EPIDEMIOLOGIC BURDEN OF TRAUMATIC BRAIN INJURIES: EFFECTS OF HEALTH INSURANCE COVERAGE AND RACE/ETHNICITY ON TRAUMA MORTALITY

A Dissertation

by

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ABSTRACT

Traumatic Brain Injury (TBI)-related public health burden disproportionately affects those ≥65 years of age and the growing burden of trauma-related mortality may be influenced by access to health insurance coverage and demographic characteristics such as race and ethnicity.

This project investigated the epidemiologic burden of TBIs in three papers. First, a systematic review of 34 published epidemiologic studies that provides an overview of TBI rate estimates in the U.S. The second paper used the Texas inpatient hospital discharge data to describe TBI-related hospitalizations and investigated factors associated with in-hospital mortality among the elderly patients hospitalized with a TBI in Texas. While the third paper used trauma registry records to investigate the burden of race/ethnicity and health insurance coverage on the risk of mortality among trauma patients in Texas.

From the systematic review, we found high variability in the methodology and data sources used by studies reporting TBI estimates contributing to the differences among the reported TBI rate estimates in the U.S. From the Texas inpatient hospitalization records, the overall 3-year TBI-related hospitalization rate was 64.68 (95% CI: 63.71 – 66.50). Males accounted for 57.83% of the patients hospitalized with a TBI and the elderly (≥65 years) had higher hospitalization rates. There were racial disparities in TBI outcomes; the adjusted odds of TBI-related in-hospital mortality for Hispanics was 1.18 times that of Whites [OR = 1.18: 95% CI (1.01 – 1.40)]. From the trauma registry, we found further outcome disparities where Hispanics of any race and Non-Hispanic Blacks had higher adjusted odds of trauma mortality compared to Whites [$OR_{Hispanics}$= 1.25: 95% CI (1.16 – 1.36)] [OR_{Blacks}= 2.11: 95% CI (1.87 – 2.37)]. Similarly, compared to privately insured, uninsured patients had 86% higher odds of trauma-related death [OR= 1.86: 95% CI (1.66 – 2.05)]. The effects of lack of health insurance on trauma mortality varied across race/ethnicity of the victims; uninsured Non-Hispanic Blacks had disproportionately higher adjusted odds of trauma mortality than uninsured Whites.

Using two different-statewide administrative datasets, we identified significant demographic and health insurance-related inequalities in trauma burden and outcomes. This identification could inform the design and implementation of future public health interventions.

DEDICATION

Dedicated to the memory of my deceased father for all the sacrifices he made to make sure I receive the best education. Also, to my brother Amiru who died from a TBI sustained from a road crash.

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NOMENCLATURE

AIS	Abbreviated Injury Score
BMI	Body Mass Index
CDC	Centers for Disease Control
CHIP	Children's Health Insurance Program
CI	Confidence Intervals
DALY	Disability Adjusted Life Year
DSHS	Department of State Health Services
ED	Emergency Department
EMS	Emergency Medical Services
GCS	Glasgow Coma Scale
HAR	Hispanic Any Race
HIV	Human Immune Deficiency Virus
ICD	International Classification of Diseases
ISS	Injury Severity Score
NHW	Non-Hispanic White
NHB	Non-Hispanic Black
NEISS	National Electronic Injury Surveillance System
OR	Odds Ratio
PUDF	Public Use Data File
PPACA	Patient Protection and Affordable Care Act

TBI	Traumatic Brain Injury
TxDOT	Texas Department of Transportation
TMA	Texas Medical Association
WHO	World Health Organization

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1. INTRODUCTION

1.1. Background

An injury or a trauma refers to any form of tissue damage following a transfer of energy beyond the capacity of the tissue to handle (Langley & Brenner, 2004). Trauma is a significant public health problem worldwide; no region or country is spared from the burden of injuries (Norton & Kobusingye, 2013). According to the World Health Organization (WHO), injuries are currently the ninth leading cause of mortality globally and is expected to increase in decades to come (WHO | Injuries 2017)]. Global burden of injury is heavily skewed against low and middle-income countries, over 90% of the injury-related mortalities occur in the low and middle-income countries (Chandran, Hyder, & Peek-Asa, 2010; Haagsma et al., 2016). In 2010, the total injury-related mortality exceeded the overall mortalities from HIV/AIDS, Malaria, and Tuberculosis (WHO | Injuries 2017).

There is a widespread perception that accidental injuries occur at random, leading to the view that there is little role for a public health intervention to reduce their incidence or impacts. The traditional classification of trauma into intentional, and unintentional (accidental) based on the presence or absence of an identifiable intent, has contributed to this perception (Krug, Sharma, & Lozano, 2000). However, the disproportionate burden of injury-related deaths seen mostly among countries with limited infrastructure and resources for interventions, suggests that intervention strategies may play a vital role in preventing both intentional and unintentional injuries (Hofman, Primack, Keusch, & Hrynkow, 2005). Even though injuries can occur irrespective of gender and age, the global burden of injuries report shows that males and younger individuals suffer a higher proportion of injuries (Stone, Jarvis, & Pless, 2001).

Describing the burden of trauma in any population requires the estimation of the contribution of trauma on both mortality and morbidity of that population. While mortality estimates are mostly straightforward, morbidity estimates are challenging because they require the estimation of both short, medium, and long-term effects of injuries (Horton, 2012; Norton & Kobusingye, 2013). On the global scale, the Disability Adjusted Life Years (DALY) is used to describe the burden for both morbidity and mortality attributed to injuries. The DALY represents an index that summarizes the number of years lost due to early death and years lost due to disability from the same injury type (Haagsma et al., 2016). DALYs are calculated by taking the sum of years lost due to premature death, and years lost due to disability (from the same injury type) weighted by the severity of the injury.

In the United States, rates of both fatal and non-fatal injuries have remained high (Rhee et al., 2014). The CDC's National Vital Statistics Report of 2018, ranked accidents (unintentional injuries) and suicides (intentional self-harm) as third and tenth leading causes of deaths (for all ages) in the United States respectively. Similarly, from the year 2000 to 2010, trauma-related deaths have increased among individuals aged twenty-five and above in the U.S. Trauma is currently the leading cause of death among individuals younger than forty-six in the U.S. (Fact sheet - injury data | WISQARS | injury center | CDC.2018).

1.1.1. Injury Classification

The injury pyramid, first described by Heinrich, et al. (1941) provides a theoretical framework for describing injury presentations based on severity (Polinder, Haagsma, Toet, & van Beeck, 2012). In a typical injury pyramid, there are four rows: The largest group at the bottom includes injured patients seen at a physician's office for mild injuries; the second largest include injuries treated at the emergency department (ED); next are patients whose injuries required hospitalization; fatal injuries are in the smallest portion on the top of the pyramid (Robertson, 2015; Wadman, Muelleman, Coto, & Kellermann, 2003).

Epidemiologic classifications of injury severity commonly rely on the clinical classifications that are assigned for prognostic purposes. Because these (severity) classifications are clinically-based, they are interpreted as the likelihood of fatality for the injured individual. However, for epidemiologic purposes, these classifications may not be adequate since they do not highlight the likelihood of disability from the injury (Stevenson, Segui-Gomez, Lescohier, Di Scala, & McDonald-Smith, 2001). Therefore, the most commonly used scales of injury severity classifications include the Abbreviated Injury Score (AIS) and the Injury Severity Score (ISS) Foreman et al., (2007).

The AIS involves assigning a score of any whole number from one to six (representing minor to lethal respectively) to nine body regions (head, face, neck, thorax, abdomen, spine, upper extremities, lower extremities and external). To obtain the maximum AIS, the scores assigned to each body region are added. In theory, the maximum AIS represents the overall severity of the injury; in other words, the higher the

AIS the more severe the injury. The ISS, on the other hand, involves regrouping the nine body regions (used in AIS) into six (head or neck, face, chest, abdominal or pelvic contents, extremities or pelvic girdle, and external). To calculate the ISS, three most severely injured regions are chosen from the six, and a sum of the squares of the highest score for those regions is calculated. The range of the ISS is 1 to 75 in an ordinal scale that represents increasing severity (Stevenson, Segui-Gomez, Lescohier, Di Scala, & McDonald-Smith, 2001).

1.1.2. Injury Mechanism and Prevention

Regardless of the type of injury, the mechanism of an injury involves the transfer of energy at levels that exceed the capacity of tolerance for human tissues. The amount of energy is also proportional to the severity level of that injury (Langley & Brenner, 2004; Li & Baker, 2012; Robertson, 2015). In traditional epidemiology, especially infectious disease epidemiology, the agent, host, and environment interaction is mostly used to determine the causes of disease. Referred to as the epidemiologic triad, this model implies that diseases are caused by an interplay of multiple factors, i.e., Agent, Host, and Environment (Li & Baker, 2012; Robertson, 2015). A similar model is also used in injury epidemiologic research to describe the pathological basis of injuries. In injury epidemiology, the agent, which is the etiologic factor, refers to the energy that is transferred to the body before an injury occurs. The host refers to the individual or groups that may be at risk of the injury. While the environment includes factors such as the circumstances or conditions that directly or indirectly influence the injury occurrence. In injury epidemiology, the environment influences both the host and the reservoir or vector that transmits the energy (Li & Baker, 2012).

The Haddon Matrix is a conceptual model that is widely used to explain the agent-host-environment relationship as far as injury prevention is concerned (Robertson, 2015). The model shows the roles and interactions of the three factors (Agent, Host, and Environment), it also highlights opportunities for different public health intervention levels.

The Haddon Matrix has three phases, the first phase is the time before an injury event, while the second phase is the time during the injury, and the third phase is the time after the injury. Primary prevention is usually aimed at eliminating the occurrence of the injury to the host before it happens. Therefore, it is limited to the pre-injury phase. There are opportunities to implement primary prevention strategies on the host, the vehicle, and the environmental factors. Secondary interventions commonly aim to reduce the amount of energy transmitted to the host, the focus is thus, on the injury phase. Intervention strategies could focus on reducing flammable building materials or providing tools with blunted edges.

Similarly, for tertiary prevention, the aim is to limit complications from injuries. Therefore, the focus is on the post-injury phase. Tertiary intervention strategies could involve measures to evacuate injured persons, or measures aimed at preventing blood loss, etc. (Li & Baker, 2012; Robertson, 2015).

1.1.3. Role of Insurance Status and Race/Ethnicity on Trauma Outcomes

In terms of overall health outcomes, previous studies have shown that health outcomes follow social gradients; individuals within lower social stratum usually suffer worst outcomes (Bovbjerg & Hadley, 2007). Studies also showed that uninsured patients generally tend to accumulate more healthcare bills and use more ambulatory health resources than insured patients (Mollayeva et al., 2018; Bovbjerg & Hadley, 2007; Davis & Rowland, 1983).

In addition, evidence suggesting the influence of demographic and economic factors such as race, gender, and health insurance coverage on access to care among patients with chronic conditions such as diabetes or kidney disease, has been presented in previous studies (Hayward, Miles, Crimmins, & Yang, 2000; Heisler, Smith, Hayward, Krein, & Kerr, 2003; Isaacs et al., 1999).

For trauma victims, studies of associations between demographic and socioeconomic factors with trauma patients' outcome have been mixed. For instance, in a study using state-level healthcare data from South Carolina, Selassie, (2004) found racial disparities in access to care; with African-American females less likely to be hospitalized following a TBI compared to their White-uninsured counterparts.

Similarly, in terms of outcomes of trauma victims, studies by Haider (2008), and Salim (2010) found that individuals who lack health insurance coverage, and those from minority racial groups may have higher mortality risks (Greene et al., 2010; Haider et al., 2008; Salim et al., 2010). Similarly, for hospitalized trauma patients, those from minority racial groups were shown to suffer worse functional outcomes after hospital discharge (Arango-Lasprilla et al., 2007; Chang et al., 2008). A systematic review and meta-analysis of studies by Haider et al., (2013) also found racial and socioeconomic disparities in the outcome of trauma patients in the U.S.

However, other studies have reported contrasting results. For example, after evaluating outcomes of patients in the Longitudinal Traumatic Brain Injury (TBI) Rehabilitation Program, Hart et al., (2005) reported no racial discrepancy in the outcome of TBI patients. Similarly, Bazarian, et al., (2003) concluded that there was no association between gender and access to care among of trauma patients. Therefore, additional research is needed to better understand the roles of demographic and economic factors in trauma patient’s outcome.

1.1.4. Health Insurance Coverage in Texas

According to the U.S. Census Bureau, Texas has an estimated total population of over twenty-eight million; this is second only to California (U.S. census bureau Quick Facts: Texas.). The Texas Medical Association (TMA) estimates that, at least 20% of Texans do not have health insurance coverage (TMA: Health Insurance Coverage 2017). Texas has both the highest number and percentage of individuals without health insurance of any U.S state. The decision by the authorities in Texas not to expand Medicaid under the Patient Protection and Affordable Care Act (PPACA) has contributed to the high proportion of the uninsured population in Texas as well as the most extensive coverage gap. About 15% of the uninsured population in Texas could receive coverage if Medicaid were to be expanded under the ACA (Texas and the ACA’s Medicaid expansion: Eligibility, enrollment, and benefits. 2019).

1.1.5. Traumatic Brain Injury (TBI)

Traumatic brain injury (TBI) is a leading public health problem globally. TBI is frequently referred to as a "silent epidemic" in part, because complications that result from TBI, such as impaired cognition and memory, are often not readily apparent (Faul, et al., 2010), and the lack of clear and unambiguous definition of TBI which hampers understanding of TBI epidemiology (Menon et al., 2010).

According to the Centers for Disease Control (CDC), a TBI is defined as “a disruption in the normal function of the brain that can be caused by a bump, blow, or jolt to the head, or penetrating head injury” (Traumatic brain injury | concussion | traumatic brain injury | CDC injury center.2019). However, the Demographic and Clinical Assessment Working Group of the International and Interagency Initiative toward Common Data Elements for Research on Traumatic Brain Injury and Psychological Health, has proposed a standard definition of TBI to be “any alteration of the brain function, or other brain pathology, caused by an external force” (Faul et al., 2010; Menon et al., 2010). Regardless of the definition, every TBI results from an external force delivered to the brain which results in either a structural or physiological change in the brain (Menon et al., 2010).

There are several methods of classifying a TBI; most of these methods relate specifically to the clinical status of the patients and are not designed specifically for epidemiologic purposes. For instance, the most commonly used classification of TBI into mild, moderate, and severe, is based on the Glasgow Coma Scale (GCS) (Udekwu, Kromhout-Schiro, Vaslef, Baker, & Oller, 2004). The GCS is a clinical scoring system of a suspected brain-injured patient that assesses three components; eye-opening, motor, and verbal responses. The total score for a fully conscious individual is fifteen, while a score of three represents a deeply comatose patient. A suspected TBI patient could be assigned any score between three and fifteen (Hawryluk & Manley, 2015). Other scoring systems used in TBI classification include the Abbreviated Injury Score (AIS), and the Injury Severity Score (ISS) described above.

Symptoms of TBI are also variable, for easy understanding, they are classified into three main categories. The first category is comprised of symptoms relating to cognitive dysfunction; these include memory loss, slowing of thought process, and concentration/attention deficits, etc. The second category includes physical symptoms such as loss of consciousness, slurring of speech, seizures, severe headaches, postural and walking difficulties, etc. The third category of symptoms comprises mainly of symptoms relating to the emotional wellbeing of the individual; they include depression, anxiety, and paranoia. The onset of symptoms is similarly variable, from a few hours to days, with some symptoms of TBI manifesting several months or years after the injury (Lundin et al., 2006). Due in part, to the variability in the onset of symptoms and the nature of the symptoms, some TBI researchers are advocating for the consideration of TBI as a chronic neurological condition rather than an event (Corrigan & Hammond, 2013; Masel & DeWitt, 2010).

1.1.6. Global and United States Burden of TBI

While there were consistent reductions in the burden of TBI from the 1950s to late 1990s, over the last 20 years, little progress has been made in reducing the numbers of TBI (Brazinova et al., 2015). The pooled global incidence of TBI was reported to be 349 (95% CI 961-266) per 100,000 person-years (Nguyen et al., 2016). Mild TBI is far more common than moderate and severe TBI, pooled global incidence of mild TBI is 224 (95% CI 120–418) per 100,000 person-years which is 10 and 17 times higher than the incidence of moderate and severe TBI respectively (Dewan et al., 2018; Li, et al., 2016; Nguyen et al., 2016)). A recent systematic review and meta-analysis of European-based observational studies describing the epidemiology of TBI reported an overall incidence rate of 262 per 100,000 from 28 studies (Peeters et al., 2015). Another European-based systematic review of TBI-related studies found crude incidence rates of TBI ranging between 47.3 per 100,000 to 694 per 100,000 (Brazinova et al., 2015).

In the U.S., the CDC estimates approximately 2.2 million people sustain a TBI annually, of those, about 52,000 are fatal, 280,000 are hospitalized, and 1.3 million are treated and released from an ED. In the U.S., the prevalence of persons living with a TBI-related disability is estimated to be between 3.2 million and 5.3 million (CDC's Report to Congress 2015). However, the national estimates provided by the CDC are based solely on extrapolations of state-level data from South Carolina and Colorado (Centers for Disease Control and Prevention, 2015). The lack of state-level data is a serious limitation to the understanding of the epidemiology of TBI, which is listed as a contributing factor in a third of all injury-related deaths. Off all types of injuries, TBI is more likely to lead to a long-term disability with survivors of TBI having an increased risk of diseases such as stroke, epilepsy, depression, and other major cardiovascular disorders (Frankel et al., 2006; Thompson et al., 2006; Nyam et al., 2019). Rates of TBI-related deaths, TBI-related hospitalizations, and ED visits are higher among the elderly (Thompson 2006). In 2010, rates of TBI-related deaths were 45.2 per 100,000 for those aged above 65; this is the highest among all age groups (TBI data and statistics | concussion | traumatic brain injury | CDC injury center.2019).

According to the CDC estimates, rates of TBI vary by age and gender. Men have higher rates of overall TBI-related ED visits, hospitalizations, and death than women. In 2001, rates of TBI-related deaths, hospitalizations, and ED visits were 27.8 per 100,000 for men, compared to 9.6 per 100,000 for women. A similar pattern was maintained throughout the decade, with men vs. women rates changing to 27.8 per 100,000 vs. 9.7 per 100,000 then 25.4 per 100,000 vs. 9.0 per 100,000 in 2005 and 2010 respectively.

In many epidemiologic studies, TBI is described according to the mechanism of injury or external cause. The CDC's TBI burden estimations commonly use six external causes of TBI in its descriptions, including (i) falls, (ii) motor vehicle traffic, (iii) assault, (iv) self-inflicted, (v) struck by/against, and (vi) others. Fall-related TBI accounts for over 50% of TBI-related deaths among those aged above 65 years. However, among children and young adults, assaults and motor vehicle traffic crashes account for most the TBI-related deaths and hospitalizations (TBI data and statistics | concussion | traumatic brain injury | CDC injury center.2019).

1.1.7. TBI Burden in Texas

In the State of Texas, reliable estimates of the burden of TBI are limited. The Texas Department of State Health Services (DSHS) injury indicators report, shows that in 2012, the total TBI-related mortality was 4,001, which was 28% of all injury-related mortalities within the state. However, no details on the distribution of TBI within the state are available (Texas DSHS: State Injury Indicators Report 2012).

Similarly, in the 2018 report, The Texas Brain Injury Advisory Council (TBIAC), a council established by Texas Legislature to "to give brain injury survivors, their families and caregivers, service providers and state agencies a voice in identifying and meeting the needs of people with brain injury" reported 22,614 cases of TBI in Texas as of August 2014. These totals likely underestimate the actual TBI burden in Texas because only 59% of the reporting hospitals had submitted data (The Texas Brain Injury Advisory Council 2018 Report, p.5-7).

Giving this data limitations, more epidemiologic studies are needed to have a more reliable estimate of TBI and understand the TBI public health burden in Texas. *Therefore, the overarching goal of this dissertation is to improve understanding of the epidemiologic burden of trauma, highlight possible mortality risk inequalities, as well as help in identifying the factors contributing to higher TBI-related mortality among the elderly.*

1.2. Specific Aims

With our understanding of both the burden and determinants of TBI changing globally, higher incidence of TBI among older individuals now seen in several developed countries (Maas, 2016; Roozenbeek, 2013). There is a need to conduct detailed epidemiologic studies that would improve our understanding of the epidemiology of TBI in the U.S. Therefore, the specific aims of this dissertation are to

AIM 1: To provide a contemporary overview of the epidemiology of TBI in the U.S. using a systematic review of published epidemiologic studies.

Rationale: Several systematic reviews describing the European population-level epidemiologic burden of TBI were published. Even though there are sociodemographic similarities between the European and the U.S. populations, to better understand the epidemiology of TBI in the U.S., there is need to conduct a similar systematic review that will focus only on the U.S. population.

AIM 2: To use the Texas in-patient's hospital records (2012 – 2014) to describe TBI-related hospitalizations and assess the clinical and demographic factors associated with in-hospital mortality among individuals aged at least 65 years that are hospitalized with a TBI.

Rationale: With increasing cases of TBI now seen among the elderly who are also reported to have the highest TBI-related mortality, public health interventions targeting this sub-group could be beneficial (Jochems et al., 2018). Therefore, the identification of modifiable factors that predict in-hospital mortality among this age group is required for interventions to be successful.

AIM 3: To use the State of Texas trauma registry records (2014 – 2016) to describe the epidemiologic burden of trauma mortality including TBI, and assess the effects of health insurance coverage, and race on the risk of mortality among trauma victims in Texas.

Hypothesis: Trauma victims from minority racial groups and those without health insurance coverage have higher risks of mortality than their counterparts.

Rationale: Previous studies using trauma records from South Carolina have reported a lack of equity in access to care and disproportionate outcomes among trauma patients based on race and health insurance coverage. However, due to variability in population demographics and access to health insurance across states, these findings may not be generalizable. The state of Texas has the largest proportion (20% in 2017) and highest number of residents without health insurance than any U.S. state.

1.3. Public Health Significance

By both definition and purpose, public health is about the promotion of health to the population. Through epidemiology, we strive to describe the distributions of public health problems, identify populations at risk, and identify modifiable factors that could reduce those risks. Development of an effective intervention against any public health problem depends not only on a valid assessment of the burden but on the identification of the population at risk, as well as possible risk factors of such a problem (Holder, 2001). Surveillance of injuries using trauma registry provides an opportunity to have a valid assessment of the epidemiologic burden of injury morbidity and mortality. This estimation is particularly important in Texas because there are many injury preventions programs throughout the state. However, there appears to be no comprehensive analysis of state-level data that describes the state-wide epidemiologic burden of trauma.

Similarly, in a state where at least 20% of the population do not have health insurance and 22% belong to different racial minority subgroups, an assessment of the effects of health insurance coverage, and race on mortality risk is needed. Findings from such investigations could help to shape future policy decisions aimed at preventing unintentional discriminations and to foster equity in the utilization of health care resources.

2. TRAUMATIC BRAIN INJURY IN THE UNITED STATES: A SYSTEMATIC REVIEW

2.1. Introduction

Traumatic brain injury (TBI) is an important public health problem in the U.S. However, it is frequently referred to as a 'silent epidemic' because the complications that result from TBI, such as impaired cognition and memory loss, are often not readily apparent and society is largely unaware of the magnitude of the TBI public health burden (Faul et al. 2010).

Reliable TBI estimates are required to identify population subgroups with the highest burden, as well as to identify determinants of TBI for the purpose of designing public health interventions (CDC, 2019). According to published studies and reports, population estimates of TBI vary depending on age and gender. For example, TBI-related death and hospitalization rates are higher among males and individuals over age 65 years compared to females and younger people (Thompson, 2006; Peterson, Xu, Daugherty, & Breiding, 2019). Variation in TBI estimates reported in epidemiologic studies are due in part to the differences in the case definitions of TBI applied in the study or to the sources and methods used to obtain data. The lack of a national TBI surveillance system has also contributed to our poor understanding of the distribution of TBI (CDC report – 2003 p.2).

According to the Centers for Disease Control (CDC), approximately 2.2 million people in the U.S. sustain a TBI annually; of those, about 52,000 are fatal, while 280,000 results in hospitalizations, and 1.3 million receive treatment and are released from an ED. The prevalence of persons living with a TBI-related disability is estimated to be between 3.2 million and 5.3 million. However, according to a 2015 CDC's report to Congress on TBI, these estimates are based on extrapolations of state-level data from South Carolina and Colorado (CDC's Report to Congress 2015 p.21).

Published systematic reviews and meta-analyses of observational studies describing the epidemiology of TBI in Europe have reported inconsistent TBI estimates from observational studies over the past twenty years. In 2015, Peeters et al. reported an overall incidence rate of 262 per 100,000 from 28 studies (Peeters et al. 2015). Another European-based systematic review of TBI-related studies found crude incidence rates of TBI ranging between 47.3 per 100,000 to 694 per 100,000 (Brazinova et al. 2016). Similarly, Tagliaferi et al. (2005) reported a pooled TBI-related hospitalization and death rates of 235 per 100,000 in Europe. However, all three reviews attributed the variability in TBI rates to differences in case definitions and inclusion criteria for individual studies.

To better understand the burden of TBI in the U.S., there is a need to conduct a systematic review focusing only on U.S. populations. This review aims to provide an overview of studies reporting the epidemiology of TBI in the United States and highlight the differences in the methodological approach followed by the studies.

2.2. Methods

The review methodology in this study was, in part, adapted from a published systematic review and meta-analysis of TBI among European populations (Peeters et al.

2015). The protocol was registered and published on the international database of prospectively registered systematic reviews – PROSPERO. *[CRD: 42019117761].* A search was conducted in the electronic databases of Medline-Ovid and CINAHL in July 2019. Search terms used included epidemiology, incidence, prevalence, traumatic, brain injury*, head injury, mortality, and United States.

Potentially relevant articles were identified and transferred to Rayyan QCRI, a web-based app for systematic reviews developed by Ouzzani, Hammady, Fedorowicz, & Elmagarmid (2016). Articles were subsequently screened against the inclusion and exclusion criteria in two steps; a title and abstract review and a whole article review.

2.2.1. Inclusion and Exclusion

Studies were included if they met all the inclusion criteria as follows: (I) Studies were required to be primary observational studies, including cohort, case-control, and cross-sectional studies. Review articles, duplications, and commentaries were excluded. (II) Studies were required to be predominantly about the epidemiology of TBI. They must report either incidence, prevalence, mortality, or case fatality rate of TBI for a U.S. population (hospital-based, local, state, or nationwide). (III) Studies must report estimates for the general population, not a subgroup such those serving in the military, athletes, or those with another specific condition. However, there was no age, gender, race-ethnicity, or injury mechanism restriction. (V) Studies were required to be published in English with full text available to be included. (IV) Studies were required to have been published between 1998 and 2019; studies reporting on data obtained exclusively before 1998 were excluded.

2.2.2. Data Extraction and Methodological Quality Assessment

Included studies were first categorized based on the population estimates they reported (e.g. national-level, state-level, or others). Studies were also stratified based on the type of estimate they reported, incidence, prevalence, or mortality rate. Studies were also grouped based on their case ascertainment method and the type of TBI investigated (e.g. mild (concussions), severe, or all types). Relevant data, where available, were extracted from the articles, including: (I) source population, (II) study period, (III) sample size, (IV) data source, (V) the estimate (incidence, prevalence, or mortality rate), (VI) age distribution, and (VII) gender distribution, (VIII) TBI severity, and (IX) publication year.

Studies were evaluated for methodological quality using the STROBE Checklist (Knottnerus & Tugwell, 2008). Individual studies were assessed for completeness and studies judged to have incomplete elements were identified, and the missing component noted.

2.3. Results

A total of 5,556 of potentially relevant studies were identified from the two electronic databases, 124 of which were duplicates. After the title and abstract review, 5,267 studies were excluded for lack of relevance leaving 165 studies for full article review. After the full article review, 131 studies were further excluded for not meeting the inclusion criteria, leaving 34 studies to be included in this review (**Figure 2.1.**)

2.3.1. Study Characteristics

Fifteen (44.1%) of the studies reported national TBI estimates, ten (29.4%) reported state-level estimates (for a single state), and five (14.7%) reported cumulative estimates for a group of selected states (**Table 2.1.**). Twenty-four studies (70.6%) investigated and reported the epidemiology of all types of TBI regardless of severity or specific injury mechanism, four (11.8%) studies reported estimates for mild TBIs and/or concussions, while four (11.8%) studies reported TBIs based on injury mechanism, location, or injury intention. Only two (5.8%) studies reported exclusively on the mortality of TBI, three (8.8%) reported on TBI prevalence, and the remaining twenty-nine (85.3%) estimated either ED visit rates, hospitalization rates, or combination of both. In terms of sources of data, thirty-one studies (91.2%) used secondary data sources including hospital and ED discharge records and trauma registries. Only three (8.8%) of the studies used data from face-to-face or telephone interviews (**Table 2.2.**). Eleven (32.4%) studies reported exclusively on the population less than 18 years old, while three (8.8%) studies reported exclusively on the elderly (65 years and above) (**Table 2.1.**).

2.3.2. Case Ascertainment and Methodological Quality

Overall, twenty-eight (82.4%) of the studies used the CDC-recommended case definitions based on ICD-9, ICD-9-CM, or ICD-10 diagnosis codes suggestive of a TBI. Among the six studies that did not use the CDC-recommended case ascertainment method, three (8.8%) relied on a self-reporting of TBI by respondents during surveys, two (5.8%) used specific codes relevant to the National Electronic Injury Surveillance

System (NEISS), and one (2.9%) study employed manual review of patient's medical records to identify TBIs (**Table 2.2.**).

In the methodological quality assessment, twenty-one (61.8%) studies were judged to have completed all the STROBE elements. Among the thirteen studies with incomplete elements, nine (26.5%) studies were missing only one element of the checklist, while the remaining six (17.6%) studies were missing multiple elements (**Table 2.2.**).

2.3.3. TBI Estimates and Trends

Considering studies that reported on TBI-related hospitalizations exclusively (irrespective of the setting; nationwide or state-level), rates ranged from 70.0/100,000 to 155.9/100,000. While for studies reporting exclusively on ED visits, the variability was higher; TBI-related ED visits rates ranged from 304/100,000 to 1722/100,000. However, there was less variability for mortality estimates, TBI-related mortality rates ranged from 18.4/100,000 to 21.6/100,000. According to the studies that reported prevalence of a TBI via self-reporting surveys, the proportion of respondents who reported having a life-time episode of a TBI ranged from 2.5 to 42.5

Focusing on studies reporting nationwide rates or used nationally representative database for estimates, TBI-related hospitalizations have fluctuated from 70.9/100,000 in 1999 to 99.9/100,000 in 2003 and finally to 96.0/100,000 in 2008 (**Table 2.1.**).

2.4. Discussion

A substantial amount of the TBI-related research published over the past two decades has been undertaken to obtain reliable estimates and improve our understanding of the distribution of TBI among subgroups in U.S. population. In previous reviews of TBI-related research, variability in data sources and case ascertainment methods was suggested as the leading cause of varying TBI estimates (Brazinova et al., 2015; Peeters et al., 2015). In this study, we reviewed studies that used highly variable sources of data and methods of case ascertainment which resulted in highly variable TBI rates. This review supports the contention that differences in case ascertainments are responsible, at least in part, for the variability in TBI rates estimates. The result from this review is consistent with previously published systematic reviews on the epidemiology of TBI in European populations (Brazinova et al., 2015; Peeters et al., 2015; Bruns Jr & Hauser, 2003; Tagliaferri, Compagnone, Korsic, Servadei, & Kraus, 2006).

2.4.1. Case Ascertainment

Currently, the gold standard for the identification of TBI cases in most electronic data sources is the CDC-recommended ICD-9, ICD-9-CM, or ICD-10 diagnostic codes. These codes are assigned by care providers to represent a diagnosis or a procedure rendered to a patient (Alexander, Conner, & Slaughter, 2003). In addition to the diagnostic codes, injured patients have an associated external code or E-code accompanying their encounter with a care provider. E-codes are used to identify the cause or circumstances of the injury. However, because both diagnostic and E-codes are primarily designed for billing and other administrative purposes, their usefulness in disease surveillance is limited. For instance, Bazarian (2008) found substantial false positives and false negatives associated with the use of ICD-9 diagnostic codes to retrospectively identify mild TBI cases. Bazarian investigated a cohort of patients presenting to an ED and found that case identification of mild TBIs using ICD-9 diagnostic codes had a sensitivity of 45.9% and a specificity of 97.6% (Bazarian, Veazie, Mookerjee, & Lerner, 2006).

In this review, several studies relied on the self-reported occurrence of a TBI. While self-reporting may capture mild TBIs that are not likely included in hospital or ED records, a failure to adhere to case definitions and recall bias could present validity issues to self-reported TBIs (Cook, 2010). For example, estimates could be biased towards the null since survivors of TBIs are more likely to have challenges with cognition and memory impacting their ability to remember past injury events including a TBI (Vakil, 2005).

2.4.2. Different types of rates

The comparisons of TBI estimates is also confounded by the differences in the type of rates reported. According to the injury pyramid, injury presentations are influenced by the severity of the injury, with severe injuries more likely to result in deaths, hospitalizations, and ED visits (Robertson, 2015; Wadman, Muelleman, Coto, & Kellermann, 2003). This means mild TBI cases are less likely to be captured in the secondary data sources used by most TBI estimates because they do not result in either death, hospitalization, or ED visit. This suggests that most available estimates are biased towards the null.

In this review, only one study tried to estimate lifetime TBI prevalence through self-reporting of any TBI. To better understand the overall TBI public health burden, the CDC has consistently encouraged the estimation of non-fatal TBIs that did not result in hospitalizations or ED visits (The CDC report – 2003). These non-fatal and less severe TBIs must be estimated to improve our understanding of the true TBI burden. Towards this effort, data from physician office visits have the potential to capture these subgroups of TBI patients not usually included in most of the calculations for TBI estimates.

2.4.3. Concussions and mild TBIs

Concussions or mild TBIs are a special group of TBIs that have received substantial amount of research (Voss, Connolly, Schwab, & Scher, 2015). Generally mild in severity, they are usually diagnosed based on a combination of symptoms and radiological imaging. Because many of the health effects of concussions come later in life, identifying determinants of concussion among population subgroups is key to the development of concussion-prevention interventions (CDC, 2019). However, concussions estimates are not reliable because not all concussion episodes are captured in most of the databases. For example, despite the legal requirement to report all concussion cases, substantial amount of athletic concussions at collegiate level are unreported (Chrisman, Schiff, Chung, Herring, & Rivara, 2014; Llewellyn, Burdette, Joyner, & Buckley, 2014).

To improve the specificity of screening for concussions, the CDC received a mandate to launch a national concussion surveillance system in 2018 (TBI Program Act, 2018). The system is expected to provide more reliable national estimates of concussion, highlight common causes of concussion, and allow for monitoring trends of concussion incidence over time (CDC, 2019). Even though any surveillance system may provide incomplete case ascertainment, there is strong evidence that public health is improved through the implementation of surveillance systems (Choi, 2012).

2.4.4. State-level estimates

National TBI estimates rely on an extrapolation of a few state-level data, this is a significant limitation that could adversely affect our understanding of the public health burden of TBI. While the CDC has called for the compilation of state-level TBI estimates from hospital discharge records, ED records, and other administrative data sources, little progress has been made towards fulfilling this mandate (CDC's Report to Congress 2015 p.19).

Stronger statewide monitoring of TBIs will help to identify the distribution and longer-term trends in TBIs that are needed for local prevention plans to be effective (Lagbas, Bazargan-Hejazi, Shaheen, Kermah, & Pan, 2013; Tieves, Yang, & Layde, 2005). From this review, we found only ten published statewide TBI estimates. While additional statewide TBI estimates may be available from sources that did not meet our inclusion criteria, a gap still exists with regards to the availability of state-level TBI estimates.

2.4.5. Strengths and limitations

This review followed the recommended best practices for systematic reviews of incidence and prevalence studies (Munn, Stern, Aromataris, Lockwood, & Jordan, 2018). The search terms used were robust enough to capture relevant studies in the two databases and inclusion criteria were deliberately constructed *a priori* to obtain studies relevant for review. However, studies may have been missed if they were not indexed in either of the two databases or published before 1998. Reports and estimates not published in peer-reviewed literature were not included, which is a limitation of many studies using population health rather than clinical data.

2.4.6. Recommendations

Reliable national TBI estimates can serve as the foundation upon which public health prevention strategies are based. The development of these prevention strategies is critical as TBI prevalence increases and the population ages. A wide range of potential sources of national-level TBI data should be considered moving forward to improve understanding of the epidemiology of TBI. Updated state-level estimates should continue to be reported; however, administrative hospital and ED discharge records may also offer important and reliable local TBI data that should be used more frequently. Because of differences in the demographics of populations across states in the U.S., we believe that the compilation and availability of additional state-level estimates will provide a clearer picture of TBI epidemiology in the U.S. than analysis of national databases. We also support the suggestion by Corrigan & Hammond (2013) for the consideration of TBI as an independent neurological condition, not just an injury. This recognition would further drive the needed clinical and epidemiologic research towards understanding TBI and reducing its impact on public health.

3. TRAUMATIC BRAIN INJURY – RELATED HOSPITALIZATIONS: FACTORS ASSOCIATED WITH IN-HOSPITAL MORTALITY AMONG ELDERLY TBI PATIENTS

3.1. Introduction

Traumatic brain injury (TBI) is a leading public health burden globally. In part because the lack of clear and unambiguous definition of TBI (Menon et al., 2010), and because deleterious effects resulting from a TBI, such as impaired cognition and memory loss, are often not readily apparent (Faul et al., 2010), TBI is frequently referred to as a "silent epidemic".

The U.S. Centers for Disease Control and Prevention (CDC) estimates approximately 2.2 million people sustain a TBI annually in the U.S.; of those, about 52,000 are fatal, while 280,000 results in hospitalizations and 1.3 million receive treatment and are released from an Emergency Department (ED). TBIs are responsible for a third of all injury-related deaths in the U.S. (Bruns Jr & Hauser, 2003; Faul et al., 2010). Among many injuries, TBI is the most likely to lead to death or a long-term disability; survivors have an increased risk of diseases such as stroke, epilepsy, depression, and other major cardiovascular disorders (Frankel et al., 2006; Thompson et al., 2006; Nyam et al., 2019). The prevalence of persons living with a TBI-related disability in the U.S. is estimated to be between 3.2 million and 5.3 million (CDC's Report to Congress 2015).

Elderly patients have higher rates of TBI-related deaths, TBI-related hospitalizations, and TBI-related ED visits (Thompson, 2006). In 2014, national rates of TBI-related deaths and hospitalizations were the highest for those aged ≥75 years (78.5 and 470.6 per 100,000, respectively) (Peterson, Xu, Daugherty, & Breiding, 2019). This increasing TBI-related mortality among the elderly calls for more investigation to identify patient and hospital factors associated with in-hospital mortality among hospitalized TBI patients.

Another limitation identified in the population-level estimates of the TBI burden is the lack of state-level estimates for many states. According to the CDC, most of the national TBI estimates are based on extrapolations of state-level data from few states. Therefore, to improve the overall TBI estimates, the CDC encouraged nationwide passive surveillance of TBI using different types of administrative health care data for state-level TBI estimates (CDC's Report to Congress 2015 p.19).

Nevertheless, in Texas, reliable estimates of TBI distribution are not available. The Texas Department of State Health Services (DSHS) injury indicators report shows that in 2012, the total number of TBI-related mortality was 4,001 with an age-adjusted rate of 16.1 per 100,000. However, no details on the distribution of TBI within the state are available (Texas DSHS: *State Injury Indicators Report 2012*).

This study aims to provide a descriptive epidemiology of TBI-related hospitalizations in Texas and investigate clinical and demographic factors associated with in-hospital mortality among elderly patients hospitalized with a TBI in Texas.

3.2. Methods

3.2.1. Study Design and Data

This is a cross-sectional study using the Public Use Data File (PUDF) of Texas Hospitals Discharge Data (2012-2014). By statute, all non-federally regulated hospitals in the state of Texas are required to submit records of all hospitalizations and discharges from their facilities to the Texas DSHS. Information submitted in the records includes relevant demographic, clinical, and provider data for each patient. However, for patients with an alcohol abuse or a Human Immunodeficiency Virus (HIV) diagnosis, the age, gender, race, and ethnicity variables are suppressed by the DSHS for confidentiality reasons (Texas Code, 2011). This data suppression involved a total of 8,645 (16.9 %) patients between 2012 to 2014. The analysis reported in this study excludes all the patients with suppressed demographic variables.

For all patients, we searched the principal diagnosis field and all the additional fields for an ICD-9-CM code representing injury-related discharge to create an all-injury cohort. We subsequently identified TBI-related hospitalizations from the all-injury related discharge cohort using ICD-9-CM codes for a TBI (**Figure 3.1.**).

3.2.2. Exposures and Outcome

In-hospital mortality, dichotomized from the status of patients at discharge, was the outcome variable for this analysis. Exposures evaluated for possible association with in-hospital mortality were selected based on what has been published in peer-reviewed literature (Utomo et al., 2009) and whether the variable was available in the dataset. The following demographic factors were included: age, categorized into five-year age-groups; gender, dichotomized into male and female, and race/ethnicity; categorized as White, Hispanics, Blacks, and Others. Clinical variables included TBI severity, obtained from the provider-assigned illness severity and categorized as moderate, severe, and critical (mild cases were excluded). TBI cause was categorized according to the CDC framework, using E-codes for fall-related, motor-vehicle accidents, assaults, struck-by or against, and others (Centers for Disease Control and Prevention, 1997). Patients were also dichotomized based on the presence of comorbid conditions listed in the Elixhauser index of comorbidities (Elixhauser, Steiner, Harris, & Coffey, 1998). Additional factors evaluated were admission type, where patients were dichotomized based on the facility they were admitted, designated trauma centers, and others. Length of stay representing the number of days the patient was hospitalized was included as a continuous variable (Ostermann et al., 2018).

3.2.3. Statistical Analysis

Counts of TBI-related hospitalizations were obtained by age-group and gender. Rates and 95% confidence intervals (CI) were estimated using same-year census data obtained from the U.S. Census Bureau (U.S. Census Bureau, 2019).

Because of the disproportionate burden of mortality against the elderly, the in-hospital mortality analysis was restricted to patients aged ≥65 years. Unadjusted logistic regression models predicting the likelihood of in-hospital mortality were fitted for each exposure to estimate the unadjusted effects of the exposure on in-hospital mortality. Odds ratios (OR) and 95% CI were estimated for each. A multivariate logistic regression model predicting the likelihood of in-hospital mortality was subsequently fitted to obtain adjusted effects of the exposures on the outcome. Covariates in the multivariate model included all the exposures irrespective of the statistical significance of their univariate (unadjusted) association with the outcome.

All statistical analyses were performed using SAS (V. 9.3). Any CI not including the null value was interpreted as indicating a statistically significant difference in the ORs.

3.3. Results

There were a total of 51,435 TBI-related hospitalizations from 2012 to 2014 in Texas; 3,546 (7.09%) died in-hospital (**Table 3.1**). Total counts and rates of TBI-related hospitalizations decreased from 18141 (69.48 per 100,000) in 2012 to 15149 (56.17 per 100,000) in 2014 (**Table 3.3**). Across the three years, TBI-related hospitalizations rates were lowest for those aged 5-9 years. However, from the age of 60, TBI-related hospitalizations consistently increased; those aged ≥85 years had the highest rates irrespective of the year **(Table 3.3**). Similarly, in each year, males had higher TBI-related hospitalization rates than females (**Table 3.1**). Falls were the leading cause of all TBI-related hospitalizations in Texas, accounting for 36.64% of all TBI-related hospitalization in 2012, 38.40% in 2013, and 37.59% in 2014 (**Table 3.1**).

The proportion of in-hospital mortality among those ≥65 years (8.93%) was higher than the overall mortality (7.48%) and mortality among those below 65 years (6.42%) **(Table 3.2).** Among the elderly (≥65 years) patients hospitalized with a TBI, in-hospital mortality was associated with increasing age, male gender, increasing severity of the TBI, comorbidities, and admission through trauma centers. Other factors associated with in-hospital mortality included the mechanism of the TBI (motor-vehicle-related TBIs) and a longer stay on admission (**Table 3.4**). In the adjusted analysis, the male gender remained an independent predictor of in-hospital mortality [OR = 1.55: 95% CI (1.36 – 1.77)]. Also, compared to Whites, Hispanics also had 1.18 times the odds of in-hospital mortality [OR = 1.18: 95% CI (1.01 – 1.40)]. Similarly, in the mechanism of injury/TBI cause category, the adjusted odds of in-hospital mortality for patients hospitalized as a result of a motor-vehicle-related TBI was1.4 times that of patients with a fall-related TBI [OR = 1.40: 95% CI (1.07 – 1.83)]. Association between TBI severity with in-hospital mortality remained statistically significant, with the highest odds of in-hospital mortality seen among those with a 'critical-level' of severity [OR = 96.29: 95% CI (76.58 – 121.08)]. However, length of stay became associated with reduced odds of in-hospital mortality in the multivariate analysis; every additional day of hospitalization was associated with a 19% reduction in the odds of in-hospital mortality [OR = 0.81: 95% CI (0.79 – 0.82)]. Lastly, compared to TBI hospitalizations in 2014, in-hospital mortality was significantly lower in 2012 [OR = 0.77: 95% CI (0.65 – 0.91)]. The variables for the presence of comorbidities and admission type were no longer statistically significantly associated with in-hospital mortality in the multivariate analysis (**Table 3.4**).

3.4. Discussion

There is a widespread perception that accidental injuries occur at random, leading to the view that there is little role for a public health intervention to reduce their incidence (Krug, Sharma, & Lozano, 2000). However, identification of modifiable factors associated with both intentional and unintentional injuries suggests that public health interventions could play a vital role in improving public safety (Hofman, Primack, Keusch, & Hrynkow, 2005). We believe that before interventions against TBIs are designed and implemented, a description of TBI distribution is necessary.

To our knowledge, this is the first study that used state-level data to describe the distributions of TBI-related hospitalizations in Texas. Similar administrative health care data were used to describe state-level TBI estimates for California, Wisconsin, Oklahoma, and Washington (Fletcher, Khalid, & Mallonee, 2007; Koepsell et al., 2011; Lagbas, Bazargan-Hejazi, Shaheen, Kermah, & Pan, 2013).

3.4.1. TBI Distribution

Consistent with the CDC's national estimates, this study found rates of TBI-related hospitalizations in Texas to be higher among males and those above 60 years old. In the national estimates, men and older adults had higher rates of overall TBI-related ED visits and hospitalizations (Peterson, Xu, Daugherty, & Breiding, 2019). The gender disparity in injury risk is likely explained through a socio-cultural context rather than biologic. Circumstances, such as type of occupation (long distance trucking), exposure to contact sports, and risky driving behaviors are seen more among men (Sorenson, 2011). Focusing specifically on motor-vehicle or traffic-related injuries, an analysis from the Insurance Institute for Highway Safety (IIHS) reveals that males were more likely to drive under the influence of alcohol, be speeding, or not using seat belts (IIHS, 2019). These factors perhaps provide a possible explanation for the gender disparity of TBI burden.

For the age-related disparity, age-associated physiologic changes unique to the elderly may be at play. Challenges such as reduced strength, poor balance, and increased burden of comorbid conditions are examples of the age-related challenges that could predispose the elderly to sustain a TBI (Krishnamoorthy, Distelhorst, Vavilala, & Thompson, 2015). In addition to the age-related physiological changes, the use of prescription drugs such as aspirin and anticoagulants, prevalent among the elderly, may also predispose to a TBI (Thompson, McCormick, & Kagan, 2006). In Texas, the proportion of individuals aged ≥65 years had increased by 7.9% from 2012 to 2015 (Texas Demographer, 2015). This increase in aging population suggest that effective, elderly-specific TBI prevention interventions are needed in Texas to reduce the elderly TBI burden.

We also found that among those aged below 55 years, rates of TBI-related hospitalizations were highest among individuals aged 15 to 24 years. A similar pattern was reported in Wisconsin's TBI epidemiology report (Tieves, Yang, & Layde, 2005). Late teens and young adults have unique injury risk factors such as exposure to contact sports and road accidents (Redeker, Smeltzer, Kirkpatrick, & Parchment, 1995); these could be responsible for the higher TBI rates seen among this age group. Interventions aimed at reducing risk-taking behaviors and promoting the use of injury protective equipment could be helpful in this age group.

Findings from this study are consistent with the literature, demonstrating falls as the leading cause of TBI, which was reported by several TBI burden studies (Harvey & Close, 2012; Ramanathan, McWilliams, Schatz, & Hillary, 2012; Tieves, Yang, &

Layde, 2005). Falls are a significant public health problem, especially among the elderly (Li et al., 2006). The combination of high rates of falls, and high rates of TBI among the elderly suggest that falls-prevention interventions could be beneficial in reducing TBI as well (Houry, Florence, Baldwin, Stevens, & McClure, 2016; Nevitt, Cummings, Kidd, & Black, 1989).

3.4.2. In-hospital Mortality

Demographic disparities in the outcome of patients hospitalized with a TBI were reported in previous studies (Bazarian, Pope, McClung, Cheng, & Flesher, 2003; Bowman, Martin, Sharar, & Zimmerman, 2007; Gary, Arango-Lasprilla, & Stevens, 2009). However, to our knowledge, this is the first study to report racial disparities in TBI outcomes in Texas. Lack of health insurance was reported as an independent predictor of worse outcomes among trauma patients (Gary, Arango-Lasprilla, & Stevens, 2009; Haider et al., 2008; Salim et al., 2010), the higher adjusted odds of in-hospital mortality among Hispanic elderly patients may be explained by socioeconomic factors such as access to health insurance. Texas has the highest uninsured population of any U.S. state with racial minorities more likely to be uninsured (Shi, 2000). The decision not to expand Medicaid under the Patient Protection and Affordable Care Act has increased the coverage gap in Texas, which may also contribute to the racial disparities in TBI outcomes (Chen, 2019). However, from this analysis, we are unable to conclude on the relationship between insurance coverage and race/ethnicity of the patients hospitalized with a TBI.

Even among the age categories encompassing the elderly (≥65 years), increasing age was associated with higher adjusted odds of in-hospital mortality, controlling for comorbidities, type, and severity of the injury. This may be suggestive of a need to explore novel treatment options for elderly patients hospitalized with a TBI. Motor-vehicle-related TBI was a significant predictor of in-hospital mortality in this analysis. Even though the analysis was restricted to patients aged at least 65 years, we expect motor vehicle crashes to have a similar impact on in-hospital mortality among other age groups. According to the Texas Department of Transportation, death rates from motor vehicle crashes increased from 1.44 per hundred million miles in 2012, to 1.46 in 2014 (Texas DoT, 2014). This emphasizes the need to increase the efforts of improving road safety in Texas.

Among this study population, more extended hospital stay was associated with higher odds of survival. Previous studies have reported that patients with prolonged hospital stay were more likely to be discharged with an impairment or disability (Cuthbert et al., 2011). Therefore, surviving in-hospital mortality after a prolonged hospitalization with a TBI may be suggestive of a significant TBI-related disability. Even though this is beyond the scope of this study, we suggest investigating this relationship by future studies, which could improve the overall understanding of the TBI burden.

3.4.3. Limitations

Although this study provided 3-year state-level estimates of TBI-related hospitalizations for the first time in Texas, it has some important limitations.

Demographic information for approximately 17% of the patients was suppressed due to privacy requirements and was not included in our analysis. Evidence of alcohol abuse on the patient during medical evaluation was, in part, the reason for the data suppression. Because alcohol is a known risk factor for injuries (Hingson & Howland, 1987; Vinson, Maclure, Reidinger, & Smith, 2003), exclusion of patients with evidence of alcohol abuse could underestimate the counts of TBI which were used in estimating the hospitalization rates.

However, compared to patients without data suppression, in-hospital mortality was lower among the patients with suppressed demographic variables (**Appendix A**). Also, the literature reporting associations between alcohol with in-hospital mortality among hospitalized TBI patients are mixed (Pandit et al., 2014; Tien et al., 2006). Similarly, because de-identified data were used in this analysis, it is possible that some TBI hospitalization cases were counted more than once. However, since the unit of analysis in this study was hospitalizations rather than individual cases, multiple hospitalizations for the same patient will not adversely affect the estimates. Another limitation is the use of a provider-assigned severity score as a proxy for the TBI severity. This was done because none of the conventional injury severity scoring information such as Glasgow Coma Scale (GCS), Abbreviated Injury Score (AIS), or Injury Severity Score (ISS)) were available in the hospital discharge records used for this analysis. However, from the results in this analysis, the provider-assigned severity scores were strong independent predictors of in-hospital mortality in both univariate and multivariate analysis, hence, could substitute for TBI severity. Additionally, because this analysis did not involve a review of the death certificates of the deceased TBI patients, it is possible that TBI was not the primary cause of death among some of the hospitalized patients. Finally, the in-hospital mortality is likely to underestimate all TBI-related mortality because it does not include TBI patients who died before hospitalizations (example in the ED) or after hospital discharge.

3.5. Conclusion

This analysis shows a sociodemographic disparity in both the burden and the outcome of TBI in Texas. Public health intervention should focus on strategies aimed at preventing falls and motor vehicle crashes. To improve population-level estimates of the TBI burden in Texas, we recommend an improvement in the collection of statewide TBI-specific data from care providers and other relevant stakeholders.

4. ASSOCIATIONS BETWEEN HEALTH INSURANCE AND RACE WITH MORTALITY AMONG TRAUMA PATIENTS WITH MODERATE INJURIES: A RETROSPECTIVE STUDY

4.1. Introduction

Trauma is a significant public health problem worldwide; no region or country is spared from the burden of trauma associated morbidity and mortality (Norton & Kobusingye, 2013). According to the World Health Organization (WHO), injuries are currently the ninth leading cause of mortality globally and is expected to increase in decades to come (WHO | Injuries 2014).

In the U.S. rates of both fatal and non-fatal injuries have remained high (Rhee et al., 2014). According to the U.S. Centers for Disease Control (CDC) accidents (unintentional injuries) and suicides (intentional self-harm) are the third and tenth leading causes of deaths (for all ages) in the U.S. respectively (National Vital Statistics Report 2018). Trauma is currently the leading cause of death among individuals younger than forty-six in the U.S. (Fact sheet - injury data | WISQARS | injury center | CDC.2018).

Evidence suggesting the influence of demographic and economic factors such as race, gender, and health insurance coverage on both access to care and outcomes of patients with chronic conditions such as diabetes or kidney disease, has been presented in previous studies (Hayward, Miles, Crimmins, & Yang, 2000; Heisler, Smith, Hayward, Krein, & Kerr, 2003; Isaacs et al., 1999; Eisner et al., 2011).

For trauma victims, similar disparities were reported by several studies. From a national sample of U.S. adults who sustained moderate injuries, uninsured patients had higher odds of deaths (Haider et al., 2008). In a retrospective cohort of adult trauma patients admitted at a level I trauma center, Salim (2010) reported that uninsured patients had a significantly high rate of mortality despite being relatively younger with less severe injuries (Salim et al., 2010). Similarly, among a sample of more than 1 million patients in the U.S., uninsured patients had an increased odd of death compared with insured patients for both blunt and penetrating trauma (Greene et al., 2010).

In another study using state-level healthcare data from South Carolina, Selassie, (2004) found racial disparities in access to care, with uninsured African-American females being less likely to be hospitalized following a Traumatic Brain Injury (TBI) compared to their White-uninsured counterparts.

However, generalizability of the findings from these studies is limited because health insurance status of patients was treated as a dichotomous variable (insured and uninsured), and patients who were ≤18 and ≥65 years were excluded due to differences in access to Medicaid and Medicare.

This study aims to address this limitation by characterizing the insured trauma victims as participants in either public or private health insurance system and by including trauma victims of all ages.

4.2. Methods

4.2.1. Study Design and Data

A retrospective study was conducted using data from January 1, 2014, to December 31, 2016 from the Texas trauma registry. The registry contains publicly available data on reportable trauma events obtained from the Emergency Medical Service (EMS) and all state-regulated hospitals in Texas. By statute, any trauma event that meets at least one of the following criteria must be reported to the registry; 1) trauma severe enough to warrant either an EMS run, or a hospital admission of over 48 hours; 2) trauma resulting in death; 3) TBIs as defined in the International Diagnostic Codes (ICD).

4.2.2. Measures

The outcome of interest for this analysis was mortality from trauma, which was dichotomized by mortality status following their trauma. The exposures of interest were race, ethnicity, and insurance status. Race and ethnicity were merged to create a race/ethnicity variable, and patients were categorized into four (race/ethnicity) groups, (i) Non-Hispanic Whites (NHW), (ii) Non-Hispanic Black (NHB) (iii) Hispanic-any race (HAR), and (iv) Others. Method of payment was used as a proxy for the health insurance status of the trauma victims, it was categorized into three groups representing those privately insured, publically insured, (including all Medicare, Medicaid and Children's Health Insurance Program (CHIP) beneficiaries), and those uninsured.

Other variables representing factors with the potential to confound the association between trauma mortality and the exposures of interest were considered in the analysis trauma fatality and the exposures of interest were considered in the analysis based on their inclusion in similar research published in the peer-reviewed literature and the practice in CDC publications (Haider et al., 2008; Centers for Disease Control and Prevention, 1997; Selassie, 2004). These potential confounding variables include injury severity, age, gender, hospital designation, injury etiology, presence of a TBI diagnosis, severity of the TBI, comorbid conditions, and year. We used fifteen-year age categories to adjust for victim's age and used International Classification of Disease (ICD) codes for the external cause (E-codes) of the injury to categorize injury cause into four groups including assault/homicide, self-inflicted, unintentional, and others/unclassified. For the injury severity, records were categorized into 'mild (ISS <9)', 'moderate (ISS 9-15), 'severe (ISS 16-25),' and 'critical (ISS >25)', using the locally assigned Injury Severity Score (ISS) at presentation in the Emergency Room (ER). Because previous research has shown that mild injuries (ISS <9) are unlikely to lead to mortality (Foreman et al., 2007), all patients with mild injuries (ISS <9) were excluded.

We used the Elixhauser index of comorbidity, which listed 30 different conditions known to influence mortality, to adjust for the presence of comorbid conditions (Elixhauser, Steiner, Harris, & Coffey, 1998). Using ICD codes for these conditions, each victim's additional diagnosis fields (provided in the registry) was searched for any of the listed conditions. Records were subsequently dichotomized by the presence or absence of comorbid conditions. In part, due to the availability of resources, trauma center designation has been shown to influence trauma outcomes (American College of Surgeons Committee on Trauma, 2016). Therefore, we adjusted for this by including the five categories of trauma centers (hospitals and trauma centers I to IV) in the analysis.

Similarly, since TBI is a leading cause of trauma mortality (Thurman, Coronado, & Selassie, 2007), the presence of TBI was adjusted for by dichotomizing patients into those with a TBI diagnosis in any of the five diagnosis fields and those without a TBI. The severity of the TBI was also adjusted for using the Glasgow Coma Scale (GCS). Records were categorized into mild-head-injury (GCS above 12), moderate-head-injury (GCS 8 to 12), and severe-head-injury (GCS less than 8) (Udekwu, Kromhout-Schiro, Vaslef, Baker, & Oller, 2004).

4.2.3. Statistical Analysis

Only records with complete data on the variables of interest (race/ethnicity and insurance status) were included in the analysis. The proportions of mortality among those excluded due to the missing data were similar to those included in the analysis (4.1% vs. 3.9%) (**Appendix A**).

A Pearson chi-square test was done to evaluate the associations (unadjusted effects) between the outcome, and the exposures of interest as well as the potential confounders. To obtain adjusted effects of race/ethnicity and insurance status on mortality, a multivariate logistic regression model predicting the likelihood of mortality by race/ethnicity and insurance status while adjusting for all the potential confounders was fitted. Odds ratios (OR), and 95% Confidence Intervals (CI) were estimated from the model.

To assess potential effect measure modification of health insurance coverage on mortality by racial group, patients were categorized into twelve groups *(i) NHW with public, (ii) NHW with private insurance, (iii) NHW without insurance, (iv) NHB with public, (v) NHB with private insurance, (vi) NHB without insurance, (vii) HAR with public insurance (viii) HAR with private insurance, (ix) HAR without insurance, (x) Others with public insurance, (xi) Others with private insurance, and (xii) Others without insurance.* A second multivariate logistic regression model predicting the likelihood of mortality was fitted. Covariates included all the potential confounders and the patient groups. NHWs with private insurance were compared with other groups. ORs and 95% CIs were estimated.

All statistical analysis was performed using SAS (V. 9.3). CIs not including the null value were interpreted to be indicating a statistically significant difference in the ORs.

4.3. Results

4.3.1. Descriptive Analysis

Within the study period (2014 to 2016), there were 415,159 reported injuries; after applying the exclusion criteria, the final sample size included in the analysis was 141,465 **(Figure 4.1**). Although the absolute number of injuries increased from 2014 to 2016, the proportion of fatal injuries decreased from 4.4% to 3.3% respectively, while the proportion of trauma victims without health insurance increased from 15.8% to 18.5% (**Table 4.1**). The race/ethnicity distribution was similar across each insurance category; NHWs were the majority followed by HAR, and NHBs (**Figure 4.2**).

In unadjusted analysis, health insurance had a statistically significant association with trauma mortality among three categories of insurance status (**Table 4.2**). Those without health insurance had higher likelihood of mortality (private insurance = 3.1%, public insurance = 3.4%, and uninsured = 6.3%), [P<0.0001]. Likelihood of fatality from trauma was higher among NHBs (7.4%), followed by Hispanics (4.9%), then NHWs (3.3%) [P<0.0001]. All the potential confounders also had a statistically significant unadjusted association with trauma fatality in the univariate analysis. Older victims and males were more likely to die from trauma. Those with a more severe injury, a TBI diagnosis, and or associated comorbidity were also more likely to die from their injuries. In terms of hospital designations, victims were less likely to die if they were treated at a trauma center with a higher designation (**Table 4.2**).

Compared to trauma victims with a private insurance, the adjusted odds of trauma-related mortality among those with a public insurance was 1.18 times higher [OR= 1.18; 95% CI (1.07 – 1.30)], while among those without health insurance the adjusted odds were1.86 times higher [OR= 1.86: 95% CI (1.66 – 2.05)]. When compared to NHWs, NHBs had 2.11 times the odds of mortality [OR = 2.11: 95% CI (1.87 – 2.37)], and Hispanics had 1.25 times higher adjusted odds of trauma mortality [OR= 1.25: 95% CI (1.16 – 1.36)]. However, the adjusted odds of mortality were significantly lower among those categorized as 'Others' [OR = 0.52 95% CI (0.41 – 0.67)]. All the potential confounding factors maintained their statistically significant association with trauma mortality at the multivariate level (**Table 4.3**).

Results of the effect measure modification analysis suggest that the effects of lack of health insurance and trauma mortality were not uniform across the race/ethnicity categories of the victims (**Table 4.4**). Specifically, the observed joint effects of Hispanic race/ethnicity and lack of insurance [OR= 2.36 95% CI (2.05 – 2.72)] was lower than the expected joint individual effects of the two factors. However, for the NHBs the over five-fold rise in the adjusted odds of mortality [OR= 5.12 95% CI (4.27 – 6.15)] was higher than the expected joint effects of the two factors **(Table 4.4).**

4.4. Discussion

This study examined potential inequalities in mortality among trauma victims in Texas. Regardless of the type and severity of an injury, the odds of death were statistically significantly associated with the victim's race/ethnicity, and health insurance status. Even among those with health insurance coverage, odds of mortality from trauma also differed by the type of health insurance.

Previous studies have reported disparities in trauma outcomes based on race and health insurance (Arthur, Hedges, Newgard, Diggs, & Mullins, 2008; Bovbjerg & Hadley, 2007; Greene et al., 2010; Haider et al., 2008; Haider et al., 2013). However, due to the variability in the methodologies, a generalization of their conclusions is limited. For instance, because of access to Medicare and Medicaid, Haider (2008) and Arthur (2008) excluded patients aged <18 years and ≥65 years from their analysis. Greene (2009) also excluded patients with injuries from burns as well as those aged ≥65 years. This study improved on this limitation by including all demographic subgroups.

By categorizing the health insurance status of the trauma victim into the three groups (private, public, and the uninsured), we avoided excluding any demographic subgroup.

In this analysis, all the potential confounders remained statistically significantly associated trauma mortality after the multivariate analysis. These findings are consistent with, and reinforce results from similar studies. (Arthur, Hedges, Newgard, Diggs, & Mullins, 2008; Burd, Jang, & Nair, 2007; Haider et al., 2013; Tiesman et al., 2007).

Analyzing the unadjusted data, we found that trauma victims who were categorized as NHW more likely to be insured (both private and public). However, after the stratified (effect medication) analysis, we found that regardless of the insurance category, racial minorities (Hispanics and NHBs) had odds of mortality significantly higher than NHW trauma victims. Therefore, the observed disparity in trauma mortality could not be completely explained by the higher likelihood of being insured observed among the NHW trauma victims.

Other possible reasons that could explain the observed disparities is the notion that uninsured patients are less likely to comply with their medications and keep follow-up appointments. Advocates of this notion argue that lack of treatment compliance (among the uninsured) may explain the observed disparities in the outcome of patients (Bovbjerg & Hadley, 2007). However, as a counter argument, we know that for trauma patients, urgent intervention (as opposed to long-term follow-up) is mostly what is required to prevent mortality. Therefore, a possible lack of treatment and follow-up compliance (among uninsured trauma patients) is not enough to explain the observed disparities.

Still on the emergent nature of trauma, it is unlikely that a trauma victim would be refused treatment or offered sub-standard care because of his/her demographics or insurance coverage (Bovbjerg & Hadley, 2007). However, these (racial and insurance coverage) considerations may come into play after the victim is stabilized and ready for further management (Nathens, Maier, Copass, & Jurkovich, 2001). Selassie (2004) reported that uninsured and racial minorities were less likely to be hospitalized (but treated and released) after the initial ED care, despite having similar injuries proportionate in severity with those who were insured or non-racial minorities (Selassie, McCarthy, & Pickelsimer, 2003: McCarthy, Serpi, Kufera, Demeter, & Paidas, 2002; Sox, Burstin, Edwards, O'Neil, & Brennan, 1998).

Additional explanations suggested for the observed health insurance-related mortality disparities relates to the health behavior pattern of patients (Lantz et al., 1998; Sudano & Baker, 2006). Kronick (2009) argued that baseline (pre-disease or pre-injury) characteristic or behavior of a person might play in role in the observed health insurance-related disparity in mortality. Factors such as marital status, smoking habit, and Body Mass Index (BMI) were reported by Kronick (2009) to be significant predictors of all-cause mortality in a population survey. According to Krnonick (2009), if these factors were to be adequately adjusted, the risk of death between insured and uninsured would be mainly the same (Kronick, 2009). However, while we concede that social factors such as cigarette smoking or marital status may influence mortality in general, we believe that they may play a more significant role in the outcomes of patients with chronic conditions not for injury victims. Additionally, controlling for comorbid conditions in this analysis should reduce the confounding (if any) these factors may have introduced.

Findings from this study raise fundamental questions regarding not just access, but quality and type of care available to trauma victims in Texas. With almost five million residents without health insurance coverage, Texas has both the highest number and proportion of uninsured of any U.S state (Texas Medical Association 2017). The decision by Texas authorities not to expand Medicaid has increased the uninsured coverage gap in Texas to the highest in the nation (Chen, 2019). Over a million Texans could be eligible for public insurance if Medicaid were to be expanded. In relation to the observed disparities in trauma-related mortality for uninsured Texan, access to health insurance may be particularly important consideration for Texas.

Chen (2019) previously reported that low-income minorities were more likely to be uninsured in Texas, which may indicate that improving access to vulnerable subgroups of Texans could reduce some of the observed disparities in trauma-related mortality.

4.4.1. Limitations

This study has limitations. First; the data do not indicate whether the recorded mortality occurred at the point of care or otherwise. It is possible that more uninsured and racial minorities died before arriving to the point of care than their respective reference group. Additionally, we excluded patients who did not have a recorded method of payment as well as those with no race/ethnicity in the registry. However, because the proportion of trauma-related mortality were similar between those excluded in the analysis and those included, we do not believe the results were affected by excluding these patients.

4.5. Conclusion

Using administrative data and standard epidemiologic methods to investigate and report significant disparities in trauma-related mortality is an important first step for identifying the needs and design for a potential intervention program. To our knowledge, this is the first study that investigated and reports significant disparities in trauma-related mortality in Texas.

5. CONCLUSIONS & FUTURE DIRECTIONS

5.1. Summary

This project intended to provide, in three separate studies, an overview of the epidemiologic burden of TBI in the United States and investigate the sociodemographic disparities associated with trauma outcomes in Texas. The first study involved a systematic review of published epidemiologic studies reporting population-level estimates of TBI in the United States. The second study was a cross-sectional analysis of TBI-related hospitalizations in Texas using the statewide inpatient hospital discharge data. The last study was a retrospective analysis of statewide trauma registry data to identify the associations between health insurance coverage and race/ethnicity with trauma-related mortality in Texas. This final section will summarize the findings, touch on the implications of each study, and suggest future directions.

5.1.1. The systematic review of studies reporting TBI estimates in the U.S.

In clinical research, systematic reviews, with or without meta-analysis, are generally believed to provide reliable epidemiologic evidence in support of associations between exposures and outcomes. They also provide a means to evaluate published epidemiologic studies in terms of risk of bias and other methodological flaws (Cook, Mulrow, & Haynes, 1997). In this project, a systematic review design was used to discuss TBI distribution in the U.S. Findings from the systematic review revealed significant variations in the methodological approaches of the reviewed studies, which likely resulted in the inconsistencies of TBI estimates. This finding was not unexpected because previously published systematic reviews from European populations revealed similar variations in TBI estimates.

An important limitation identified from the systematic review was the lack of state-level estimates of TBI from most U.S. states. The importance of state-level estimates was highlighted previously. However, going forward, we recommend strengthening of linkages and collaborations between all stakeholders to make sure more local and state TBI estimates are reported.

5.1.2. TBI burden in Texas

This study built upon the identified limitation regarding the lack of state-level estimates from several states. The study used the CDC's recommended case definitions of TBI to report a three-year-TBI-related hospitalization from the Texas hospital inpatient discharge record. Key findings from this study include higher TBI-related hospitalization rates among males and the elderly of both genders. The study also revealed falls as the most common injury mechanism among TBI victims. These findings were consistent with the national TBI estimates published by the CDC (Peterson, Xu, Daugherty, & Breiding, 2019).

This study also found that increasing age, severe TBIs, Hispanic ethnicity, and motor vehicle-related TBIs were significantly associated with in-hospital mortality among hospitalized TBI patients aged ≥65 years. The public health implications of this study include the identification of a potential racial disparity in TBI outcomes. The fact that state-level TBI rates were estimated, for the time, across age groups and gender provides foundations upon which TBI prevention strategies could be implemented. Data collection should be strengthened for a better understanding of TBI determinants and distribution.

5.1.3. Role of health insurance and race/ethnicity on trauma mortality

Since a lack of health insurance was shown to influence trauma mortality in previously published studies, this study became necessary in the light of the high rates of the uninsured population in Texas. In addition, the apparent racial disparity in the outcome of hospitalized TBI patients observed in the previous study provided more justification to investigate outcome disparities in a larger cohort (all trauma victims). The study found a higher likelihood of trauma-related mortality among racial minorities and those without health insurance. After evaluating the interaction between race/ethnicity and health insurance, findings from this study showed that the likelihood of trauma-related mortality became significantly higher for racial minorities without health insurance.

The public health implications of these findings go to the heart of the inequalities that public health strives to eliminate. Authorities in Texas should do more to reduce health disparities and improve access to affordable health insurance, which is the fundamental step needed towards achieving this goal. Because racial minorities are mostly the ones at the receiving end of health disparities, interventions focusing on minority groups should be encouraged.

5.2. Future Directions

The Cost implication of the public health burden of trauma is as important as the estimation of trauma-related mortality and morbidity. Evaluation of the costs associated with the management of trauma patients is outside the scope of this project. However, this does not suggest its lack of importance towards understanding the overall epidemiologic burden of trauma. Therefore, it is strongly suggested that future studies consider an evaluation of trauma-associated cost using available administrative data. Insurance claims data either for private or for public insurance such as Medicare could provide reliable cost of information required to undertake such kind of investigation.

Another important suggestion for future studies is the investigation of TBI-related disabilities. It is known that TBIs lead to disabilities, substantial number of hospitalized TBI patients will require rehabilitations to restore functionality after hospital stay. Therefore, it will be useful to describe this important group and to investigate determinants of discharge to rehabilitation centers.

TABLES AND FIGURES

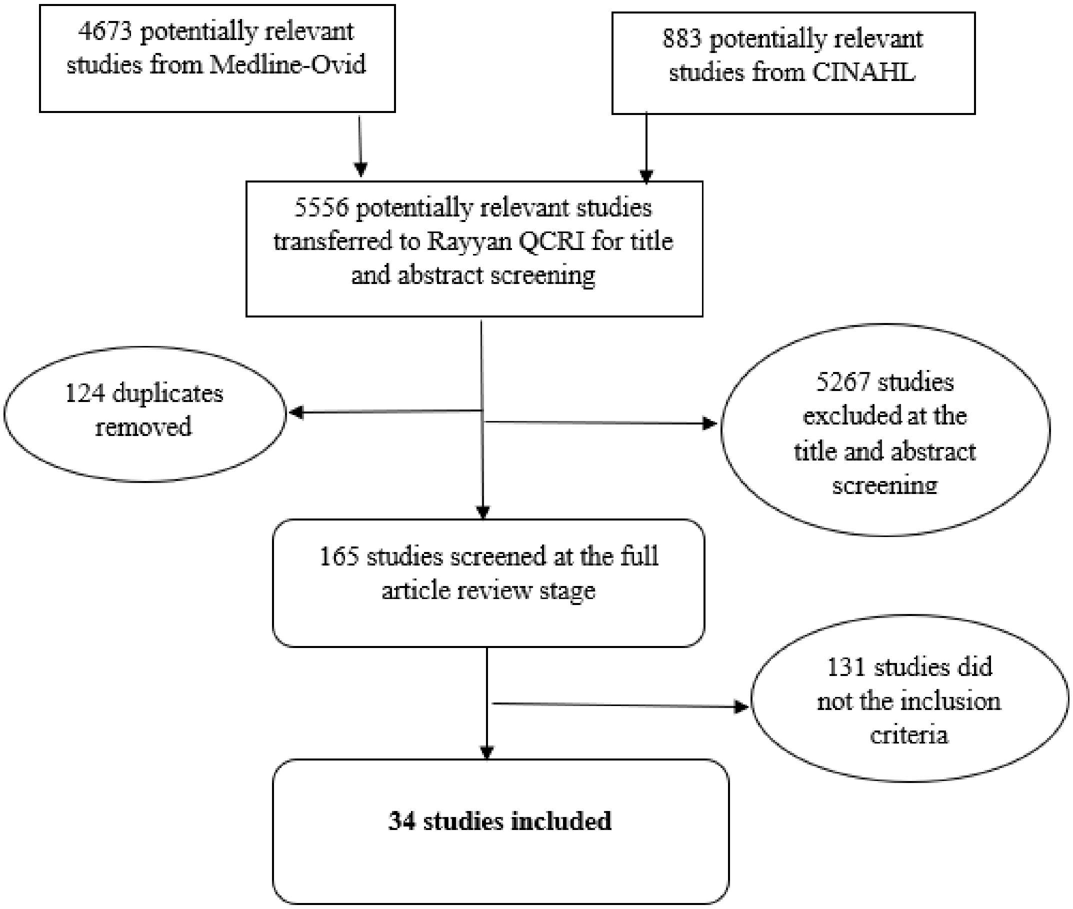

Figure 2.1 Systematic Review Flow-Chart

Table 2.1. Characteristics of Published Studies Reporting on the Epidemiology of TBI in the United States (1998 – 2019)

Study I. D	Setting	Estimate Type	Study Duration	Age group	TBI Estimate	TBI Type
Haarbauer-Kruppa et al. (2018)	National	Prevalence	2011 - 2012	0 – 17 years	2.5/100	All types
Corrigan et al. (2017)	Statewide - Ohio	Prevalence	2014	At least 18 years old	21.7/100	TBI with loss of consciousness
Leonhard et al. (2015)	Statewide - Oregon	Incidence – Not specified	2009 - 2012	0 – 19 years	87/100000	All types
CDC-MMWR - Taylor et al. (2017)	Nationwide	ED Visits, Hospitalizations and Deaths	2013	No age restriction	889.6/100000	All types
Cancelliere et al. (2017)	Nationwide	Incidence – ED Visits	2006 – 2012	No age restriction	690.7/100000	Mild
Amanullah et al. (2018)	Nationwide	Incidence – ED Visits	2003 - 2012	0 – 12 months	1722/100000	All types
Lagbas et al. (2013)	Statewide - California	Incidence - % of Hospitalizations	2001 - 2009	No age restriction	11.9/100	All types
Cheng et al. (2016)	Nationwide	Incidence - Hospitalizations	2001 - 2013	0 – 14 years	34.7/100000	Playground TBI
Zhang et al. (2016)	Nationwide	Incidence – Not specified	2007 - 2014	0 – 64 years	2.09/1000	Concussions
Whiteneck et al. (2016)	Statewide - Ohio	Prevalence	2008 - 2010	At least 18 years old	42.5/100	All types
Haring et al. (2015)	Nationwide	Incidence – ED Visits	2006 - 2011	No age restriction	26.5/100000	Sports-related

Table 2.1. Continued

Study I. D	Setting	Estimate Type	Study Duration	Age group	TBI Estimate	TBI Type
Schneier et al. (2006)	National	Incidence - Hospitalizations	2011	0 – 17 years	70/100000	All types
Ramanathan et al. (2012)	Statewide - Pennsylvania	Incidence – Not specified	1992 - 2009	65 years or older	1.4/10000	Moderate to Severe
Kayani et al. (2009)	Statewide - Missouri	Incidence – ED Visits & Hospitalizations	2001 - 2005	No age restriction	238.6/100000	All types
CDC-MMWR (2006)	Statewide - twelve states	Incidence - Hospitalizations	2002	No age restriction	79/100000	All types
Sills et al. (2005)	Statewide - Colorado	Incidence – Not specified	1994 - 2002	0 – 36 months	47/100000	All types
Koepsell et al. (2011)	Countywide – King County Washington	Incidence – ED Visits	2007 - 2008	0 – 17 years	304/100000	All types
Leibson et al. (2011)	Countywide – Olmstead County Minnesota	Incidence – Not specified	1985 - 2000	No age restriction	558/100000	All types
Rutland-Brown et al. (2005)	Statewide – thirteen states	Incidence - Hospitalizations	1997 - 1999	No age restriction	70.9/100000	All types
Tieves et al. (2005)	Statewide - Wisconsin	Incidence – Deaths & Hospitalizations	2001	No age restriction	94.4/100000	All types
Bazarian et al. (2005)	Nationwide	Incidence – ED Visits	1998 - 2000	No age restriction	503.1/100000	Mild

Table 2.1. Continued

Study I. D	Setting	Estimate Type	Study Duration	Age group	TBI Estimate	TBI Type
CDC-MMWR - Coronado (2011)	Nationwide	Mortality	1997 - 2007	No age restriction	18.4/100000	All type
Thomas et al. (2005)	Nationwide	Mortality	2005	65 years or older	21.6/100000	Fall-related TBIs
Ellingson et al. (2008)	Statewide – thirty-six states	Incidence - Hospitalizations	2003	0 – 12 months	32.2/100000	Inflicted TBIs
Meehan et al, (2010)	Nationwide	Incidence – ED Visits	2002 - 2006	0 – 17 years	18/100	Concussions
Ghobrial et al. (2014)	Nationwide	Incidence - Hospitalizations	2008	No age restriction	96.0/100000	All types
Kerr et al. (2014)	Statewide – North Carolina	Incidence – ED Visits	2010 - 2011	No age restriction	7.3/10000	All types
Lee et al. (2014)	Selected Emergency Departments	Incidence – Deaths & Hospitalizations	2004 - 2006	0 – 18 years	1.9/100	All type
Piatt et al. (2012)	Nationwide	Incidence - Hospitalizations	1997 - 2009	0 – 17 years	63.5/100000	All types
Rutland-Brown et al. (2003)	Nationwide	Incidence – ED Visits, Hospitalizations and Deaths	2003	No age restriction	538.2/100000	All types
Coronado et al. (2005)	Statewide – Fifteen states	Incidence - Hospitalizations	1999	65 years or older	155.9/100000	All types
Eisele et al. (2006)	Statewide – Fifteen states	Incidence - Hospitalizations	1999	0 – 12 months	122/100000	All types

Table 2.2. Individual Study's Data Sources, Case Definition, and Methodological Quality Assessment Using STROBE Checklist

Study I. D	Data Source	Case Definition	STROBE Elements Completion
Haarbauer-Kruppa et al. (2018)	National Survey	Self-reported brain Injury or concussion diagnosis by a doctor or health care provider	Complete
Corrigan et al. (2017)	Statewide Phone Survey (Modified BRFSS)	Self-reported injury to the head or neck resulting in a loss of consciousness	Complete
Leonhard et al. (2015)	Oregon Trauma Registry	The International Classification of Diseases, 9th Revision, and Clinical Modification (ICD-9-CM) diagnosis codes, as specified in the Barell Injury Diagnosis Matrix	Complete
CDC-MMWR - Taylor et al. (2017)	Nationwide Emergency Department visit Database	ICD-9-CM diagnosis codes suggestive of any type of TBI	Complete
Cancelliere et al. (2017)	Nationwide Emergency Department Database	ICD-9-CM diagnosis codes suggestive of a mild TBI	Incomplete: participants
Amanullah et al. (2018)	National Electronic Injury Surveillance System	A NEISS diagnosis code for concussion (diagnosis code "52"), internal injury in which "head" was the body part affected (diagnosis code "62" and body part "75"), or fracture in which "head" was the body part affected (diagnosis code "57" and body part "75")	Complete
Lagbas et al. (2013)	California Hospital Discharge Database	ICD-9-CM diagnosis codes suggestive of a TBI-related hospitalization	Complete
Cheng et al. (2016)	National Electronic Injury Surveillance System	A primary body part injured been the head and the principal diagnosis was either concussion or internal organ injury	Complete

Table 2.2. Continued

Study I. D	Data Source	Case Definition	STROBE Elements Completion
Tieves et al. (2005)	National Vital Statistics and Wisconsin Hospital Discharge Database	ICD-9-CM and ICD-10 diagnosis codes suggestive of any TBI	Incomplete: study design, participants, generalizability
Bazarian et al. (2005)	National Hospital Ambulatory Care Survey	ICD-9-CM diagnosis codes suggestive of any mild TBI	Complete
CDC-MMWR - Coronado et al. (2011)	CDC-Multiple-Cause-of-Death Files	ICD-9-CM and ICD-10 diagnosis codes suggestive of any TBI-related mortality	Complete
Thomas et al. (2005)	CDC-Multiple-Cause-of-Death Files	ICD-10 diagnosis codes suggestive of mortality from a fall-related TBI	Incomplete: objectives, study design, generalizability
Ellingson et al. (2008)	Kids Inpatient Database (KID)	ICD-9-CM diagnosis codes suggestive of any TBI excluding codes for skull fractures	Complete
Meehan et al. (2010)	National Hospital Ambulatory Medical Care Survey	ICD-9-CM diagnosis codes suggestive of a concussion	Incomplete: generalizability
Ghobrial et al. (2014)	National Inpatient Sample	ICD-9 diagnosis codes suggestive of any TBI	Complete
Kerr et al. (2014)	North Carolina Disease Event Tracking and Epidemiologic Collection Tool	ICD-9-CM diagnosis codes suggestive of any TBI-related ED Visit	Complete
Lee et al. (2014)	Patient Medical Records	(1) Death from intra-cranial injury, (2) Any neurosurgical intervention, (3) Intubation longer than 24 hours for the head injury, or (4) Hospitalization for 2 nights or longer owing to the head injury in association with TBI on CT	Complete

Table 2.2. Continued

Study I. D	Data Sources	Case Definition	STROBE elements completion
Zhang et al. (2016)	Administrative Health Records	ICD-9-CM diagnosis codes suggestive of a concussion	Complete
Whiteneck et al. (2016)	Statewide Phone Survey	Self-reported injury to the head or neck resulting in a loss or altered consciousness	Incomplete: generalizability
Haring et al. (2015)	Nationwide Emergency Department Database	International Classification of Diseases, ninth (ICD – 9th) edition [800.0–801.9, 803.0–804.9 and 850.0–854.19]	Complete
Schneier et al. (2006)	Kids Inpatient Database (KID)	ICD-9-CM diagnosis codes suggestive of a TBI-related hospitalization	Complete
Ramanathan et al. (2012)	Pennsylvania Statewide Trauma Registry	ICD-9-CM diagnosis codes suggestive of any TBI	Incomplete: generalizability
Kayani et al. (2009)	Missouri Hospital Discharge Database	ICD-9-CM and ICD-10 diagnosis codes suggestive of any TBI	Incomplete: objectives, participants, generalizability
CDC-MMWR (2006)	State-level Hospital and Emergency Department visit data	ICD-9-CM diagnosis codes suggestive of a TBI-related hospitalization	Incomplete: objectives, participants, generalizability
Sills et al. (2005)	Colorado TBI Surveillance System Database	ICD-9-CM and ICD-10 diagnosis codes suggestive of any TBI	Incomplete: study design
Koepsell et al. (2011)	Emergency Department Records	ICD-9 diagnosis codes suggestive of any TBI	Incomplete: study design
Leibson et al. (2011)	Hospital-managed Medical Records	ICD-9-CM diagnosis codes suggestive of a TBI-related hospitalization or ED Visit	Complete
Rutland-Brown et al. (2005)	State-level Hospital and Emergency Department visit data	ICD-9-CM diagnosis codes suggestive of any TBI	Complete

Table 2.2. Continued

Study I. D	Data Sources	Case Definition	STROBE elements completion
Piatt et al. (2012)	Kids Inpatient Database (KID)	ICD-9-CM diagnosis codes suggestive of any TBI-related Hospitalization	Complete
Rutland-Brown et al. (2003	National Hospital Ambulatory Medical Care Survey	ICD-9-CM diagnosis codes suggestive of any TBI-related ED Visit and Hospitalization. ICD-10 codes for any TBI-related deaths	Incomplete: study design
Coronado et al. (2005)	Statewide Hospital Discharge Database	ICD-9-CM diagnosis codes suggestive of any TBI-related Hospitalization	Complete
Eisele et al. (2006)	Statewide Hospital Discharge Database	ICD-9-CM diagnosis codes suggestive of any TBI-related Hospitalization	Incomplete: generalizability
Langlois et al. (2005)	National Vital Statistics System for deaths, National Hospital Discharge Survey (NHDS) for hospitalizations, and National Hospital Ambulatory Medical Care Survey (NHAMCS) for ED visits	ICD-9-CM and ICD-10 diagnosis codes suggestive of any TBI-related hospitalization, ED visit, or mortality	Complete
Day et al. (2006)	Statewide patient records	ICD-9-CM diagnosis codes suggestive of any TBI-related ED Visit	Incomplete: study design, participants

Table 2.3. Summary TBI Rate Estimates in the U.S. from 34 Observational Studies (1998 – 2019)

Study Categories		Range of Estimates per 100,000
Setting	Nationwide (all types)	63.50 to 889.60
	Statewide (all types)	47.00 to 238.60
	Local (all types)	304.00 to 558.00
Estimate Type	Hospitalization rates	70.00 to 155.90
	ED Visits rates	304.00 to 1722.00
	Prevalence*	2.50 to 42.50
	Mortality rates	18.40 to 21.60
Age Distribution	Below 18 years	47.00 – 1722.00
	65 years & Above	14.00 to 155.90
	No age restriction	18.40 to 889.60
Data Source	Survey*	2.50 to 42.50
	Hospital Records	26.50 to 70.90
	ED Records	34.70 to 1722.00
	Others	32.20 to 1722.00

*Estimates reported as proportions

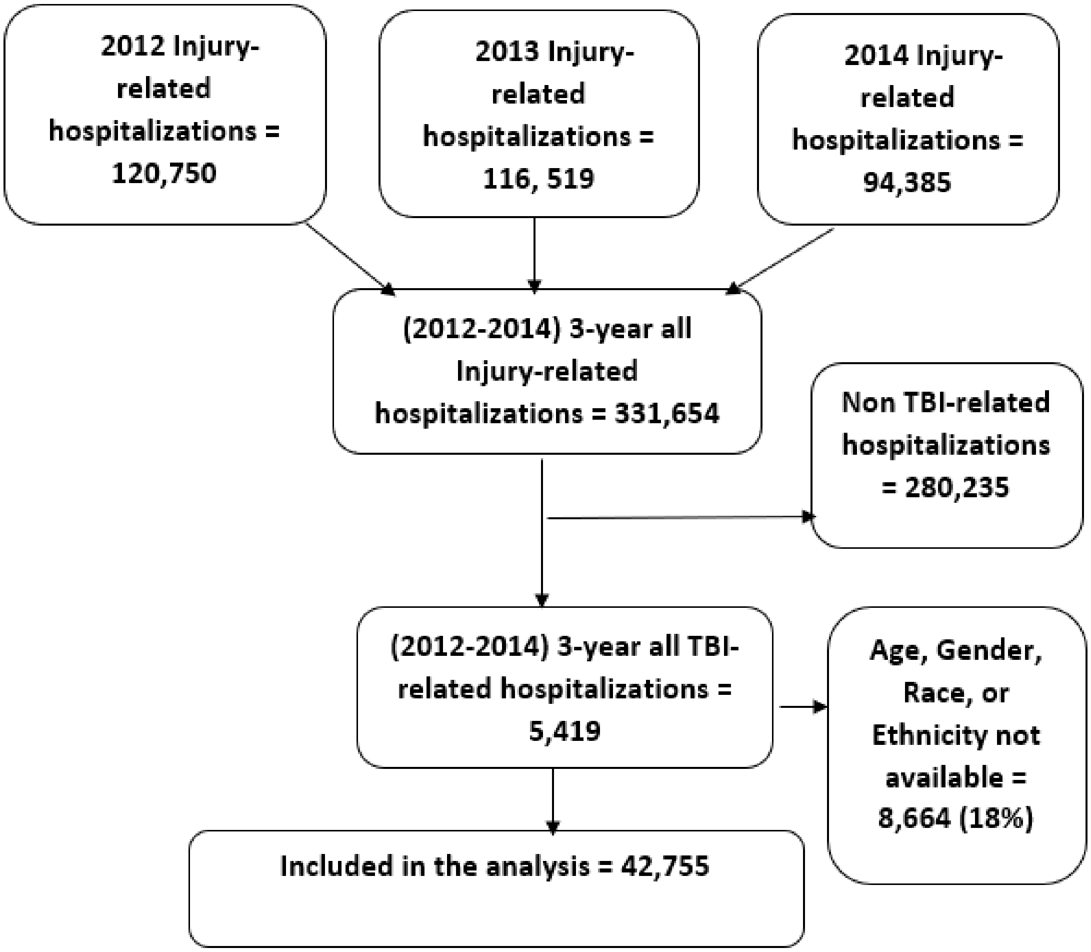

Figure 3.1. Study Flow Chart

Table 3.1. Clinical and Demographic Characteristics of Patients with a TBI-Related Hospitalization in Texas (2012-2014)

Variable		2012 (%)	2013 (%)	2014 (%)
Discharge Status	Alive	16430 (92.89)	16334 (92.75)	13723 (93.14)
	Died	1258 (7.11)	1277 (7.25)	1010 (6.86)
Age Categories (years)	< 5	1058 (5.83)	1005 (5.55)	782 (516)
	5-9	371 (2.05)	381 (2.10)	312 (2.06)
	10 – 14	468 (2.58)	417 (2.30)	388 (2.23)
	15 – 19	861 (4.75)	843 (4.65)	640 (4.22)
	20 – 24	936 (5.16)	863 (4.76)	657 (4.34)
	25 - 29	731 (4.03)	684 (3.77)	583 (3.85)
	30 – 34	631 (3.48)	621 93.43)	484 (3.19)
	35 - 39	508 (2.8)	504 (2.78)	410 (2.71)
	40 – 44	517 (2.85)	541 (2.98)	437 (2.88)
	45 – 49	597 (3.29)	543 (3.00)	439 (2.90)
	50 – 54	696 (3.84)	636 (3.51)	566 (3.74)
	55 – 59	739 (4.07)	781 (4.31)	625 (4.13)
	60 - 64	762 (4.12)	748 (4.13)	687 (4.53)
	65 – 69	861 (4.75)	826 (4.56)	697 (4.60)
	70 -74	931 (5.13)	987 (5.44)	853 (5.63)
	75 - 79	1117 (6.16)	1175 (6.48)	966 (6.38)
	80 – 84	1354 (7.46)	1422 (7.84)	1234 (8.15)
	≥ 85	2044 (11.27)	2048 (11.30)	1857 (12.26)
Gender	Female	6197 (41.96)	6102 (41.89)	5194 (42.56)
	Male	8573 (58.04)	8464 (58.11)	7010 (57.44)
Race/Ethnicity	White	9288 (58.44)	9729 (58.49)	8580 (60.76)
	Hispanic	4973 (31.29)	5046 (30.34)	3992 (28.27)
	Black	1404 (8.83)	1564 (9.40)	1283 (9.09)
	Others	228 (1.43)	294 (1.77)	266 (1.88)
TBI Severity	Moderate	5537 (32.53)	5996 (34.91)	4993 (34.68)
	Severe	4957 (29.13)	4598 (26.77)	4027 (27.93)
	Critical	3156 (18.54)	3116 (18.14)	2554 (17.74)

Table 3.1. Continued.

Variable		2012 (%)	2013 (%)	2014 (%)
Comorbidity	None	14510 (82.08)	14396 (81.75)	12061 (81.90)
	Present	3167 (17.92)	3213 (18.25)	2666 (18.10)
TBI Cause	Struck-by or Against	433 (2.54)	383 (2.23)	346 (2.4)
	Assault-related	1086 (6.38)	1062 (6.18)	816 (5.67)
	Motor-vehicle-related	3472 (20.40)	3780 (22.01)	2970 (20.63)
	Fall-related	6235 (36.64)	6595 (38.40)	5412 (37.59)
	Others/Unknown	5793 (34.04)	5355 (31.18)	4855 (33.72)
Admission Type	Others	14209 (83.49)	14030 (81.69)	11308 (78.53)
	Trauma Center	2810 (16.51)	3145 (18.31)	3091 (21.47)
Length of Stay*	Average	6.60 (10.23)	6.55 (10.01)	6.67 (13.74)
Overall Total Count		18141	18129	15149

**Variable was summarized using means and standard deviation*

Table 3.2. Proportion of in-hospital mortality between hospitalized TBI patients below and above 65 years of age (2012 – 2014)

Outcome at Discharge	Patients aged below 65 years N (%)	Patients aged at least 65 years N (%)	Total
Alive at Discharge	22419 (93.58)	16013 (91.07)	38432 (92.52)
Died in-hospital	1537 (6.42)	1571 (8.93)	3108 (7.48)
Total	23956	17584	41540 (100.00)

Table 3.3. Rates of TBI-Related Hospitalizations in Texas (2012 – 2014)

Categories	2012 (95% CI)	2013 (95% CI)	2014 (95% CI)
Age Group (years)		Rates per 100, 000	
Under 5	54.52 (51.28 – 57.90)	51.70 (48.56 – 55.00)	39.99 (37.25 – 42.88)
5-9	18.80 (16.90 – 20.82)	19.08 (17.21 – 21.09)	15.52 (13.84 – 17.36)
10 – 14	24.13 (21.99 – 26.42)	21.25 (19.25 – 23.39)	19.49 (17.62 – 21.51)
15 – 19	45.76 (42.75 – 48.92)	44.60 (41.62 – 4769)	33.59 (31.04 – 36.30)
20 – 24	48.35 (41.30 – 51.60)	43.74 (40.87 – 46.76)	32.84 (30.38 – 35.45)
25 – 29	38.44 (35.70 - 41.30)	35.58 (32.96 – 38.95)	29.63 (27.27 – 32.13)
30 - 34	33.74 (31.16 – 36.48)	32.38 (29.39 – 35.03)	24.72 (22.67 – 27.03)
35 – 39	28.89 (26.43 – 31. 52)	28.38 (25.95 - 30.97)	22.65 (20.51 – 24.95)
40 – 44	28.92 (26.48 – 31.52)	29.89 (27.43 – 32.52)	23.95 (21.76 – 23.31)
45 – 49	34.67 (31.94 – 37.96)	31.80 (29.19 – 34.60)	25.72 (23.37 – 28.24)
50 – 54	40.02 (37.23 – 43.25)	36.33 (33.57 – 39.47)	32.07 (29.48 – 34.83)
55 – 59	48.02 (44.62 – 51.39)	49.36 (45.96 – 52.95)	42.43 (35.63 – 41.74)
60 – 64	60.20 (56.00 – 64.63)	57.57 (53.51 – 61.84)	51.15 (47.44 – 55.12)
65 – 69	88.76 (82.93 – 94.90)	80.75 (75.34 – 86.45)	64.79 (60.07 – 69.78)
70 – 74	137.56 (137.90 – 146.70)	137.50 (129.11 – 146.40)	112.58 (105.21 – 120.10)
75 – 79	223.59 (210.71 – 237.11)	216.89 (213.17 – 221.10)	182.21 (170.90 – 194.10)
80 – 84	373.30 (353.70 – 393.72)	386.30 (366.51 – 406.90)	330.03 (311.90 - 348.81)
85+	607.11 (581.10 – 633.40)	576.90 (568.90 -584.91)	513.69 (490.60 – 537.61)
Gender			
Male	67.94 (66.52 – 69.37)	66.47 (65.09 – 67.88)	53.95 (52.71 – 55.21)
Female	48.48 (47.30 – 49.69)	47.03 (45.87 – 48.20)	39.35 (38.29 – 40.42)
Total	69.48 (69.10 – 69.74)	68.39 (67.39 – 69.39)	56.17 (54.64 – 60.38)

Table 3.4. Factors Associated with TBI-Related In-Hospital Mortality among Patients 65 years and older in Texas (2012- 2014)

Variable		Unadjusted Odds (95% CI)	Adjusted Odds (95% CI)
Age Categories (years)	65 - 69	Reference	Reference
	70 – 74	1.12 (0.89 – 1.39)	1.19 (0.91 – 1.56)
	75 - 79	1.33 (1.08 – 1.65)	1.51 (1.17 – 1.95)
	80 – 84	1.25 (1.02 – 1.54)	1.44 (1.13 – 1.85)
	85– 89	1.49 (1.21 – 1.83)	1.85 (1.44 – 2.38)
	90+	1.55 (1.25 – 1.93)	2.03 (1.55 – 2.66)
Gender	Female	Reference	Reference
	Male	1.65 (1.48 – 1.84)	1.55 (1.36 – 1.77)
Race/Ethnicity	Whites	Reference	Reference
	Hispanics	1.05 (0.92 – 1. 21)	1.18 (1.01 – 1.40)
	Blacks	0.78 (0.57 – 1.03)	0.73 (0.52 – 1.02)
	Others	1.22 (0.86 – 1.72)	1.23 (0.80 – 1.90)
TBI Severity	Moderate	Reference	Reference
	Severe	5.01 (4.09 – 6.14)	6.97 (5.67 – 8.57)
	Critical	24.9 (21.25 – 31.65)	96.29 (76.58 – 121.08)
TBI Cause	Fall-related	Reference	Reference
	Assault-related	1.21 (0.65 – 2.26)	1.77 (0.79 – 3.95)
	Motor-vehicle-related	1.72 (1.42 – 2.08)	1.40 (1.07 – 1.83)
	Struck-by or Against	0.72 (0.40 – 1.30)	0.60 (0.27 – 1.34)
	Others/Unknown	1.27 (1.13 – 1.42)	1.31 (1.13 – 1.51)
Comorbidity	None	Reference	Reference
	Present	1.47 (1.31 – 1.65)	0.97 (0.85 – 1.12)
Admission Type	Others	Reference	Reference
	Trauma Center	1.33 (1.14 – 1.55)	1.13 (0.94 – 1.37)
Year of Admission	2014	Reference	Reference
	2012	0.94 (0.82 – 1.08)	0.77 (0.65 – 0.91)
	2013	0.92 (0.81 – 1.05)	0.96 (0.82 – 1.13)
Length of Stay	Each additional day	1.03 (1.01 – 1.04)	0.81 0.79 – 0.82)

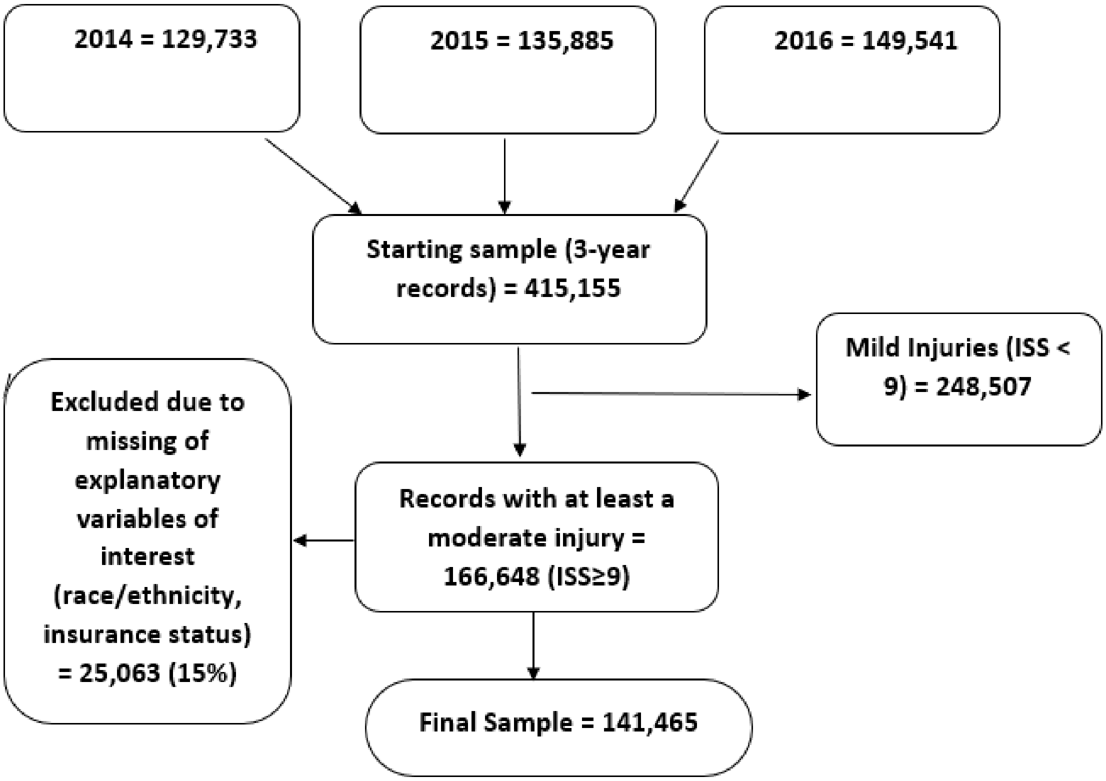

Figure 4.1. Study Sample Size Derivation (Flow-Chart)

Table 4.1. Demographic Characteristics of Trauma Victims with at least a Moderate Injury (N = 141,465)

Characteristic		Year		
		2014 N (%)	2015 N (%)	2016 N (%)
Trauma Outcome	Fatal	1648 (4.40)	1429 (3.60)	1499 (3.30)
	Non-fatal	35701 (95.60)	37837 (96.40)	44267 (96.70)
Insurance Status	Private	12595 (33.70)	12869 (38.80)	14462 (31.60)
	Public	19570 (52.40)	20663 (52.60)	23753 (51.90)
	Uninsured	5184 (13.90)	5734 (14.60)	7551 (16.50)
Race	Non-Hispanic White	31101 (63.60)	32243 (70.30)	34893 (74.70)
	Non-Hispanic Black	3755 (7.70)	3346 (7.30)	2967 (6.40)
	Hispanic Any Race	13277 (27.20)	8213 (17.90)	6627 (14.20)
	Others	751 (1.50)	2046 (4.50)	2246 (4.80)
Gender	*Female*	21869 (44.70)	20642 (45.00)	20879 (44.70)
	Male	27015 (55.30)	25206 (55.00)	25854 (55.30)

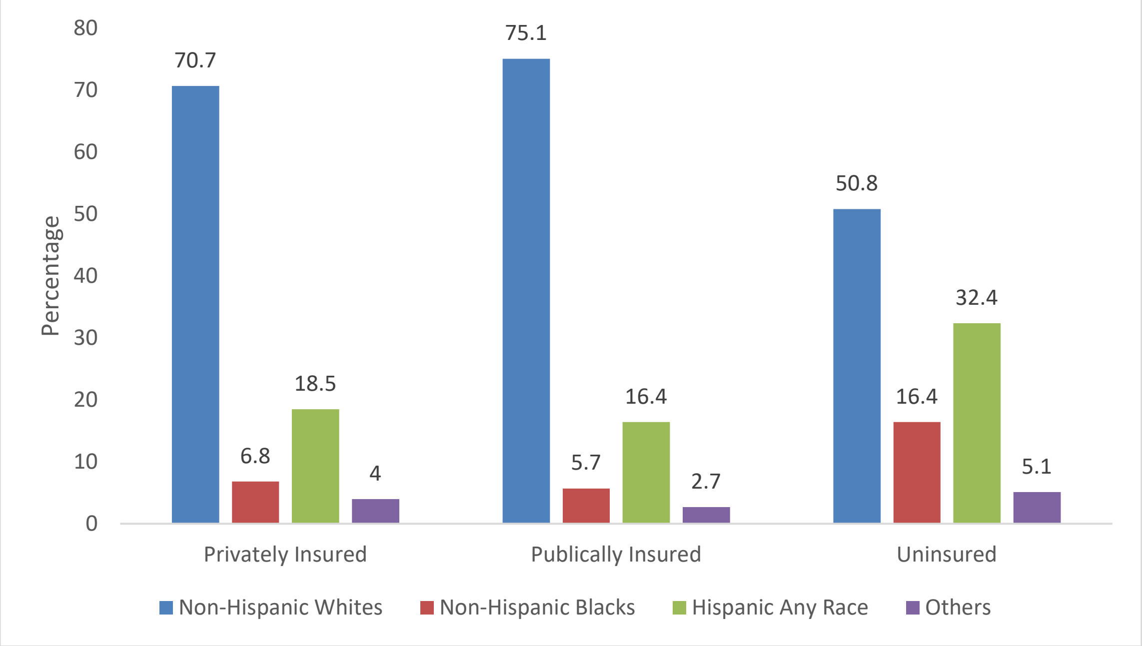

Figure 4.2. Health Insurance Coverage by Race

Table 4.2. Univariate Associations between Trauma Mortality and Victim's Characteristics

Characteristic		Trauma Fatality		p-value*
	Categories	Fatal N (%)	Non-fatal N (%)	
Insurance Status				<.0001
	Private	1425 (3.10)	44370 (96.90)	
	Public	2427 (3.40)	68637 (96.60)	
	Uninsured	1606 (6.30)	23000 (93.50)	
Race				<.0001
	Non-Hispanic White	3216 (3.30)	95021 (96.70)	
	Non-Hispanic Black	747 (7.40)	9321 (92.00)	
	Hispanic Any Race	1400 (4.90)	26717 (95.10)	
	Others	95 (1.70)	4948 (98.10)	
Gender				<.0001
	Male	3684 (4.70)	74391 (95.30)	
	Female	1774 (2.80)	61616 (97.20)	
Age group (Years)				<.0001
	01 – 14	269 (2.50)	10670 (97.40)	
	15 – 29	1037 (4.90)	20157 (95.10)	
	30 – 44	760 (4.60)	15860 (95.40)	
	45 – 59	886 (4.39)	19347 (95.61)	
	60 - 74	902 (3.49)	25082 (96.51)	
	75 - 90	1595 (3.40)	44871 (96.60)	
Injury Severity (ISS)*				<.0001
	Moderate	1472 (1.4)	102263 (98.6)	
	Severe	861 (3.7)	22408 (96.3)	
	Critical	3125 (21.6)	11336 (733.4)	
Comorbid Conditions				<.0001
	No Comorbid Conditions	5190 (3.80)	130872 (96.20)	
	Had Comorbid Conditions	268 (5.01)	5135 (94.99)	
Hospital Designation				<.0001
	Hospital	73 (5.45)	1242 (94.55)	
	Trauma Level - I	2331 (5.10)	43500 (94.90)	
	Trauma Level - II	696 (3.90)	16911 (96.10)	
	Trauma Level – III	1193 (3.60)	32230 (96.40)	
	Trauma Level – IV	549 (2.40)	22506 (97.60)	

**P-values are from a Pearson Chi-Square Test comparing two or more categories*

Table 4.2: Continued

Characteristic	Categories	Trauma Fatality Fatal N (%)	Non-fatal N (%)	p-value*
Injury Type				<.0001
	Assault/Homicide	192 (4.10)	4516 (95.9)	
	Self-Inflicted	266 (25.30)	785 (74.7)	
	Unintentional	145 (0.71)	19940 (99.29)	
	Other/Unclassified	3973 (4.1)	92564 (94.9)	
Traumatic Brain Injury (TBI)				<.0001
	Included a TBI Diagnosis	2577 (9.50)	24713 (90.60)	
	Did not Include a TBI Diagnosis	2.52 (2.50)	111294 (97.50)	
Severity of Head Trauma				<.0001
	Mild	1447 (1.82)	110407 (98.18)	
	Moderate	318 (5.40)	5581 (94.60)	
	Severe	3316 (29.40)	7974 (70.60)	
Year				<.0001
	2014	2227 (4.60)	46657 (95.40)	
	2015	1731 (3.80)	44117 (96.20)	
	2016	1500 (3.20)	45233 (96.80)	

**P-values are from a Pearson Chi-Square Test comparing two or more categories*

Table 4.3. Multivariate Analysis for Odds of Trauma Fatality by Insurance Status and Race

Characteristic	Categories	Adjusted OR	95% Confidence Limits
Insurance Status			
	Private	Reference	
	Public	1.18	1.07 – 1.30
	Uninsured	1.86	1.66 – 2.05
Race			
	Non-Hispanic White	Reference	
	Non-Hispanic Blacks	2.11	1.87 – 2.37
	Hispanic Any Race	1.25	1.16 – 1.36
	Others	0.52	0.41 – 0.67
Gender			
	Female	Reference	
	Male	1.19	1.10 – 1.29
Age group (Years)			
	01 – 14	Reference	
	15 – 29	1.06	0.88 – 1.27
	30 – 44	1.17	0.96 – 1.41
	45 – 59	1.80	1.49 – 2.17
	60 - 74	2.80	2.32 – 3.38
	75 - 90	5.21	4.33 – 6.28
Injury Severity (ISS)*			
	Moderate	Reference	
	Severe	1.60	1.43 – 1.78
	Critical	5.45	4.93 – 6.02
Comorbid Conditions			
	No Comorbid Conditions	Reference	
	Had Comorbid Conditions	1.52	1.27 – 1.81
Hospital Designation			
	Trauma Level - I	Reference	
	Trauma Level - II	1.40	1.25 – 1.56
	Trauma Level – III	1.20	1.09 – 1.33
	Trauma Level - IV	1.28	1.17 – 1.40
	Hospital	2.48	1.85 – 3.35
Injury Type			
	Unintentional	Reference	
	Assault/Homicide	4.48	3.55 – 5.66
	Self-Inflicted	11.52	9.02 – 14.73
	Other/Unclassified	5.82	4.85 – 6.99

Table 4.3. Continued

Characteristic	Categories	Adjusted OR	95% Confidence Limits
Traumatic Brain Injury (TBI)			
	Did not Include a TBI Diagnosis	Reference	
	Included a TBI Diagnosis	1.31	1.21 – 1.42
Severity of Head Trauma			
	Mild	Reference	
	Moderate	3.00	2.61 – 3.46
	Severe	21.81	19.82 – 24.00
Year			
	2016	Reference	
	2015	0.79	0.73 – 0.86
	2014	0.87	0.79 – 0.96

**ISS = Injury Severity Score assigned at presentation*

Table 4.4. Modification of the Effects of Insurance Coverage on Trauma Mortality by Race

	Health Insurance Status		
	Private	Public	Uninsured
Race/Ethnicity	OR** (95% CI)	OR** (95% CI)	OR** (95% CI)
Non-Hispanic White	Reference	1.28 (1.13 – 1.44)	1.66 (1.45 – 1.90)
Non-Hispanic Black	1.96 (1.57 – 2.45)	2.01 (1.66 – 2.44)	5.12 (4.27 – 6.15)
Hispanic Any Race	1.36 (1.16 – 1.60)	1.40 (1.21 – 1.63)	2.36 (2.05 – 2.72)
Others	0.39 (0.23 – 0.66)	0.71 (0.48 – 1.07)	1.02 (0.69 – 1.51)

***OR were adjusted for the severity, injury type, comorbidities, gender, age, TBI, and trauma center.*

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APPENDIX A

ADDITIONAL TABLES

Table A.1: Missing data analysis for trauma victims with invalid entry on health insurance status and race/ethnicity

	Trauma Mortality		
	Fatal (%)	Non-Fatal (%)	Total
Missing any of the explanatory variables of Interest	1038 (4.10)	24025 (95.90)	25063 (15.10)
Not missing any of the explanatory variables of Interest	5458 (3.90)	136007 (96.10)	141465 (84.90)
Total	6496	160032	166528 (100.00)

Table A.2: Missing data analysis for TBI patients with suppressed age, gender, and race variables

	TBI In-hospital Mortality		
	In-hospital mortality (%)	Discharged alive (%)	Total
Missing age, gender, or race	428 (5.05)	8045 (94.95)	8473 (16.94)
No missing variables	3108 (7.67)	38432 (92.33)	41540 (83.06)
Total	3536	46477	50013 (100.00)

Table A.3: Elixhuaser Comorbidity Measures for Administrative Data (Reprinted from Elixhauser, et al., 1998)

	Condition	ICD Code
1	Congestive Heart Failure	398.91, 402.11, 402.91, 404.11, 404.13, 404.91, 404.93,428.0-428.9
2	Cardiac Arrythmias	426.10, 426.11, 426.13, 426.2-426.53, 426.6-426.89, 427.0, 427.2, 427.31, 427.60,427.9, 785.0, V45.0, V53
3	Valvular Disease	093.20-093.24, 394.0-397.1, 424.0-424.91, 746.3-746.6, V42.2, V43.3
4	Pulmonary circulation disorders	416.0-416
5	Peripheral vascular disorders	440.0-440.9, 441.2, 441.4, 441.7, 441.9, 443.1-443.9, 447.1, 557.1, 557.9, V43.4
6	Hypertension (combined) Hypertension, uncomplicated Hypertension, complicated	401.1, 401.9, 402.10, 402.90, 404.10, 404.90, 405.11, 405.19, 405.91, 405.99
7	Paralysis	342.0-342.12, 342.9, 344.9
8	Other neurological disorders	331.9, 332.0, 333.4,333.5,334.0-335.9,340, 341.1-341.9,345.00-345.11, 345.40-345.51, 345.80-345.91, 348.1, 348.3, 780.3, 784.3
9	Chronic pulmonary disease	490-492.8, 493.00-493.91, 494, 495.0-505, 506.4
10	Diabetes, uncomplicated	250.00 – 250.33
11	Diabetes, complicated	250.40-250.73, 250.90-250.93
12	Hypothyroidism	243-244.2, 244.8, 244.9
13	Renal failure	403.11, 403.91, 404.12, 404.92, 585, 586, V42.0, V45.1, V56.8
14	Liver disease	070.32, 070.33, 070.54, 456.0, 456.1, 456.20, 456.21 571.0, 571.2, 571.3, 571.40-571.49, 571.5, 571.6, 571.8, 571.9, 572.3, 572.8 V42.7
15	Peptic ulcer disease excluding bleeding	531.70, 531.90, 532.70, 532.90, 533.70, 533.90, 534.70, 534.90, V12.71
16	AIDS	042-044.99
17	Lymphoma	-202.38, 202.50-203.01,203.8-203.81, 238.6, 273.3, V10.71, V10.72, V10.79
18	Metastatic cancer	196.0, 199.1

Table A.3: Continued

	Condition	ICD - Code
19	Solid tumor without metastasis	140.0-172.9,174.0-175.9,179-195.8, V10.00-V10.9
20	Rheumatoid Arthritis/collage Vascular diseases	701.0, 710.0-710.9, 714.0-714.9, 720.0-720.9, 725
21	Coagulopathy	0-2869, 287.1, 287.3-287.5
22	Obesity	278.0
23	Weight loss	260 - 263.9
24	Fluid and electrolyte disorders	276.0 – 276.9
25	Blood loss anemias	2800
26	Deficiency anemias	280.1-281.9, 285.9
27	Alcohol abuse	291.2, 291.5, 291.8, 291.9, 303.90-303.93,305.00-305.03, V113
28	Drug abuse	92.82-292.89,292.9,304.00-304.93, 305.20-305.93
29	Psychoses	295.00 -298.9, 299.10-299.11
30	Depression	300.4, 301.12, 309.0, 309.1, 311

Table A.4: ICD-9-CM Codes for Traumatic Brain Injury-related Hospitalization or ED Visit (Reprinted from Faul, M. et al., 2010).

Description	ICD-9-CM (Hospitalizations and ED Visits)
Fracture of the vault or base of skull	800.0-801.9
Other and unqualified multiple fractures of the skull	803.0-804.9
Intracranial injury, including concussion, contusion, laceration, and hemorrhage	850.0-854.1
Injury to optic nerve and pathways	950.1-950.3
Shaken baby syndrome	995.55
Head injury, unspecified	959.01

Table A.5: ICD-10 Codes for Traumatic Brain Injury-related Mortality (Reprinted from Faul, M, et al., 2010).

Description	ICD-10 (Deaths)
Open wound of the head	S01.0-S01.9
Fracture of the skull and facial bones	S02.0, S02.1, S02.3, S02.7-S02.9
Injury to optic nerve and pathways	S04.0
Intracranial injury	S06.0-S06.9
Crushing injury of head	S07.0, S07.1, S07.8, S07.9
Other unspecified injuries of head	S09.7-S09.9
Open wounds involving head with neck	T01.0
Fractures involving head with neck	T02.0
Crushing injuries involving head with neck	T04.0
Injuries of brain and cranial nerves with injuries of nerves and spinal cord at neck level	T06.0
Sequelae of injuries of head	T90.1, T90.2, T90.4, T90.5, T90.8, T90.9

Table A.6: External Cause (E-Code) Categories of TBI-related ED Visits or Hospitalizations (Reprinted from Faul, M. et al., 2010).

Description	ICD-9-CM	ICD-10
Motor vehicle traffic related (MVT) [unintentional]	E810-E819	V02-V04 (.1, .9), V09.2, V12-V14 (.3-.9), V19 (.4-.6), V20-V28 (.3-.9), V29 (.4-.9), V30-V79 (.4-.9), V80 (.3-.5), V81.1, V82.1, V83-V86 (.0-.3), V87 (.0-.8), V89.2
MVT Sub-set: Occupant	E810-E819 (.0,.1)	V30-V79 (.4-.9), V81.1, V82.1, V83-V86 (.0-.3)
MVT Sub-set: Motorcycle	E810-E819 (.2,.3)	V20-V28 (.3-.9), V29 (.4-.9)
MVT Sub-set: Pedal Cycle	E810-E819 (.6)	V12-V14 (.3-.9), V19 (.4-.6)
MVT Sub-set: Pedestrian	E810-E819 (.7)	V02-V04 (.1, .9), V09.2
MVT Sub-set: Other and Unspecified	E810-E819 (.4, .5, .8, .9)	V80 (.3-.5), V87(.0-.8), V89.2
Falls [unintentional and undetermined]	E880-E886, E888, E987	W00-W19, Y30
Assault [includes firearms and other methods]	E960-E969	X85-Y09, Y87.1
Struck by and Struck Against	E916, E917	W20-W22, W50-W52, Y29
Other and Unspecified	All other E codes	All other cause codes