rosenfeld & Tee, 2015).

Our findings suggest that health delivery systems need to consider elderly-unique factors such as lower suspicion of significant brain injury with falls, delayed access to services, recognition of head injury with impaired cognition, as well as decreased disposition to offer invasive treatment options that affect outcomes. If elderly patients with TBI are managed differently than young patients, then these differences could significantly impact both short and long-term outcomes.

Undertaking research which can be utilized to develop effective treatment programs, in the context of distinct clinical care pathways observed among older patients with differing TBI presentation, will be key to improving outcomes in this vulnerable population.

6.1.7 Older Age and TBI with Multisystem Trauma are Associated with Increased Mortality Among Hospitalized Adult Patients (Study 2)

Study 2 (Chapter 3) sought to examine the determinants of in-hospital mortality among an adult TBI cohort in the context of distinct TBI sub-type presentations (iTBI and TBI+). Both younger adult and geriatric patients were studied. It was hypothesized that advanced age would be associated with increased mortality, and that survivor outcomes would be a function of injury severity and TBI+ presentation.

As expected - and consistent with previous research – older age was strongly associated with increased mortality among our TBI population. The risk of mortality increased as age advanced. The greater frequency of pre-existing comorbidities in the geriatric population may have influenced this observed mortality risk. Our study also found that the occurrence of hospital complications was associated with an increased risk of mortality.

In general, our findings agree with past reports. Age, (Hukkelhoven et al., 2003; Mosenthal et al., 2002), frequency of pre-existing comorbidities (Bergeron, Lavoie, Moore, Clas, & Rossignol, 2005; W. W. Fu et al., 2017; Hawley et al., 2017; Hildebrand, Pape, Horst, Andruszkow, Kobbe, Simon, Marx, & Schürholz, 2016), and hospital-acquired complications (Perdue, Watts, Kaufmann, & Trask, 1998; Sampalis et al., 2009; L. J. Scheetz, 2018) have been reported as strong factors influencing both mortality and morbidity following TBI. Their occurrence has been shown to be linearly associated with poor outcomes.

The present study also demonstrated significant increased risk of in-hospital death amongst patients experiencing a TBI+. As has previously been reported, multisystem trauma involving significant head injury results in the highest risk of mortality amongst all multisystem trauma patients (Hawley et al., 2017; A. Kehoe, Smith, et al., 2015),. This seems to be largely due to the interactive and additive pathophysiological events between organ systems (McDonald et al., 2016).

Thus, age appears to be a particularly important factor in TBI mortality. The mortality rate of patients older than 65 years is reported to be more than twice that for younger adult patients with TBI (Johnson, Thomas, Thomas, & Sarmiento, 2009). This risk is understood to increase with each consecutive decade over the age of 65 years (McIntyre et al., 2013). Geriatric trauma patients are inherently disposed to declining physiological reserves, and have diminished capacity to withstand and/or recover from serious injury (Hildebrand, Pape, Horst, Andruszkow, Kobbe, Simon, Marx, & Schurholz, 2016). They are particularly vulnerable to poor outcomes following a TBI - including increased risk of death - especially with significant concomitant extracranial injury (de Vries et al., 2018). Even when factors of injury severity are controlled, high rates of mortality persist among the elderly with TBI and multisystem trauma (R. Richmond et al., 2011; Røe et al., 2013).

The increased mortality risks we observed among geriatric patients suggest the urgent need for specialized care for this TBI subpopulation. Moreover, increased provision of acute care and recovery services may further facilitate improved outcomes in this patient population.

6.1.8 Heterogeneity in TBI Presentation Influences Hospital LOS and Costs in Geriatric Patients (Study 3)

Study 3 (Chapter 4) aimed to evaluate clinical care pathways for geriatric TBI by assessing determinants of hospital length of stay (LOS) and associated costs for acute care medical treatment. It was hypothesized that the TBI+ subtype would be associated with increased LOS and increased inpatient costs.

We identified the following key determinants of LOS: discharge destination, hospital-acquired complications, ICU management, GTCS exposure, physician service, and TBI+ presentation.

The present study found that patients with a TBI+ presentation accounted for 20% of all hospital bed-days and 23% of all hospital expenditures, despite representing only 10% of the entire cohort.

An important observation was that delivery of care disproportionally targeted TBI+ patients receiving GTCS management, which in turn greatly influenced hospital LOS. Relatedly, and in agreement with past reports, prolonged LOS was strongly associated with greater disposition to continuing care (i.e. in-patient rehabilitation) and identification of in-hospital complications (Farhat et al., 2019; Tardif et al., 2016), both of which have been attributed with GTCS management and enhanced quality of care for geriatric-specific needs (Dugan et al., 2017; W. Fallon et al., 2006; M Lenartowicz et al., 2012).

Furthermore, although risk of hospitalization and medical costs are known to increase with age, costs for long-term care are a substantial driver of health expenditures in the geriatric patient population and by definition place a proportion of older patients in a high-cost category (Ronksley et al., 2016; Ronksley et al., 2015).

Thus, our findings suggest that, despite certain heterogeneity among TBI subtype presentation and distinct clinical care pathways associated with each subtype, the health care burden associated with focused geriatric management in the acute care setting, may be off-set by addressing the availability of post-acute resources for this patient population.

6.1.9 Specialized Geriatric Trauma Management (GTCS) in TBI Patients Is Associated With Greater Resource Intensity and Increased Disposition to Continuing Care (Study 4)

Study 4 (Chapter 5) aimed to assess the impact of GTCS management on resource utilization and short-term discharge disposition among geriatric TBI patients. The study compared demographic, admission, and injury profile characteristics of GTCS versus UC-managed patients with TBI. We hypothesized that focused geriatric management by way of GTCS would improve acute care outcomes in older TBI patients by enhancing the quality of care those patients received.

In this study, we found that GTCS managed patients were associated with increased ICU and ALC admission, hospital-acquired complications, and overall LOS compared to their UC-managed counterparts. Furthermore, disposition to in-patient rehabilitation (IR) was higher amongst the GTCS patients.

These findings suggest that patients under GTCS management received more resources and were more likely to be referred for IR, all of which may contribute to a better quality of care, but also to a prolonged LOS. Therefore, the question of whether GTCS enhances geriatric TBI quality of care and whether it serves both as an effective and efficient intervention deserves further research.

Although, similarities between previous studies concentrating on GTCS, in general trauma care, suggest that improved outcomes in elderly trauma patients can be brought about by an emphasis on specialized geriatric care, the timely identification and treatment of complications and comorbidities, and an early (in the hospital course) focus on discharge placement (Dugan et al., 2017; W. Fallon et al., 2006; M Lenartowicz et al., 2012), important (clinically meaningful) differences between our exposure groups may have confounded our results – despite the matching strategy employed.

In addition, although GTCS management has been associated with increased sub-specialist consults, higher rates of ICU admission, and identification of hospital-acquired complications (Barry et al., 2019; M Lenartowicz et al., 2012), our comparable observations may not be generalizable. For example, at SMH, ICU admission takes place directly from trauma resuscitation bay (and before GTCS) - though we can infer that geriatric TBI patients with more severe injuries are more likely to be initially admitted to ICU and thereafter require GTCS management (Zador et al., 2016) - the distinct clinical care pathways among our exposure groups may have influenced these findings.

Therefore, in light of this studies methodological limitations, the results cannot fully support its hypothesis. Larger sample sizes, preferably from multiple TCs, would allow for better matching among comparators, specifically in terms of procuring a homogeneous injury group (iTBI or TBI+).

6.2 Limitations

Our overall goal was to see how generalizations from the literature applied to our local Level 1 TC. We found that, with some exceptions, they do.

Beyond this limited goal, however - as noted above - our data have a number of limitations. One of the clear limitations was the use of data from a single clinical setting. Our observations were derived from a single-center's clinical database of prospectively collected data and not originally collected to answer our specific study questions. The use of retrospective data adds in the potential for selection bias that is inherent to this type of analysis. Because our sample is observational in nature and taken from a single Level I TC, our results are not generalizable to the wider patient population, to all trauma centers where TBI is treated, or to health care systems without universal access payment structures.

Changes in data collection protocols and diagnostic coding procedures during the study time period could potentially bias the results and limit the generalizability of the findings. Patient- and treatment-level characteristics/variables chosen for analyses were limited by adequate access and availability to data in the registries, thus the results may be confounded by a number of factors influencing the observations. For example, the severity of pre-existing comorbidity, extracranial injury, and post-traumatic hospital-acquired complications were not expounded. The complexity of trauma management among the geriatric population is understood to pose additional challenges to the health care team which are largely attributed with pre-morbid health status (Brown et al., 2016) and propensity for in-hospital complications (Zafar, Shah, et al., 2015). Similarly, we did not expound on the severity or types of extracranial injuries and how they may effect patient outcomes. There is substantial evidence describing the significant impact that multisystem injuries in addition to a TBI have on patient outcomes, and when poorly defined may obscure descriptive conclusions (Mosenthal et al., 2004).

Our results may also be influenced by the choice to define age-associated differences on the basis of a chronological distinction of age 65 years. In the TBI population, wide discrepancies in outcomes are observed among discreet age stratums with some studies identifying 45 years or more as an inflection point by which the manifestations of declining physiological reserve reduces a patient's capacity to withstand and recover from serious injury (Adams et al., 2012; Caterino et al., 2010; Livingston et al., 2005). Even among the elderly sub-population, different patterns of trauma management and resulting outcomes emerge among discreet age-groupings (Hildebrand, Pape, Horst, Andruszkow, Kobbe, Simon, Marx, & Schürholz, 2016). This has led some to suggest that outcomes assessment of traumatic injury based on the concept of chronological age is challenged by factors corresponding to the patient's physiological age

(Buurman et al., 2011; W. Fallon et al., 2006). Therefore, when assessing acute care outcomes associated with TBI and other traumatic injuries, the evidence suggests that age ought to be treated as a continuous variable in an effort to address the physical properties of advancing age. However, in the present study we could not assess our end-points in that manner and even stratifying patients further by discreet age-subgrouping was difficult; the limited number of patient subjects would compromise the power of our analyses and flaw the ability to detect meaningful differences on outcome measures of interest.

Many of our conclusions are founded on statistically significant or clinically meaningful correlations. These relationships ought not to lead us to assume causality, such that a change in one variable causes the change in the other (correlated) outcomes. This is particularly germane to our interpretations of findings in the GTCS (Chapter 5) studies, where several factors associated with GTCS were clearly not caused by GTCS. Although strong correlations were revealed among patients receiving GTCS and clinical care factors such as increased ICU management and decreased surgical interventions, it would be erroneous to conclude that geriacentric care - by way of GTCS - is a causal factor for the hospital course described by the latter factors. Indeed, clinical decisions of either ICU and/or surgical management precedes GTCS patient referrals and are thus exclusive of GTCS intervention in the hospital course of patients.

In terms of cost estimates, the limited time period of the studies prevented us from reporting long-term costs of TBI upon discharge or investigating how LOS is associated with costs. We were also unable to explore the impact of physician billing on costs for patients and the wider healthcare system. Moreover, the use of age may also have obscured key differences, related to frailty, among our adult patient population. Age-associated differences in primary end points (mortality, LOS, resource use) may be over- or under-estimated because they were evaluated among patients admitted solely to our referral center and did not account for death, LOS, clinical procedures, or continuing care among patients during care at referring centers or in their post-acute dispositions.

6.3 Future Directions

Although the findings of this thesis are based on single-center observational study designs, they have provided important insights into the acute care characteristics of geriatric TBI patients in an efficient and timely fashion. The single-center design using data from the SMH trauma database, a large registry comprised of 7000 TBI adults which is maintained with strict adherence to national and international trauma data standards, provided comprehensive uniform data with limited missing variables of interest. Moreover, confounding factors such as heterogeneity in clinical practice over multiple TC were mitigated as a result of the single-center design. Thus, the interpretation of these results may be confidently applied to the generation of hypotheses for future prospective studies.

Among the areas that clearly deserve follow up are the surprising findings related to length of stay and resource use, and the unexpected findings related to the GTSC. Most importantly, further research is necessary to determine the evidence-based health care provision that is best able to meet the complex needs of those of all ages who experience a TBI. Moreover, performing multicenter randomized and longitudinal trials will be pertinent for developing a more comprehensive outlook of different long-term outcomes shaping the healthcare burden of geriatric TBI.

To investigate the associations between age and TBI in more detail, future studies might consider utilizing frailty measures within analyses, as well as considering mortality rate and LOS in pre-index hospital and post-acute phases of care among patients. This would allow us to better estimate risks for mortality and total hospitalization LOS. The ≥65 years of age designation may also obscure important differences within younger cohorts, thus fueling the need for investigations into more defined age ranges. This factor should be taken into account in studies that further evaluate distinct acute clinical pathways for older TBI patients, and the different intervention strategies necessary for distinct age brackets and injury types.

Additionally, further work is needed to evaluate the clinical course characteristics of patients exposed to GTCS, and in turn, how GTCS impacts specific clinical pathways. To adjust for such differences in clinical decision-making, future studies should investigate a larger sample size to better match patients with their triage and admitting physician characteristics. Consequently, future work should also compare geriatric iTBI patients admitted to neurosurgery versus TBI+ patients, as well as differentiate between orthodpedic versus neurosurgical interventions. Matching can be done on the basis of brain injury types instead, e.g. Marshall score classifications, frailty measures, and/or only iTBI or multisystem TBI patients. This further work would allow us to control for distinct TBI injury patterns when assessing quality improvements of GTCS in future work. Factors such as patient and family satisfaction, decision to continue care, and improvements in symptoms of delirium, depression, and pain, should also be further explored in this context.

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