DISSERTATION

UNDERSTANDING THE ASSOCIATION BETWEEN THE ABBREVIATED INJURY SCALE SCORE FOR THE HEAD REGION AND OUTCOMES FOLLOWING TRAUMATIC BRAIN INJURY, COLORADO 1998 – 2000

Submitted by

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In partial fulfillment of the requirements

For the Degree of Doctor of Philosophy

Colorado State University

Fort Collins, Colorado

Fall 2007

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COLORADO STATE UNIVERSITY

August 28, 2007

WE HEREBY RECOMMEND THAT THE DISSERTATION PREPARED UNDER OUR SUPERVISION BY INDIRA BEATRICE GUJRAL ENTITLED UNDERSTANDING THE ASSOCIATION BETWEEN THE ABBREVIATED INJURY SCALE SCORE FOR THE HEAD REGION AND OUTCOMES FOLLOWING TRAUMATIC BRAIN INJURY, COLORADO 1998 – 2000 BE ACCEPTED AS FULFILLING IN PART REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY.

Committee on Graduate Work

Adviser

Department Head/Director

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ABSTRACT OF DISSERTATION

UNDERSTANDING THE ASSOCIATION BETWEEN THE ABBREVIATED INJURY SEVERITY SCALE SCORE FOR THE HEAD REGION AND OUTCOMES FOLLOWING TRAUMATIC BRAIN INJURY, COLORADO 1998 – 2000

Annually, an estimated 1.4 million Americans are affected by traumatic brain injury (TBI). It is the leading cause of morbidity and mortality among trauma individuals. While advances in medicine have helped to decrease mortality from TBI, less is known about the long-term outcomes following TBI. The goal of this research was to further our understanding of long-term outcomes following TBI by identifying associations between one anatomical coding system and one-year outcomes following TBI.

The Abbreviated Injury Severity Score is an anatomical scoring system used by injury researchers throughout the United States and the world to characterize individual injury. One attribute of this measure is the ability to independently characterize injury severity for one body region, for this study, specifically, the head region. Although the Abbreviated Injury Severity Score for the Head region (HAIS) is an anatomic measure of TBI severity, no study has assessed the inter- and intra-rater agreement of HAIS between trauma registrars at hospitals and trained state coders. Further, no studies have specifically assessed the association between HAIS and long-term outcomes following TBI using population-based data. The objectives of this study were to utilize data from two Colorado population-based studies containing HAIS scores to investigate the reliability of HAIS and its ability to predict long-term physical and cognitive outcomes after traumatic brain injury. The purposes of this study were:

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1) to describe the intra-rater reliability of HAIS scores by having a trained coder employed by the Colorado Department of Public Health and Environment recode HAIS scores for traumatic brain injured cases from the Colorado Traumatic Brain Injury Surveillance system for the years 1999-2000;

2) to describe the inter-rater reliability of HAIS scores by comparing HAIS scores from cases in the Colorado Traumatic Brain Injury Surveillance system for 2000 to HAIS scores from trauma registrars at hospitals throughout Colorado; and,

3) to use HAIS scores to evaluate functional outcomes of traumatic brain injured individuals in Colorado who were enrolled between 1998 and 1999 in the Colorado Traumatic Brain Injury Registry and Follow-up System.

Cases were defined using the International Classification of Diseases, 9th Revision, Clinical Modification diagnostic codes for TBI (800 – 801.9, 803 – 804.9, or 850 854.1, and 959.01) and included Colorado residents who were either admitted to hospitals or died prior to reaching the hospital from a TBI. To assess inter- and intra-rater agreement, data was selected from the Colorado Traumatic Brain Injury Surveillance system for years 1999 – 2000. A sample of 250 cases was randomly selected to assess intra-rater agreement. Approximately 624 cases were selected to assess inter-rater agreement. Weighted and non-weighted kappa statistics were used to assess inter- and intra-rater agreement, respectively. Landis and Koch (1977) cut points were used to interpret agreement findings. To identify long-term outcomes following TBI, 1,802 cases were used from the Colorado Traumatic Brain Injury Registry and Follow-up System (CTBIRFS), 1998 - 1999. Outcomes selected for this study were based on the conceptual model of function and disability developed by the World Health Organization. Logistic

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regression models were used to determine the association between TBI severity categories (HAIS) and one-year activity and societal participation outcomes. Logistic regression was used to determine the association between HAIS and cognitive outcomes one-year following TBI. All statistical analyses were conducted using SAS 9.1©.

Results of this study found intra-rater agreement of HAIS to be "almost perfect" while inter-rater agreement between the trained state coder and the hospital trauma registrars was "substantial." This finding was surprising given that individuals performing the coding often have varying levels of education and training, experience, and use and knowledge of database systems. Factors that potentially affect agreement that were not tested include injury factors such as impact forces, multi-system trauma, pharmaceutical drug usage, and use of personal protective equipment, such as helmets. Future studies should be conducted to identify the role of these factors when coding HAIS.

In order to accurately assess function and disability following TBI, the severity of the TBI must be taken into account. Using HAIS categories mild, moderate, and severe TBI, individuals with moderate TBI (5.04 [95% confidence interval (1.67, 15.6)]) and severe TBI (4.08 [95% confidence interval (1.29, 12.7)]),were five times as likely to report needing help with Activities of Daily Living throughout the study period as compared to those with mild TBI, after adjusting for identified potential confounders. Similarly, subjects with moderate and severe TBI were more than 60% as likely to report needing help with Instrumental Activities of Daily Living throughout the study period as compared to those with mild TBI. The odds ratios for moderate and severe TBI were 1.90 [95% confidence interval (1.01, 3.57)] and 1.62 [95% confidence interval (0.81, 3.26)],

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respectively. Adjusting for identified potential confounders, subjects with moderate and severe TBI were more than 50% as likely to report diminished societal participation throughout the study period as compared to those with mild TBI. The odds ratios for moderate and severe TBI were 1.72 [95% confidence interval (1.18, 2.51)] and 1.58 [95% confidence interval (1.01, 2.47)], respectively. However, moderate and severe TBI were not associated with cognitive dysfunction. The results of this study indicate that HAIS is a good predictor of function and disability at the individual and societal levels, as measured by the activities and participation domains. The study failed to find an association between HAIS and cognitive disability. The results of this study support the need for individuals with a moderate and severe TBI (HAIS score greater than three) to participate in some form of rehabilitation to increase function and reduce disability following TBI.

The objective of this study was to use data from the CTBIRFS and the CO TBI Surveillance system to expand upon the literature regarding outcomes following TBI. Specifically, the purpose of this study was to increase understanding of the Abbreviated Injury Scale for the head (HAIS) – an anatomical scoring system that potentially could be a predictor for long-term outcomes following TBI. As medicine advances and more individuals survive TBI, demands on rehabilitation resources will rise. The results of this study indicate that HAIS is a reliable scoring system that is associated with one-year outcomes following TBI. Using HAIS to assess severity of TBI will allow clinicians to identify and target rehabilitative efforts for TBI individuals and help individuals receive the rehabilitation services they need. Future research is needed to expand upon these

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findings to identify barriers to rehabilitation, such as cost and access to care, and to assess the role of rehabilitation on quality of life following TBI.

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ACKNOWLEDGEMENTS

I would like to thank my committee at Colorado State University for their constant guidance and support through the doctoral process. Specifically, this dissertation would never have been possible without the valuable lessons learned by Dr. Lorann Stallones. Thank you for your valuable role as mentor, and for pushing me to think critically and to be a better writer. You are a gifted epidemiologist.

Dr. Thomas Keefe, thank you for making statistics fun, exciting, and enjoyable. You are a great teacher. Dr.'s Chen, Peel, and Sample, thank you for your insight and wisdom during this process. Lastly, I would like to thank Barbara Gabella from the Colorado Department of Public Health and Environment and Dr. Gale Whiteneck from Craig Hospital for sharing sage advice and being passionate advocates for individuals with traumatic brain injury.

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DEDICATION

This dissertation is dedicated to a host of influential individuals in my life. To Jason, best friend and love of my life, thank you for your constant support, your belief in my abilities, and for your constant encouragement. I could not have done this without you. For my parents, Kathleen and Surinder, thank you for believing in my abilities. I am thankful for all your wisdom and support. To Kathleen, Sundhya, and Paul, for being my pillars of support and my life coaches, thanks for always making me laugh.

Lastly, this dissertation is dedicated to all individuals affected by traumatic brain injury, including our soldiers returning from the Iraq war. May your afflictions help us to better understand traumatic brain injury and foster future research to ameliorate its affects.

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CHAPTER 1

INTRODUCTION

Each year in the United States, an estimated 1.4 million people sustain a brain injury and approximately 50,000 individuals die from one [1;2]. While the epidemiology of traumatic brain injury has been characterized and potential confounders for sustaining a traumatic brain injury have been identified, less is known about the physiological and anatomical changes following a traumatic brain injury. Similarly, researchers and clinicians are just beginning to assess the breadth of physical and cognitive long-term complications resulting from head injury.

A number of scoring systems have been developed to assess the severity of traumatic brain injury. The leading measure is the Glasgow Coma Scale, a scoring system based on physiological responses to head injury [3]. Glasgow Coma Scale scores are used by clinicians to assess patient progress during treatment. Unfortunately, scores are directly affected by external factors such as the use of paralytic agents during treatment which consequently directly affect scoring validity [4;5]. While Glasgow Coma Scale scores have been found to predict mortality from traumatic brain injury, they have not been found to predict long-term functional outcomes [4;6].

One promising scoring system which may predict long-term outcomes from traumatic brain injury is the Abbreviated Injury Scale for the head (HAIS) [7]. HAIS is based solely on anatomic descriptors of head injury and is scored post-injury, meaning;

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HAIS does not contribute directly to the treatment of traumatic brain injury. The literature on the intra-rater and inter-rater reliability of HAIS scores is limited and little has been reported on the predictive value of HAIS scores related to cognitive and physical functional abilities after discharge from hospital and rehabilitation facilities.

A few studies have shown that HAIS is predictive of traumatic brain injury mortality, but no population-based studies have been conducted to specifically assess the predictive ability of HAIS for morbidity following a traumatic brain injury [8]. Two main reasons for this are: 1) few population-based studies have been conducted regarding morbidity following traumatic brain injury; and, 2) HAIS scoring is time intensive (approximately 30 minutes per case) and is usually not performed unless it is financially supported by a statewide surveillance system or an external funding source [9]. If deemed predictive, HAIS is a simple scoring measure which could potentially aid clinicians in targeting traumatic brain injured individuals for specific rehabilitation efforts. The end result of maximizing rehabilitation efforts would be an increase the quality of life for both the individuals and their families.

The Colorado Department of Public Health and Environment is unique because it houses three overlapping population-based data sets containing HAIS scores for traumatic brain injured individuals. Colorado population-based datasets include: the Colorado Traumatic Brain Injury Surveillance system; the Colorado Trauma Registry; and, the Colorado Traumatic Brain Injury Registry and Follow-up System. These population-based data sets provide a unique opportunity to determine if HAIS can predict long-term cognitive and physical disabilities after traumatic brain injury.

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Classifying traumatic brain injury at the two ends of the spectrum, at the beginning (initial injury severity) and at the end (outcome) is important because initial severity is a prognostic indicator for the outcome [4]. The objectives of this study were to utilize these Colorado population-based studies containing HAIS scores to investigate the agreement of HAIS and its ability to predict long-term physical and cognitive outcomes after traumatic brain injury. The purposes of this study were:

1) to describe the intra-rater agreement of HAIS scores by having a trained coder employed by the Colorado Department of Public Health and Environment recode HAIS scores for traumatic brain injured cases from the Colorado Traumatic Brain Injury Surveillance system for the years 1999-2000;

2) to describe the inter-rater agreement of HAIS scores by comparing HAIS scores from cases in the Colorado Traumatic Brain Injury Surveillance system for 2000 to HAIS scores from trauma registrars at hospitals throughout Colorado; and,

3) to use HAIS scores to evaluate functional outcomes of traumatic brain injured individuals in Colorado who were enrolled between 1998 and 1999 in the Colorado Traumatic Brain Injury Registry and Follow-up System.

The following steps were used to address the specific aims. First, to assess intra-rater agreement, data from 1999-2000 from the Colorado Traumatic Brain Injury Surveillance system were used. The Colorado Traumatic Brain Injury Surveillance system is a statewide population-based system requiring mandatory reporting of traumatic brain injury cases. Each year, a sample of cases is randomly selected for further data abstraction. Data collected includes HAIS scores and data abstraction is performed

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by a trained coder at the Colorado Department of Public Health and Environment. To assess intra-rater agreement, a sub-sample of the records for years 1999-2000 were selected and recoded and scores from the original HAIS were compared to recoded HAIS scores to determine agreement based on coding by the same individual.

Second, to assess inter-rater agreement, HAIS scores from the sampled cases in the Colorado Traumatic Brain Injury Surveillance system were used to compare HAIS scores from traumatic brain injured cases in the Colorado Trauma Registry for 2000. The Colorado Trauma Registry is a population-based statewide mandatory reporting system of trauma cases (including traumatic brain injury) from all hospitals in Colorado. Each hospital employs at least one trauma registrar who is responsible for providing HAIS scores. To determine inter-rater agreement, Trauma Registry records were linked to Colorado Traumatic Brain Injury Surveillance system records by name and date of birth and sampled cases from the Colorado Traumatic Brain Injury Surveillance system were used to compare to HAIS scores coded by hospital registrars to the same case coded by trauma registry personnel.

Third, data from the Colorado Traumatic Brain Injury Registry and Follow-up System was used to determine the predictive ability of HAIS. The Colorado Traumatic Brain Injury Registry and Follow-up System is the only population-based study assessing one year outcomes among traumatic brain injured individuals discharged from Colorado hospitals between 1996 and 1999. Cases were identified using the Colorado Traumatic Brain Injury Surveillance system. The trained coder at the Colorado Department of Public Health and Environment provided HAIS scores for cases in the Colorado Traumatic Brain Injury Registry and Follow-up System. For this study, the third cohort of

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the Colorado Traumatic Brain Injury Registry and Follow-up System was used. The third cohort consists of outcome assessments for traumatic brain injured cases discharged between 1998 and 1999. Outcomes of interest for the third cohort include self-reported measures of disability, health status, quality of life, productivity and physical and cognitive symptoms. To better understand the role of HAIS in predicting long-term outcomes, outcome data from the third cohort of the Colorado Traumatic Brain Injury Registry and Follow-up System was used to assess the predictive ability of HAIS while adjusting for potential confounders such as age and sex.

To accomplish study goals and objectives, this dissertation is organized into six chapters. While chapter one has introduced the purpose of this study and the specific objectives, chapters two and three provide an in-depth review of measuring the severity of traumatic brain injury and measuring long-term functioning following traumatic brain injury, respectively. Chapter four assesses the inter- and intra-rater agreement of HAIS and chapter five uses HAIS to assess functional status one-year after hospitalization for traumatic brain injury. Chapter six provides a summary of all study findings.

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CHAPTER 2

MEASURING SEVERITY OF TRAUMATIC BRAIN INJURY

Traumatic brain injury is an acute blow or jolt to the head that disrupts brain function [10]. Over the past twenty-five years, public health officials have witnessed a decrease in the number of fatalities from traumatic brain injury. Although officials initially hailed this decrease as an indicator of prevention success, it does not mark the end of the "silent epidemic [11]." Rather sadly, it represents the beginning of a new epidemic that is occurring in the United States, disability from traumatic brain injury [11].

A paradigm shift is occurring among public health officials. Gone are the days of simply trying to reduce the incidence and mortality from brain injury [11]. Now officials must also work to characterize the prevalence of disability in their communities and help serve the increasing number of disabled [11]. The purpose of this literature review is to characterize the many facets of brain injury including anatomy and function and the tools used to measure brain injury. Scientists still do not have a firm understanding of the physiological responses to brain injury and the long-term associated with brain injury. The goal of this review is to present recent literature regarding measuring the severity of traumatic brain injury.

Overview of Brain Structure and Function

The human brain is made up of billions of different types of cells which form two

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hemispheres mounted on the spinal cord [12]. There are four main anatomical divisions of the brain, the telencephalon (cerebral hemisphere), diencephalon (thalamus, hypothalamus, and pituitary gland), mesencephalon (tegmentum, and superior and inferior colliculus), and the rohombencephalon (pons, cerebellum, and medulla oblongata) [12]. Within each of these divisions are various glands and functional units which control both voluntary and involuntary reactions and responses [12].

The cerebral cortex located in the telencephalon division is the most likely to be damaged by traumatic brain injury [12]. As the outer covering of the cerebral hemisphere, the cerebral cortex comprises 80% of the human brain compared to only 30% in rodents [12]. The cerebral cortex is composed of a thin tissue (between 1.5 and 4.0 mm in thickness) with a surface area of $2000cm^2$ and is responsible for cognitive function [12]. Within the cerebral cortex are four distinct lobes [12]. The frontal lobe is located right under the forehead and is known as the "executive of the brain" because it controls movement, memory, language and personality functions [12]. The temporal lobe, located on the side of the head above the ears, is responsible for processing language and memory [12]. Near the back and top of the head is the parietal lobe which receives and analyzes information from the skin and aids in language and memory [12]. At the back of the head is the occipital lobe which processes visual information and aids in motor movement [12].

Although these lobes were originally thought to function independently, current research has been directed toward identifying the functional inter-dependence among the four lobes [12]. "Localization of function" has been the guiding doctrine for neuroscience research over the last century [12]. This principle surmises that each of the four lobes operates independently from the others [12]. But, over time, examples have emerged in

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which functional areas have been destroyed without the predicted loss of function [12]. For example, Rose and Johnson (1996) point to the case of railway worker Phineas Gage who suffered a terrible accident when a metal bar one inch in diameter went through his head starting from the lower cheek to the forehead [12]. Traditionally, injury to the frontal lobe results in changes in personality, impulsivity, problem solving, memory and judgment [12]. Although Phineas did experience a marked change in his personality, it was reported that the trauma that he sustained did not impair him as predicted [12].

Over time, examples such as this have led to the principle of "plasticity." Defined by Bullock, Oakland, and Grinnell (1997), plasticity is "an inferred property of the brain that allows an adaptive change in activity as a result of experience or as a result of damage to one of its parts (page 10) [13]." This principle created a paradigm shift in neuroscience because functions that were once thought to be specifically associated with certain areas of the brain were now believed to be more widely distributed throughout the cerebral cortex [13]. Among rehabilitation personnel, this theory provided hope that individuals once thought to be incurable were now possibly able to be rehabilitated [12].

Neuroscientists speculate that although there are specific localized areas of the brain that are responsible for specific functions, there are also larger areas that are composed of a number of discrete regions which cooperate to provide overall function [13]. The identity of these discrete regions is unknown and future research will be needed to identify these regions and their role in brain function [14]. Current research efforts include the development of diffusion tension imaging, a radiological test which identifies cerebral cortex changes which are not seen on conventional magnetic resonance imaging [15]. This imaging may help to better identify brain regions in regard to function and prove or

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disprove that discrete regions of function explain why humans exhibit a greater cognitive capacity compared to other species [15]. Nevertheless, neuroscientists realize that the brain is a complex organ and brain function requires cooperation of the entire organ [14].

Overview of Traumatic Brain Injury Pathophysiology

In response to the lack of a uniform operational definition for traumatic brain injury, CDC published a standard clinical definition in 1995 [10]. The clinical definition of traumatic brain injury is:

> "an occurrence of injury to the head (arising from blunt or penetrating trauma or from acceleration-deceleration forces) that is associated with symptoms or signs attributable to the injury: decreased level of consciousness, amnesia, other neurological or neuropsychological abnormalities, skull fracture, diagnosed intracranial lesions or death [10]."

This definition further classifies injury as either blunt or penetrating. For example, a blunt or closed traumatic brain injury means the cranial contents have not been penetrated; air is not inside the protective layer of the skull [10]. An open or penetrating traumatic brain injury means that the skull is penetrated and the brain is exposed to air [10]. A gunshot wound to the head would be considered an open traumatic brain injury while a head injury occurring as a result of a motor vehicle crash (with no penetrating object involved) would be considered a closed traumatic brain injury [10]. These descriptions of traumatic brain injury have helped researchers to describe the type of head injury sustained, but regardless of whether an injury is either blunt or penetrating, the pathophysiology is the same [13].

The pathophysiology of traumatic brain injury is separated into two stages, primary and secondary injuries [16]. Primary injuries occur at impact and cannot be controlled clinically [16]. Primary injuries are categorized as open or closed and examples

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include contusions, lacerations, fractures of the skull and intracranial hemorrhage [16]. These injuries involve the physical disruption of vascular and neuronal tissue as well as the physical shearing or tearing of neurons and axons [16]. Secondary injuries develop minutes to days after primary injuries [16]. The main target of secondary effects is the vasculature of the brain [16]. Edema, a swelling of the brain, causes a rise in intracranial pressure which prevents blood from circulating and ultimately leads to brain cell death [16]. In response to secondary injuries two waves of edema appear; the first wave starts a few hours after injury and can last 3-5 days, while the second wave begins five days after injury and can last an additional 2-3 days [16].

Secondary brain injury is the most devastating aspect of traumatic brain injury [16]. During this time, autoregulation is lost and the supply of blood to the brain known as cerebral perfusion pressure (CPP) becomes directly related to the mean arterial blood pressure (MAP) and the intracranial pressure (ICP) [17]. Hence, CPP = MAP – ICP, where intracranial pressure becomes extremely important as 70% of all traumatic brain injured individuals who are in a coma have significantly raised intracranial pressure [17]. It is therefore necessary to control intracranial pressure to maintain adequate cerebral blood flow [17]. One additional problem with secondary injury is that many individuals are asymptomatic for increased intracranial pressure for days after the injury and when this occurs, the symptoms often occur late and irreversible brain damage can result [17].

Using aggressive treatment, secondary brain injury can be avoided [17]. Treatments that aim to prevent secondary brain injury from hypoxia (loss of oxygen), hypotension (low blood pressure) and raised intracranial pressure include: resuscitation; managing airways; stabilization of other injuries; and, assessing neurological status [17]. Further, by

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controlling intracranial pressure through head posture, intravenous fluids, drug therapies, and constant monitoring, a patient will be less likely to develop long-term disability from traumatic brain injury [17].

Researchers have identified and quantified the role of secondary injury in terms of long-term outcomes. For example, Kohi et al. (1984) found that individuals who experienced hypoxia (loss of oxygen) and hypotension (low blood pressure) were more likely to have poorer outcomes six months after their injury compared to brain injured individuals that did not [18;19]. Similarly, Chesnut et al. (1993) concluded that out of 699 severely brain injured individuals studied, poor outcomes, as measured by the Glasgow Outcome Scale, were found among 79% of the individuals whom experienced hypotension and hypoxia [19;20]. The role of secondary head injury can not be understated and even though medical advancements have increased traumatic brain survival, the level of disability stemming from secondary brain injury mechanisms is still very high [21].

Traumatic Brain Injury: A System of Hospital Care

When a traumatic brain injury occurs, survivors who receive clinical care will either be treated in doctors' offices or in hospitals. For those who are seen in the emergency department at a hospital, they can either be hospitalized or treated and released [22]. Among those treated and released with head injury, individuals are often classified with "mild" traumatic brain injury[23]. Mild traumatic brain injury is defined as having a loss of consciousness for less than 10 minutes, no skull fracture on physical examination, and a nonfocal neurological exam [22;23]. Mild traumatic brain injuries make up the largest percentage of all traumatic brain injuries, around 85%, but the long-term consequences are not well known; however, this is changing as more resources are being

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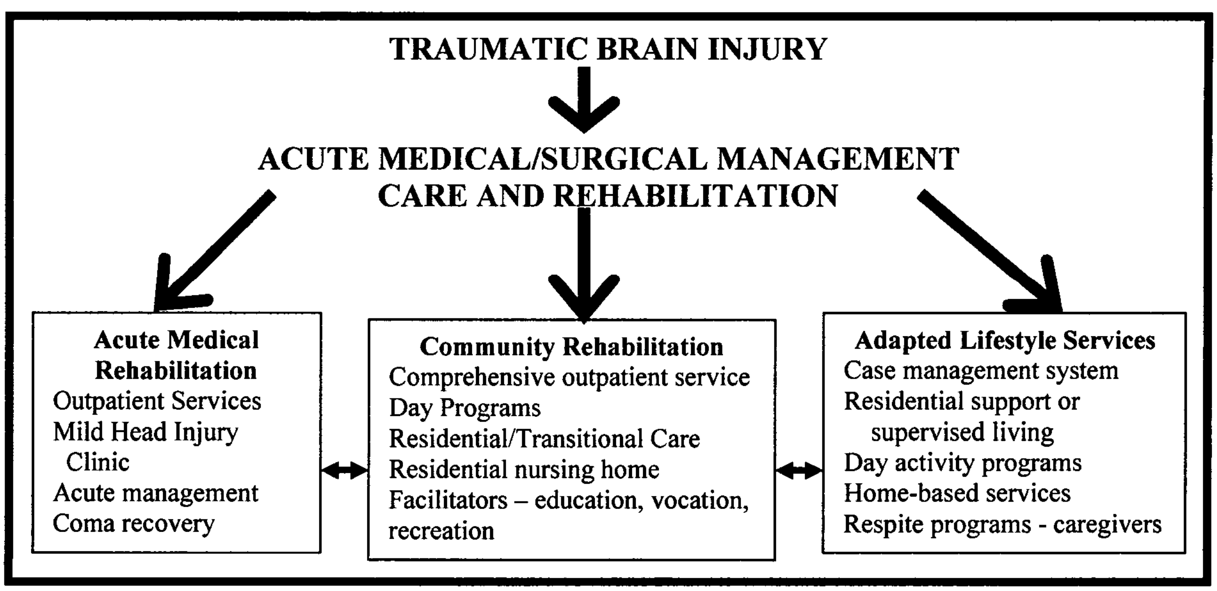
allocated for mild traumatic brain injury outcome research [22].

Hospitalized traumatic brain injury cases represent more severe injuries and upon hospitalization they enter three phases of treatment [24]. During phase one, it is important to closely monitor and treat the acute injury [16]. The goal of phase two, sub-acute treatment, is to rehabilitate and return the patient to the community [24]. During this phase, family and/or staff watch and treat bedsores, infections and other complications such as secondary brain swelling [24]. Phase three is defined as the continual process of rehabilitating and treating the individual for long-term impairments [24].

The overall goal of phase three treatment is to help the patient progress to a level of functional independence [25]. Depending on head injury severity, individuals receive one or all of the following treatments during phase three (rehabilitation): acute medical rehabilitation, community rehabilitation, and/or lifestyle services [24]. Within each of these rehabilitation services are programs provided by hospital staff, social workers, community partners, and family. Figure 2.1 by Khan et al. (2003) illustrates the flow of rehabilitation for individuals with traumatic brain injury [26].

Figure 2.1: Rehabilitation phases following Traumatic Brain Injury (Khan F, Baguley IJ, Cameron ID. Rehabilitation after traumatic brain injury. *Med J Aust.* 2003;178:290-295.)



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The arrows in Figure 2.1 depict the dynamic nature of rehabilitation with each patient moving from one program to another as individual needs change [26]. While the goal of acute medical rehabilitation is to provide inpatient and outpatient services, the goal of community rehabilitation is to provide resources for integrating individuals back into the community [26]. At the end of the continuum are the adapted lifestyle services [26]. The goal of these services is to provide long-term services to individuals with traumatic brain injury disabilities [26]. Often, barriers to community rehabilitation services such as financial constraints and a lack of community services prohibit traumatic brain injured individuals from entering these programs [26;27]. The inability to attend and participate in these services often places long-term responsibilities on patient families which potentially lead to inadequate and unsupervised care for individuals [26].

The traumatic brain injury system of care for hospitalized individuals is well understood [27]. Each of the three phases of care, acute, sub-acute, and rehabilitation, is critical to reducing the burden of disability among head injured individuals [27]. Over time, advancements in medical technology have improved treatment phases one (acute care) and two (sub-acute care) [27]. Although progress has been made with phase three treatment (rehabilitation), barriers to accessing rehabilitative services still exist [27]. Phase three of treatment (rehabilitation) is critical for brain injured individuals to gain functional independence and future public health resources should be allocated towards reducing barriers such as access to care [27].

Epidemiology of Traumatic Brain Injury in the United States

The epidemiology of sustaining a traumatic brain injury is well documented in developed nations such as the United States. Currently, incidence rates for traumatic

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brain injury are higher in the United States (9.5/10,000) compared to other developed nations such as The Federal Republic of Germany (1.0/10,000) and the Netherlands (7.9/10,000) [4]. Although the United States has increased funding for prevention efforts to reduce traumatic brain injury occurrence, less research has been done to assess the long-term outcomes from traumatic brain injury [28].

Among all injury deaths, one-third or 50,000 individuals die from traumatic brain injury each year [29]. While an estimated 1.4 million Americans sustain a traumatic brain injury yearly, only 230,000 are hospitalized [2]. It is estimated that 1.1 million individuals or 85% of all brain injured individuals are treated and released from emergency departments with mild traumatic brain injury each year [2;22;23]. An estimated 15,000 individuals are believed to either receive medical care outside of a hospital setting in a doctor's office or clinic or are suspected to not receive any care at all [2]. Currently, it is estimated that approximately 70,000 to 90,000 individuals are affected by long-term disability from traumatic brain injury each year with approximately 5.3 million Americans (2% of the United States population) living with traumatic brain injury-related disabilities [30].

Quantifying traumatic brain injury mortality is easier than quantifying morbidity because standard outcome measures, such as death certificates, are more readily available [10]. Quantifying head injury morbidity is more difficult because traumatic brain injury surveillance data is often collected for hospitalized individuals only; therefore, individuals not hospitalized are excluded from data collection [10]. Over the past twenty years fewer individuals have been hospitalized with head injuries [30]. For example, Thurman et al. (1999) reported that between 1980 and 1994, hospitalization rates for

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traumatic brain injury decreased 51%, with a 29% decrease in hospitalization rates for all hospital admissions [30]. Upon further investigation, researchers concluded that a reduction in inpatient services was directly associated with an increase in outpatient services [31]. This shift may be attributed to a host of factors including changes to payment system reimbursement plans, managed care, hospital policies excluding individuals experiencing mild traumatic brain injury, and/or improvements in diagnostic technology [30].

Rates of hospitalization for mild traumatic brain injury declined significantly ($p < 0.001$) compared to hospitalization rates for moderate and severe traumatic brain injury [30]. As a result of these changes, approximately 80% of individuals evaluated for a traumatic brain injury were never hospitalized [30]. These findings are problematic for traumatic brain injury researchers for two reasons. First, because emergency department surveillance data are not routinely collected, investigators have little understanding of long-term disability among mild traumatic brain injured individuals. Second, among hospitalized survivors of traumatic brain injury, approximately 35% experience long-term disability [30]. The actual number of individuals experiencing long-term disability and deficits from traumatic brain injury may be higher due to a large number of mild traumatic brain injured individuals who experience adverse outcomes but are not treated for them. Given this fact, researchers have estimated the total cost to society for individuals living with brain injury disabilities at 48.3 billion dollars per year [30].

Potential confounders for sustaining a head injury include sex, age, and race [2]. Current United States estimates indicate that males are 1.5 times more likely than females to sustain a traumatic brain injury [2]. Among males hospitalized for traumatic brain injury, the average ratio for males to females is 1.8 [30]. Children 0-4 years of age have the

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highest rates of traumatic brain injury-related emergency department visits and adults over 75 years of age have the highest rate of traumatic brain injury-related hospitalization and death [2]. African-Americans have the highest traumatic brain injury-related death rates followed by whites [2].

The leading external causes of traumatic brain injury in the United States are motor vehicle crashes, falls, assaults, homicides, suicides, and firearms. Firearms have surpassed motor vehicle crashes as the leading external cause for all traumatic brain injury-related mortality [29]. Although only 10% of all traumatic brain injuries are caused by firearms, they account for 44% of all traumatic brain injury-related deaths [29]. In fact, 9 out of 10 people die when sustaining a brain injury from a firearm [29].

Traumatic brain injury is often referred to as a “silent epidemic” and although the epidemiology for sustaining a traumatic brain injury has been well documented, long-term disability following brain injury is not as well understood. Long-term effects from traumatic brain injury include functional changes with cognition, movement, sensation and/or emotion. Brain injury researchers and clinicians are working to develop better functional assessment tools and interventions. For example, Mackay et al. (1992) evaluated 38 severely head injured individuals and found that individuals who received early rehabilitation services experienced one-third the length of acute rehabilitation stays as individuals receiving regular services [32]. These types of studies help to further the understanding of traumatic brain injury treatment options and highlight the importance of developing models to identify effective strategies to improving outcomes and minimizing disability.

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Epidemiology of Traumatic Brain Injury in Colorado

The Centers for Disease Control and Prevention provides funding to twelve state health departments to maintain traumatic brain injury surveillance systems [10]. The Colorado Department of Public Health and Environment Traumatic Brain Injury Surveillance system in Denver, Colorado, is one recipient of brain injury surveillance funding. Since 1991 the Colorado Traumatic Brain Injury Surveillance system has been routinely collected information on fatalities and hospitalized cases of traumatic brain injury.

Nearly half or 42% of all injury deaths in Colorado result from traumatic brain injuries; this is higher than the national average in which 34% of all injury deaths are the result of traumatic brain injury [31;33]. Each year in Colorado, there are approximately 4,000 hospitalized cases of traumatic brain injury, over 3,000 cases are non-fatal and an average 984 Coloradoans die [33].

Among Colorado males, the incidence rate for traumatic brain injury is three times higher than that of females [33]. Among those hospitalized in Colorado, the rate of traumatic brain injury is two times higher for males than females [33]. Rates for leading causes of traumatic brain injury in Colorado follow similar trends as the United States; however, unlike the United States, the leading external cause of brain injury mortality is motor vehicle crashes and not firearms [33]. These estimates are based on hospitalizations and do not include individuals treated and released for mild head injury in the emergency department or doctors offices [30]. A majority of hospitalized traumatic brain injury cases in Colorado are classified as sustaining moderate to severe head injuries [30].

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Overview of Traumatic Brain Injury Severity Measures

Severity of traumatic brain injury ranges from mild or having a brief change in mental status to severe or experiencing extended periods of unconsciousness [1]. Over the past 50 years, a number of scales for categorizing injury severity have been developed [7;34]. There are two types of scales, physiologic and anatomic [3;7]. Common head injury measures include the physiological measure, Glasgow Coma Scale, and the anatomical measures, the Injury Severity Score, and its parent the Abbreviated Injury Severity (AIS) score [3;7;35]. All three measures have contributed to trauma research efforts independently and as contributors to other injury severity measures [35].

History of the Abbreviated Injury Scale

The Abbreviated Injury Scale (AIS) was developed in 1969 by the Association for the Advancement of Automotive Medicine to provide a standard system for rating injury [7]. Originally intended to provide a method for categorizing injury severity resulting from motor vehicle crashes, AIS has evolved over time and is now used by clinicians and researchers to evaluate injury severity from all types of injury mechanisms [36]. For example, early on, AIS was adopted by crash investigators at the United States Department of Transportation to standardize data in regard to the severity of motor vehicle related injuries [37]. Over time, AIS has been incorporated into research by university researchers and the hospital industry in the United States, Europe, and Australia[37]. Trauma center investigators use AIS for predicting the probability of survival, while rehabilitation researchers use it for evaluating health care treatments and outcomes [37]. Economists have utilized AIS to assess societal costs of injuries after adjusting for injury severity [37].

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AIS has evolved and undergone a number of changes. Four AIS revisions have been made and are identified by the year in which changes were published [37]. The first revision occurred in 1980 when the Committee on Injury Scaling of the American Association for Automotive Medicine modified and expanded the injury dictionary three-fold and improved injury descriptions [37]. At this time, changes such as level and length of unconsciousness were made in the brain injury section to parallel the advancements in understanding head injuries [36;37].

In 1985, a second revision of AIS, AIS-85 was released [37]. Changes included coding for penetrating injuries [37]. Simultaneously, trauma care systems started to evolve and trauma registries were created [37]. AIS-85 revisions were heralded by the trauma community as a success, providing a universal standard to facilitate communication among injury researchers around the world [36;37].

In 1990, major revisions were made to characterize injuries not just from motor vehicle crashes but for all causes of injuries [36]. The third revision of AIS released in 1990 (AIS-90), provided a more complete description of penetrating injuries, increased the number of codes for pediatric injuries and, reclassified the coding structure by body region, e.g. all head injuries started with the number one [38]. Prior to the 1990 revision, in analysis of large databases, serious brain injuries were identified as being under coded when compared to other body regions [37]. To correct for inconsistencies, the section for the head was expanded to include brain contusions by size, location and number of lesions, volume and size of hematoma, and sections on intracranial vessels and cranial nerves were added [37]. Thus, AIS-90 is considered to better represent head injury severity than any of its predecessors [39].

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The last modification to AIS-90 occurred in 1998 (AIS-90 1998 Revision) in which minor changes were made to the injury dictionary [37]. Even though AIS has undergone major revisions, the principles of AIS have remained the same. The Association for the Advancement of Automotive Medicine defines AIS as "an anatomically based, consensus derived, global severity scoring system that classifies each injury in every body region according to its relative importance on a 6 point ordinal scale (page 1 [37])." AIS basic principles are: 1) the AIS should be simple; 2) there should be a standard way to describe injuries; 3) the AIS should apply to many injuries; 4) AIS should be compatible for large and small scale data collection; 5) injury descriptors are based on anatomical descriptors and not physiologic descriptors; 6) AIS is time independent, (there is no time requirement for scoring – a score can be calculated at hospital discharge or a year after hospital discharge); and, 6) the severity score reflects the injury for that specific body region [36].

For this study, the sixth principle of AIS is the most important; AIS scoring reflects the injury for that specific body region. This principle assumes that each body region can be assessed independently because an individual severity score is assigned for each individual body region. This is a major assumption for assessing AIS scores for the head region (HAIS) [37].

Abbreviated Injury Scale – The Scoring System

AIS scores are generated using anatomical descriptors abstracted from medical records including results from radiographic tests [37]. Such descriptors include keywords such as laceration, lesion, fracture, and hematoma [37]. To use AIS, the body is divided into nine body regions and an AIS score is generated for each body region [37]. The nine body

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regions are: head, face, neck, thorax, abdomen, spine, upper extremities, lower extremities, and unspecified [7].

AIS ranges from 1-6 and is defined as follows: 1 = minor injury; 2 = moderate; 3 = serious; 4 = severe; 5 = critical; and, 6 = maximum injury/virtually unsurvivable [37;40]. AIS scores are ordinal, meaning that each severity measure has a rank and ordered sequence [37;40]. As observed with ordinal variables, one can not assume that intervals between values are equal. For example, the distance between the AIS interval one to two is not the same as the interval distance between a three and a four [41]. This is particularly evident for body regions such as the head where mortality is more likely to occur as the score increases [38;41].

AIS is used by hospital trauma facilities to evaluate quality of care, trauma registries and statewide surveillance systems [7;42-46]. At the national level, AIS scores provide a standard for doctors, hospitals, and states to communicate [47]. Further, these scores allow for the comparison of injury related research with countries with comparable medical records [47].

Limitations of AIS include dependence on quality medical record information from hospital records and abstraction of detail requiring between 10 and 30 minutes per medical record [48]. Because of the personnel time required for coding, AIS is not routinely coded, however, researchers often collect AIS measures for injury surveillance systems and evaluation of hospital quality assurance[48]. Further, AIS scoring is subjective because scoring agreement depends on experts who are trained to identify injuries from medical records and generate AIS scores for each of the body regions [40]. Regardless of these limitations, AIS is the most widely used anatomical scale for rating injury severity

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[49]. In fact, today, AIS is the most commonly used anatomic injury measure and it has been accepted by hospitals and researchers worldwide [40].

Injury Severity Score

Although AIS scores can be generated for each of the nine body regions, these scores do not provide an overall picture of injury severity. In 1974, Baker et al. (1974) developed the Injury Severity Score (ISS), a method to assess overall body injury based on AIS scores [7]. While AIS characterizes injury severity in a specific body region, ISS combines the separate AIS scores and provides a single injury score.

The ISS is calculated by summing the squares of AIS scores from the top three severe body regions: $ISS = A^2 + B^2 + C^2$ [7]. ISS values can range from 1 through 75. A patient with an AIS of six automatically receives and ISS of 75 [38]. When an ISS is less than 25, the risk of death is minimal [41]. When an ISS is equal to 50 then the risk of death is 50% and when an ISS is above 70 the risk of death is almost 100% [41].

Advantages of the ISS include the linear correlation with mortality, morbidity, hospital stay, poor quality of care, and cost [38;41;50]. The limitations of the ISS include equal weighting of all injured body regions, the inability to account for multiple injuries the same body region, and the inability to use this tool prospectively [40]. Since the ISS relies on squared AIS scores, errors in scoring AIS greatly impact ISS errors. Both AIS and ISS are computed retrospectively through medical record reviews and consequently, neither contributes to triage or to patient management.

The main limitation of ISS results from the manner in which it is calculated; it provides equal weight and importance to the three body regions. A biased result can occur when a patient suffers a severe head injury and no other injury. An ISS for a severe

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head injury with no other body region involved would result in a 4 for the head region and 0 for each of the other body regions. Therefore, the overall ISS would be computed as $4^2 + 0^2 + 0^2 = 16$. Although an AIS score of 4 for the head region is strongly correlated with death, an ISS of 16 indicates minimal risk of death. Had the injury taken place in a body region other than the head region, such as lower extremities, an ISS of 16 would accurately reflect minimal risk of death. Therefore the ISS does not accurately represent the likelihood of survival [38;45]. Despite these limitations, the ISS is still widely used by clinicians and researchers to gather a sense of overall bodily injury for trauma individuals[35;45].

Reliability of the Abbreviated Injury Scale

Using the 1980 revision of AIS, MacKenzie et al. (1985) assessed inter- and intra-rater reliability among 15 hospital staff members including nurses, emergency medical technicians, and trained coders [47]. The study addressed two questions: 1) did coders identify the same injuries from the medical records; and, 2) did they assign the same AIS code for those injuries [47]. For this study, physicians were the "gold standard" and their responses were compared to those from nurses, emergency medial technicians, and trained coders. Coders identified a significantly greater number of injuries from medical records during the second round of coding compared to the first round of coding [47]. For injuries identified in both rounds of coding, the intra-rater reliability was almost perfect [47]. Comparing physician coding to other raters, the inter-rater agreement for blunt injury was higher than for penetrating injury, Kappa statistics ranged from 0.53 to 0.74, indicating moderate to substantial agreement [51].

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MacKenzie et al. (1985) reported that medical technicians and trained coders were as reliable at coding AIS as nurses and physicians [47]. In fact, medical technicians and trained coders were more likely to find injuries in a medical chart than nurses and emergency medical technicians. MacKenzie et al. (1985) suggested that medical technicians are taught to record AIS scores from 1 to 6, versus nurses whom frequently record the injury severity as "unknown" [47]. MacKenzie et al. (1985) further hypothesized that the high proportion of AIS values scored as "unknown" by nurses may be the result of knowing enough to interpret an injury and lacking the confidence to assign a numeric AIS value [47].

A more recent study on inter-rater reliability of the ISS derived from AIS (1990 revision) scores was based on calculated percent agreement between six coders using data from the Queensland Trauma Registry in Queensland, Australia [52]. The ISS comparisons revealed high inter-rater reliability, with Kappa values > 0.80, but agreement between coders for AIS-90 values were low; severity of head injuries was not specifically investigated [53]. One explanation for the differences between high agreement for ISS and low agreement for individual AIS-90 scores may be due to compensating differences; raters may have identified AIS-90 scores for different body regions but the sum of the three top AIS-90 scores may provide the same ISS score.

These studies indicate that the assignment of AIS scores is subjective, meaning that variation of AIS scores for identical injuries may occur [47]. Although the reliability of AIS and ISS measures have been assessed, to date, no studies have specifically assessed the intra- and inter-rater reliability of AIS for the head region (HAIS) using the AIS 1990 Revision (Update 1998). HAIS reliability is important because head injury is the largest

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contributor to trauma center death [54;55]. In Colorado, nearly half (42%) of all injury deaths are the result of a traumatic brain injury [33].

In order to determine if HAIS can be used to predict long-term outcomes from traumatic brain injury, reliability of HAIS must first be evaluated. After determining HAIS reliability, HAIS can be used to determine their relationship with long-term outcomes of traumatic brain injury.

Benefits and Limitations of Retrospective Coding

Both AIS and the ISS are scored after a patient has been discharged or died. During the course of an injury, physiological changes are occurring, particularly for body regions such as the head [50]. To identify if AIS could be used prospectively, Morgan et al (1988) compared AIS scores within the first 24 hours of hospital care to scoring after 24 hours. They concluded that scores after 24 hours were more accurate and reflected the true anatomical nature of an injury [50]. Hence, later coding of AIS makes it less vulnerable to variations during treatment. Therefore, researchers are able to make comparisons across diverse populations, control for injury severity while assessing injury-related outcomes, identify injury trends over time, and characterize specific injuries, such as head injury [38]. Although researchers use data to characterize trauma related injuries, they are unable to use AIS or ISS to directly influence treatment.

Glasgow Coma Scale

One measure that influences treatment of traumatic brain injury is the Glasgow Coma Scale. The Glasgow Coma Scale measures physiological changes resulting from head injury and aids clinicians in assessing patient progress. The purpose of the Glasgow Coma Scale is to measure consciousness following brain injury to determine appropriate

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treatment [3]. Scoring is done on a continual basis during a hospital stay. An initial Glasgow Coma Scale score is assigned within 48 hours and rechecked periodically [56]. Glasgow Coma Scale scoring is based on three response criteria: eye opening, motor or movement responses and verbal responses [3]. Eye-opening is graded on a 4-point scale, verbal responses are graded on a 5-point scale and motor responses are on a 6-point scale[3]. Glasgow Coma Scale scores range from 3 to 15, with 3 being the most severe, coma, and 15 representing mild head injury [57].

Because Glasgow Coma Scale scoring must be performed at the hospital and within the first 48 hours of injury, there is great variability across scores. Further, although the Glasgow Coma Scale is a valuable measure for treating a patient, published results indicate it is not always accurate [58]. Glasgow Coma Scale scoring is influenced by temporal changes, variations in regard to brain injury pathology as well as by treatment options and external factors such as alcohol [5]. Marion et al. (1994) investigated the association between Glasgow Coma Scale scoring and pre-hospital treatment at 17 major neurotrauma centers [5]. The researchers concluded that Glasgow Coma Scale scores were non-uniform and inconsistent and the factors such as pre-hospital treatment, the use of alcohol and/or drugs, and treatment factors such as intubations influence the scores [5]. Similar findings from additional studies resulted in scoring the Glasgow Coma Scale post-resuscitation or six hours post-injury[5]. Although changing to a post-resuscitation scoring system was supposed to reduce outside influences, intubated and mechanically ventilated individuals can not be resuscitated and hence Glasgow Coma Scale scores can not be assigned[5]. For example, in a survey conducted by the European Brain Injury Consortium among moderate and severe traumatic brain injured individuals, only 77% of

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the individuals could be tested to assign a Glasgow Coma Scale score on admission to the hospital [4]. Gill et al. (2004) investigated the inter-rater reliability of post-resuscitation Glasgow Coma Scale scores and concluded that among a 116 individuals at a top level trauma facility, inter-rater agreement was 32%, or poor to fair [59]. Glasgow Coma Scale scores are collected for brain injury assessment and treatment and are routinely used to control for brain injury severity; however, scores are considered unreliable and will not be used for the model prediction portion of this study.

Predicting Traumatic Brain Injury Morbidity

Over the years, researchers have evaluated individuals with traumatic brain injury using one of the aforementioned severity measures, the Glasgow Coma Scale and the Abbreviated Injury Scale. Researchers rely on the Glasgow Coma Scale more often than the Abbreviated Injury Scale because Glasgow Coma Scale scores are more routinely collected. In regard to predicting outcome, Glasgow Coma Scale scores have been found to be poor predictors of long-term morbidity outcomes from traumatic brain injury [4;60-63]. For instance, Zafonte et al. (1996) correlated initial and lowest Glasgow Coma Scale scores (representing the most severe head injury) among individuals admitted for traumatic brain injury rehabilitation [64]. Investigator's concluded that Glasgow Coma Scale scores provided little value in predicting Functional Independence Measures among the traumatic brain injury rehabilitation population[64].

Using individuals admitted for more than 24 hours for TBI at the Level I Carolinas Medical Center between September 1997 and May 1998, Wagner et al. (2000) assessed the predictive value of the Glasgow Coma Scale to Disability Rating Scale scores among individuals discharged one-year after entering a rehabilitation facility [65].

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Results indicated high predictive values of the Glasgow Coma Scale when used in combination with demographic (sex, minority race, and education) and previous traumatic brain injury[66]. Although this result refutes previous findings regarding the predictive value of Glasgow Coma Scale scores, results should be interpreted with caution. The problem with the results lies with the outcome measure, the Disability Rating Scale. Although there are four components which make up the Disability Rating Scale score, one is the Glasgow Coma Scale [67]. Therefore, one would expect the measures to be highly correlated. Researchers have concluded that the Glasgow Coma Scale is associated with traumatic brain injury mortality, the predictive value in relation to long-term functional outcomes is very limited [4].

Fife et al. (1984) assessed the relationship between brain injury severity and overall injury severity and concluded that "brain injury severity was the major determinant of overall injury severity" among individuals with head injury (page 697) [55]. Similarly, MacKenzie et al. (1987) concluded that head and spinal cord injuries resulted in the most significant disabilities among trauma individuals [68]. AIS scores for specific body regions, such as the head, were more useful in predicting functional deficit than the overall injury severity measure, ISS [68].

The development of imaging capabilities such as computed tomography or CT scans, has aided clinicians in evaluating head injured individuals by providing anatomical descriptions for injuries [4]. These anatomical descriptions of injury aid in coding AIS scores. Since each AIS score is treated independently for each body region, using an AIS score for a single body region is feasible, i.e. head AIS (HAIS). In 1992, Ross et al. evaluated HAIS as a prognostic tool for functional outcome among individuals admitted

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to the New Jersey Trauma Center, 1986-1988. The outcome of interest was Glasgow Outcome Scale – a scale classifying outcome into five categories ranging from good recovery to death [69]. A statistically significant ($p < 0.001$) association between HAIS and scores from the Glasgow Outcome Scale was found [70]. Further, Walder et al. (1995) found comparing HAIS scores to six month scores from the Glasgow Outcome Scale among British individuals at the Queen's Medical Center, 1986-1988 that lower morbidity was associated with HAIS severity scores [71].

Similarly, in Major Trauma Outcome Study, an eight-year study of outcomes following trauma, increased HAIS scores among head injured persons were associated with death [72]. Individuals with moderate to severe head injury (HAIS scores greater than 4), were less likely to be discharged home than their non-head injured peers. Using the Functional Independence Measures, investigators concluded that at all levels of AIS, those with head injuries always scored worse than their non-head injured counterparts [72]. This study indicates a difference in mortality and morbidity can be expected among trauma individuals experiencing head injury as compared to those without a head injury.

Recently, Demetriades et al. (2004) investigated whether scores from the Glasgow Coma Scale and HAIS were predictive of traumatic brain injury mortality [73]. Using 7,764 individuals from two local Los Angeles hospitals, investigators concluded that the Glasgow Coma Scale score was not a good predictor of traumatic brain injury mortality but HAIS was a useful prognostic indicator of mortality from head injury after adjusting for age [73]. Further, researchers then compared HAIS scores to Glasgow Coma Scales and concluded that there was poor ($r < 0.30$) correlation between Glasgow Coma Scales and HAIS [73]. HAIS was found to be significantly affected by age (≤ 65 years old and ≥ 65

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years old) and type of injury (blunt versus penetrating) [73]. This study was significant because the Glasgow Coma Scale was not found to be a good predictor of traumatic brain injury outcomes but its anatomical counterpart, HAIS, was when accounting for age and injury mechanism [73].

Although past studies addressing the predictive ability of HAIS have been conducted, none have been population-based which means that none of these studies are generalizable to the general brain injured population. Therefore, the goal of this study is to assess the reliability of HAIS and to determine if HAIS is capable of predicting outcomes among traumatic brain injury survivors.

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CHAPTER 3

MEASURES OF ONE-YEAR FUNCTIONING FOLLOWING TRAUMATIC BRAIN INJURY

Collecting outcomes data is important for reducing unexplained variation in clinical care, improving the quality of care, and lowering the associated costs [74]. The goals of collecting and analyzing one-year outcomes from traumatic brain injury are: 1) to identify long-term trends among survivors; 2) to increase knowledge on the role of rehabilitation in improving independence, function, and quality of life; and, 3) to accurately assess the cost to society and increase resources to improve rehabilitation [74]. As medical advancements decrease traumatic brain injury mortality, it will become increasingly important to conduct more outcome studies to identify rehabilitative service needs [75].

For individuals with traumatic brain injury, receiving rehabilitation can be vital for improving function, independence, and quality of life [76]. A recent definition of rehabilitation is the "process of helping a person to reach the fullest physical, psychological, social, vocational, avocational, and educational potential consistent with his or her physiologic or anatomic impairment, environmental limitations, and desires and life plans (page 3) [76]." The main goal of rehabilitation is for individuals and their families to work in conjunction with rehabilitation experts to set and obtain realistic

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functional goals [76]. However, not all individuals receive rehabilitation care after hospital discharge. For example, among persons hospitalized with traumatic brain injury in Colorado, researchers found that only one-third (353) of 1059 identified cases had received extra rehabilitation services following discharge from acute care facilities [77]. By not receiving rehabilitation, individuals miss opportunities to gain independence, increase functional abilities and improve quality of life [76;78].

Conceptual Models of Rehabilitation

Until the middle of the 20th century, rehabilitation treatment was supervised by physicians. Under the medical model, physicians treated the disabled individually and often ignored environmental and societal factors, such as societal participation [79]. A paradigm shift occurred when physicians and researchers began to recognize the importance of these factors. This shift created movement away from the traditional medical model toward new conceptual models of rehabilitation emphasizing the environment as an important determinant of disability [80].

Two broad categories of rehabilitation services were integrated as a result of the paradigm shift, medical and psychosocial [81]. Medical rehabilitation services for brain injuries focused on impairments at the organ or function and structure level. Psychosocial rehabilitation focused on needs related to activity and societal participation[81]. Over time the medical and psychosocial categories were incorporated into conceptual models of disability. Examples of such models include but are not limited to:

1) the **Quebec** model by Fougeyrollas et al. (1993)[80]. This was the first model to describe how environmental factors influenced the participation of people with disabilities. This model highlights three determinants of participation:

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impairments in body structure and function, activity limitations, and environmental factors [80].

2) the **Institute of Medicine** model describes an individuals environment as a three-dimensional mat[80]. The mat can either be strong or weak depending on the interactions between impairment and environment. Hence, the Institute of Medicine model defines disability as the interaction between an individual and his or her environment [80;82].

3) the **International Classification of Functioning Disability and Health** model was created by the World Health Organization in 1980[83]. Updated in 2001, this international model provides a standard language for health and health-related components. In this model, there are five main domains which interact to describe disability [80;83].

Compared to other models, the advantage of the World Health Organization model (2001) is the multi-perspective method to classifying function and disability as interactive and evolutionary processes [80;83]. For example, Figure 3.1 below depicts the interaction of various domains in the World Health Organization's conceptual model entitled the International Classification of Functioning Disability and Health. This model was developed to provide a map for the classification of functioning and disability. There are two main parts to this model, functioning and disability, and contextual factors [83]. There are three domains which comprise functioning and disability and two domains that are classified under contextual factors [83]. Each domain represents a different aspect of disability and is integral to the model. Further, each domain is independent from one another.

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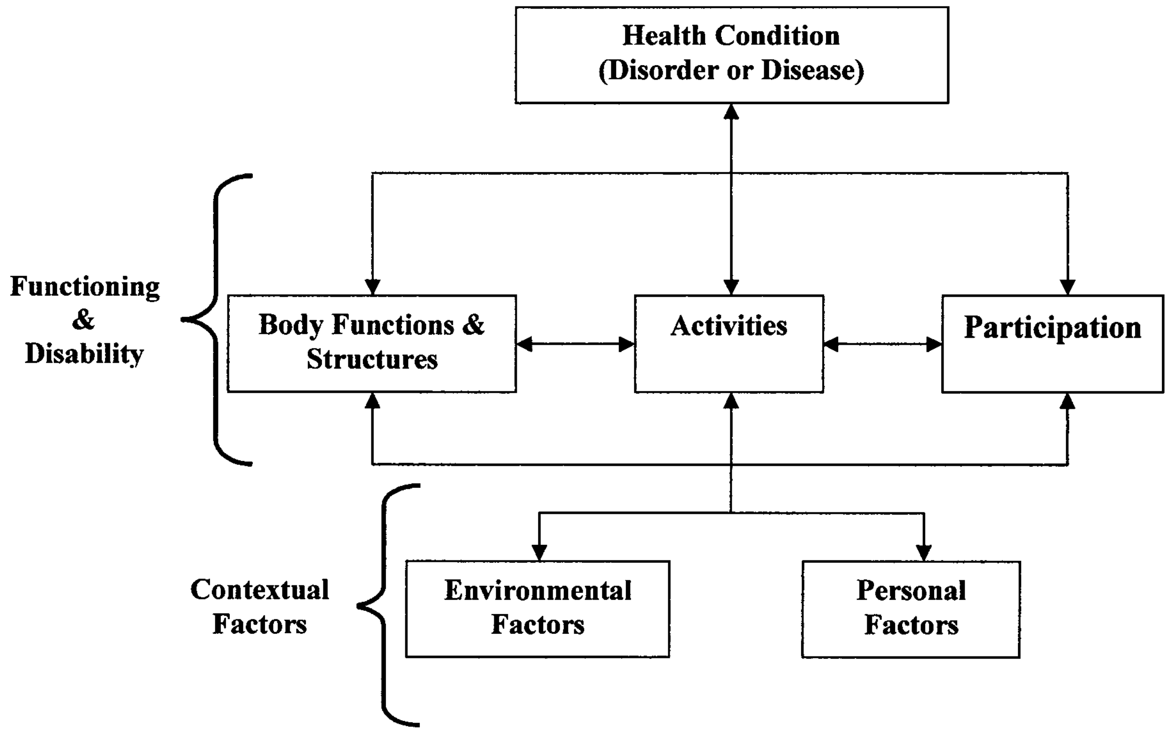

Figure 3.1: The conceptual model based on the World Health Organizations International Classification of Functioning, Disability and Health model (2001)

Functioning and disability is made up of three domains. Formerly called impairment, the *body functions and structures* domain assesses disability at the organ level by characterizing physiological functions of the body system and the anatomic parts of the body [83]. This is different from the *activity* domain which describes disability at the individual level [83]. Formerly called disability, the *activity* domain refers to restrictions in the execution of a task or action [83]. The third domain, *participation*, characterizes an individual's disability at the societal level [83]. Once called handicap, the purpose of *participation* is to describe involvement, such as taking part in activities, being included or engaged in an area of life, and/or being accepted [83].

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Contextual factors can be divided into two domains, *environmental* and *personal factors*. These domains differ from the "performance" domains in functioning and disability [83]. For example, the *environmental factor* domain includes the physical, social and attitudinal environment in which people live [83]. Often, the *environmental factor* domain is further classified into two different levels, the individual, and society in which they live. The *personal factor* domain includes a person's sex, race, age, fitness level, habits, education, and lifestyle[83].

As the World Health Organization model depicts in figure 3.1, rehabilitation is often a combination of many domains interacting [83]. Contextual factors often influence functioning and disability. For example, a person's age (*personal factor*) may influence recovery from the initial injury (*body function and structure*), ability to perform specific everyday tasks (*activities*), ability to go to work (*participation*), and accessibility to home (*environmental factor*). Overall, these domains help to define a level of function, disability, and health for each individual [83].

There are a few limitations to the World Health Organization model. First, it excludes quality of life. Most instruments used in the World Health Organization conceptual model are objective, meaning that they assess facts or conditions that are not distorted by personal feelings or interpretations. Quality of life instruments are subjective, meaning; they are perceived thoughts. Another limitation is the lack of standardized outcome measures [81]. Rehabilitation outcome studies following traumatic brain injury have identified trends in rehabilitation outcomes; however, variation results when more than one set of outcome measures are used to describe aspects of disability.

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Operational Model of Rehabilitation

Because the World Health Organization conceptual model was revised in 2001, after the Colorado Traumatic Brain Injury Registry and Follow-up System study was conducted, domains were reorganized to reflect the updated model. This reorganization was performed with the assistance of the principal investigator of the original study, Dr. Gale Whiteneck from Craig Rehabilitation Hospital located in Englewood, Colorado.

For this study, the operational model consists of the original five domains from the World Health Organization conceptual model. Each domain represents an individual aspect of functioning and disability. Figure 3.2 provides a visual representation of this operational model which is based on the original 2001 World Health Organization International Classification of Functioning, Disability, and Health conceptual model[83]. Included in each domain are the measurement tools used by the Colorado Traumatic Brain Injury Registry and Follow-up System to assess each disability and function following TBI[9].

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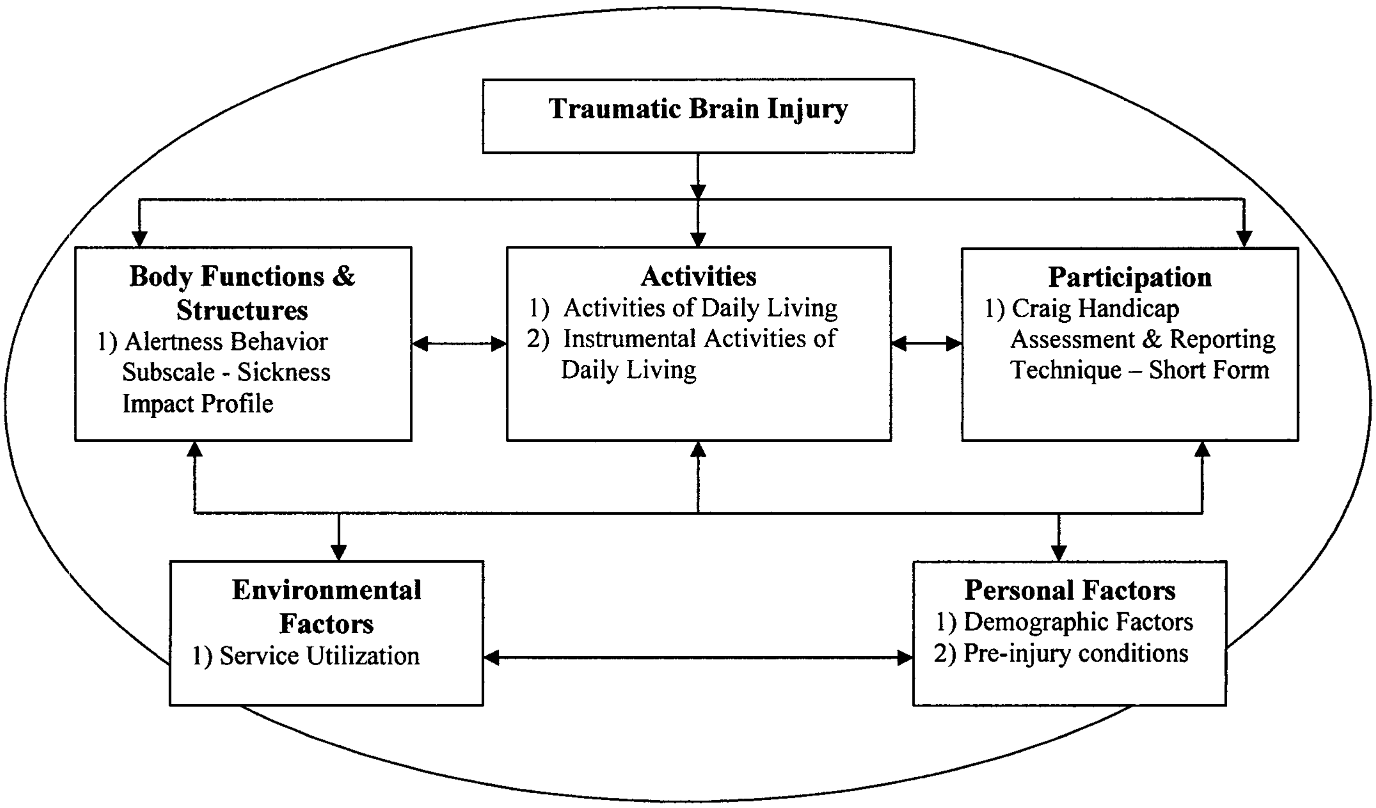

Figure 3.2: Study operational model for the Colorado Traumatic Brain Injury Registry and Follow-up System, 1998-1999.

Measurement tools used for the Colorado Traumatic Brain Injury Registry and Follow-up System were selected by a group of advisors with different areas of expertise [9]. Some advisors were individuals afflicted by TBI, others were physicians, social workers, academics, and clinicians and researchers [9]. Advisors aided in project focus and were instrumental in helping select variables, instruments and methodologies employed in the study [9]. Four objectives drove the variable selection process: 1) to identify the burden of disabilities; 2) to monitor trends among those with disabilities; 3) to identify subgroups of traumatic brain injury cases at high risk for a disability; and 4) to determine service utilization [9].

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In order to assess each domain, a host of psychosocial instruments have been developed to assess people with disabilities for each domain [84]. As a result, there are no industry standards in terms of instruments and new ones are continually developed to measure outcomes [84]. The following is a description of the instruments used in the Colorado Traumatic Brain Injury Registry and Follow-up System for each World Health Organization domain.

Domains

Body Functions and Structures Domain

The b*ody functions and structures* domain characterizes disability at the organ level. The instrument used to access this domain was the Alertness Behavior Subscale of the Sickness Impact Profile. Although not developed specifically for assessing individuals with TBI, the Sickness Impact Profile has been used in a number of studies of TBI [85-87]. The Sickness Impact Profile is an instrument composed of 136 questions measuring the presence of sickness-related behaviors [9]. These questions are broken down into two dimensions, physical and psychosocial, and include 12 subscales [85]. The Alertness Behavior Subscale, used in the Colorado Traumatic Brain Injury Registry and Follow-up System study, is one of four categories that comprise the psychosocial dimension.

The Alertness Behavior Subscale was used to focus on cognitive symptoms. Cognitive symptoms were characterized in the following categories: confusion; accidents; reacting slowly; finishing things that are started; reasoning; disorientation; forgetfulness; attentiveness; mistakes; and, concentration [9]. Scoring ranged from 0 to 100 with a higher score indicating greater dysfunction [9]. Overall, the Sickness Impact Profile

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is considered a reliable measure with reliability ranging from 0.79 to 0.95; however, reliability of the Alertness Behavior Subscale by itself is unknown [9].

Activities

The *activities* domain characterizes disability at the individual level by assessing a patient's cognitive and physical limitation in regard to performing specific activities at the individual level [9]. Two measures were used to assess physical *Activities* following TBI, the Activities of Daily Living and the Instrumental Activities of Daily Living [9]. The Activities of Daily Living assess whether a person needs help, support or aid in one of the following activities: bathing or showering; dressing; eating; getting in and out of a bed or chair; walking; and, toileting[9]. The Instrumental Activities of Daily Living asks whether an individual needs help with preparing meals, shopping for grocery or personal items, and managing money[9]. In an 11-state study to identify needs following TBI, unmet needs were associated with at least one area of functional dependence in Activities of Daily Living [88;89]. Corrigan et al. (2004) observed an association between cognitive problems and needing assistance with Instrumental Activities of Daily Living among individuals with TBI [88]. Both the Instrumental Activities of Daily Living and the Activities of Daily Living have been useful measurement tools for TBI research [9;84;88].

Participation

The *participation* domain measures the level of societal participation for people with traumatic brain injury. The Craig Handicap Assessment and Reporting Technique – Short Form is a tool for measuring societal participation for individuals with disabilities [9;90]. Comprised of 19 questions, the Craig Handicap Assessment and Reporting Technique – Short Form focuses on objective criteria [90]. The Short Form is composed of

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six subscales: physical independence, cognitive independence, mobility, occupation, social integration, and economic independence [9]. For each of the subscales, scores range from 0 – 100 with 100 equaling participation at the same level as a non-disabled person [9]. Sub-scale scores are further dichotomized as less than 75 (diminished participation) or greater than or equal to 75 [9]. An overall score of less than 450 indicates diminished participation [9]. In regard to reliability, the test-retest coefficient was 0.93 overall and ranged between 0.80 and 0.95 for the subscales [9]. However, when this measurement tool is used by proxy, reliability drops to 0.83 overall [9].

Environmental Factors

Medical and mental health service utilization is important because these therapies are beneficial for persons afflicted with traumatic brain injury. In order to identify services being utilized and barriers to care, an advisory panel for the Colorado Traumatic Brain Injury Registry and Follow-up System study identified five distinct categories of services. These five categories for assessing service utilization include: therapy (physical therapy, occupational therapy, audiology, speech therapy); medical (physician services, respiratory therapy); nursing (nursing services, adult day care; personal care attendant); psychological (psychologist, neuropsychologist); and, other services (independent living, family counseling, social work, support groups, recreational therapy, vocational services, alcohol and drug abuse services, case management, legal services, transportation).

A number of studies have been conducted to identify service needs among those afflicted with TBI. One of the first studies was the Los Angeles Head Injury Survey in which participants who had received rehabilitation were asked to identify the long-term needs [91]. Since then, a number of states (New York, Ohio, Wisconsin) have conducted

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similar studies[88]. The results of these studies have identified that specific services differed with functional status[88;91;92]. Individuals with the greatest functional dependence were in the greatest need for therapy, medical and nursing services[92]. Conversely, individuals considered independent were in need of memory training and psychological services[92]. The array of service utilization characterizes the vastly different affects of brain injury experienced.

Personal Factors

The personal factor domain is comprised of demographic and pre-injury conditions which may affect an individual's outcome response to a traumatic brain injury. In addition, the variable injury mechanism will be assessed to attempt to discriminate between diffuse and focal head injuries. The following is a brief description of each risk factor/potential confounding variables to be assessed.

Demographic variables include: age (16-24, 25-44, 45-64, and 65+ years of age); sex (male or female); discharge disposition from the hospital (home or other facility); income (≤34,999, ≥35,000, unknown); insurance (government, private, none); education (no high school diploma or GED, high school diploma or GED, some college, bachelor's degree, graduate degree, unknown); and, race (black, white, and other) and ethnicity (Hispanic and non-Hispanic). For demographic variables such as marital, employment or residence status, each variable will be evaluated for changes in status prior to the injury versus post injury. Each of these demographic factors has been found to be associated with adverse outcomes following TBI. For example, in an 11-state study to identify needs following TBI, unmet needs were associated with psychological well being, lower life satisfaction, younger age, race (specifically, African American), and single marital status

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[88;89]. In a study looking at TBI rehabilitation outcomes among whites and Hispanics by Arango-Lasprilla (2007), Hispanics showed significantly reduced outcomes after rehabilitation as compared to whites [93].

Pre-injury conditions can influence outcomes following TBI. These conditions include physical, mental, and behavioral factors such as stroke, epilepsy or seizures, psychiatric disorder, drug or alcohol problems, learning disabilities, and, the number of times knocked out unconscious [9].

Summary

Scientists are unsure about focal and diffuse head injuries. For example, it is possible that a small area of the brain can be damaged resulting in a significant impairment of cognitive function [94]. Although it is hypothesized that both diffuse and focal damage occur, this is one of many unknowns regarding the brains response to injury [94]. Although different individuals experience different focal points when injured, one-year function is believed to be the result of diffuse axonal damage throughout the brain regardless of the initial focal point of injury [94]. The variability of an individual's response to brain injury has made outcome prediction difficult. Using the WHO conceptual model of function and disability provides a framework to fully identify function and disability following a TBI.

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CHAPTER 4

INTRA-RATER AND INTER-RATER AGREEMENT OF THE ABBREVIATED INJURY SCALE SCORE FOR THE HEAD REGION, COLORADO 2000

Introduction

Among all injury deaths, one-third or 50,000 individuals die from traumatic brain injury (TBI) each year [29]. Yet, mortality from TBI represents only a fraction of the overall burden. Among the 1.4 million Americans whom sustain a TBI each year, an estimated 230,000 require hospitalization and 1.1 million are treated and released from emergency departments with mild TBI [2;22;23]. TBI morbidity affects such a large population (~2% of the United States (US)) that it is often referred to as the "silent epidemic [31]." Direct medical costs and indirect costs, such as a loss of productivity due to TBI, totaled an estimated 60 billion dollars in the US in 2000 [95].

One goal of injury research is to reduce the burden of injury on the individual [48]. To accomplish this goal, clinicians and researchers rely on scoring systems such as the Abbreviated Injury Scale (AIS) to characterize patient outcomes relative to injury severity [37]. Developed in 1971 by the Joint Committee on Injury Scaling with involvement from organizations including the American Medical Association and the Association for the Advancement of Automotive Medicine (AAAM) [7], the original goal

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of AIS was to provide a standard system for rating severity of injuries resulting from motor vehicle crashes [7]. Since then, AIS has been expanded to apply to all causes of injuries. Coded retrospectively, the AIS provides a score of injury severity for nine body regions, including the head (HAIS) [7]. The AIS has undergone four major revisions, the most recent revision was completed in 2005 (AIS-05). This study serves as a historical benchmark for the 1990 revision (AIS-90).

The HAIS may be a good predictor of one-year outcomes from TBI; however, in order to investigate its prognostic abilities, reliability of AIS-90 of the head region must first be evaluated. The reliability of AIS has been assessed but, to date, no studies have assessed inter- and intra-rater agreement of HAIS using the 1990 revision (HAIS-90). Brain injury is a major contributor to injury severity [55;68] and may be a good predictor of functional outcomes [68], therefore having a reliability measure of head injury severity is important. The purpose of this study was to assess the inter- and intra-rater agreement of HAIS-90 scores using two Colorado population-based datasets.

Methods

Intra-Rater Agreement

Data Source

Few population-based surveillance systems obtain Abbreviated Injury Scale scores due to time and financial constraints. However, the Division of Injury at the Colorado Department of Public Health and Environment, in Denver, Colorado, has been collecting Abbreviated Injury Scale scores as part the Colorado Traumatic Brain Injury Surveillance system. Since 1991, the Colorado Traumatic Brain Injury Surveillance system has been conducting population-based statewide surveillance of traumatic brain

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injury (deaths and hospitalizations). This surveillance system is one of 12 statewide systems tracking trends in traumatic brain injury. These systems are vital for documenting the epidemiology of traumatic brain injury by identifying trends and educating both the public and health officials.

Abbreviated Injury Scale

AIS-90 scores are generated from anatomical descriptors abstracted from medical records and documented descriptors are used to guide scoring for each of the nine body regions (head, face, neck, thorax, abdomen, spine, and upper and lower extremities) [7]. AIS-90 scores range from one to six and are defined as follows: 1 (minor injuries); 2 (moderate injuries); 3 (serious injuries); 4 (severe injuries); 5 (critical injuries); and, 6 (maximum injuries/virtually unsurvivable) [37;40]. Scores are ordinal, and as often observed with ordinal variables, intervals between values are not necessarily equal. For example, in head injury, the distance between the AIS interval one to two is not the same as the interval between a three and a four. This is particularly evident in TBI victims where individuals with serious to severe head injuries may be more likely to have higher morbidity and mortality [96;97].

Case Definition

Traumatic brain injury surveillance cases include Colorado residents who were either admitted to hospitals or died prior to reaching the hospital from a traumatic brain injury. Since 1991, acute care facilities (hospitals) in Colorado have been required to report hospitalized traumatic brain injury cases to the Colorado Department of Public Health and Environment via their trade association, the Colorado Health and Hospital Association. Similarly, traumatic brain injury deaths are electronically reported by the

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Division of Health Statistics, located at the Colorado Department of Public Health and Environment. Traumatic brain injury cases are defined using the International Classification of Diseases, 9th Revision, Clinical Modification diagnostic codes for traumatic brain injury: 800 – 801.9, 803 – 804.9, or 850 854.1, and 959.01 [10]. The surveillance system excludes cases involving brain injuries resulting from disease processes, such as tumors, or from decreases in oxygen to the brain, such as drowning [10].

Since its inception, the Colorado Traumatic Brain Injury Surveillance system has annually sampled one-fourth of cases for quality control, approximately 1,000 cases per year. Sampling methods are based on Centers of Disease Control and Prevention recommendations for sampling based on the number of licensed beds – small hospital (< 100 beds) and large hospital (> 100 beds). The purpose of the sample is to verify diagnosis and to code for additional factors such as the use of personal protective equipment (i.e., seatbelt, helmet, etc.) along with injury severity measures such as HAIS scores.

Data Analysis

Figure one contains the approach used to determine intra-rater agreement. To establish intra-rater agreement, the Colorado Traumatic Brain Injury Surveillance system coder was asked to recode HAIS scores and abstract data from a sub-sample of sampled records for 1999 and 2000. Between October 2001 and May 2002, the coder reviewed medical records and assigned HAIS scores for 970 persons from a stratified random sample of unduplicated hospitalized traumatic brain injury cases occurring in 1999 and 2000. Methods for the stratified random sample were based on Centers of Disease Control and Prevention recommendations – number of licensed beds – small hospital (<

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100 beds) and large hospital (> 100 beds). For study years 1999-2000, approximately 20% of all sampled cases were derived from small hospitals and 80% from large hospitals.

To determine the appropriate sub-sample size while reducing the chances of a false positive result, a power of 80% was used to determine if an effect exists. Based on power calculations for 80% power, a random sub-sample of 250 (27.8%) records from the original 970 records were chosen for testing intra-rater agreement. During the fall of 2003, the same coder obtained medical records for 248 of the 250 cases and independently recoded HAIS and abstracted all other variables.

A kappa statistic was used to assess agreement of HAIS scores for the same coder between time one and time two [51;98]. The kappa statistic is used to correct for the possibility of a chance agreement. Landis and Koch (1977) kappa statistic cut points will be used in this study to be consistent with past studies assessing inter-rater agreement of Abbreviated Injury Scale measures [51].

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There are four steps for the intra-rater agreement process:

1. Using the existing Colorado Traumatic Brain Injury Surveillance database, identify the total number of traumatic brain injury cases for years 1999-2000 (n ~ 8,000)
2. Identify sampled cases with HAIS scores from the Colorado Traumatic Brain Injury Surveillance, 1999-2000 (n = 970)
3. Using the stratified random sampling methods as outlined by the Centers for Disease Control and Prevention (hospitals with ≤ 100 beds or ≥ 101 beds) randomly select a sub-sample of cases with HAIS scores (based on 80% power calculations) (n = 250).
4. Identify and locate charts for 250 individuals, reassign HAIS scores, and abstract data (n = 248)

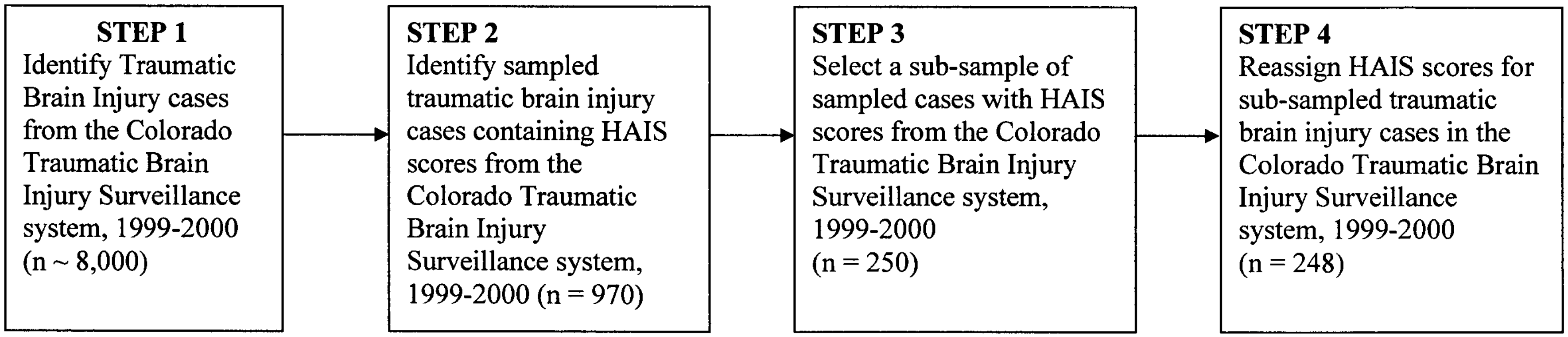

Figure 4.1: Intra-rater Agreement Methods using data from the Colorado Traumatic Brain Injury Surveillance system, 1999-2000

Inter-Rater Agreement Materials and Methods

Data Source

Individuals hospitalized and treated for traumatic brain injury are classified as trauma individuals; these individuals require immediate attention for their injuries. In Colorado, information regarding trauma individuals is routinely collected by the Colorado Trauma Registry, a statewide database containing detailed information about injured trauma individuals hospitalized in acute care facilities throughout Colorado. Operated by the Colorado Department of Public Health and Environment, in Denver, Colorado, the purpose of the Colorado Trauma Registry is to conduct statewide surveillance of trauma risk factors and to analyze and evaluate traumatic injury trends occurring in Colorado over time.

The Colorado Trauma Registry collects data from specific acute care facilities known as trauma centers. Classified as level I, II, or III trauma centers, these facilities are required to report information to the statewide Trauma Registry. Each year, trauma facilities are credentialed and designated by the Colorado Department of Public Health and Environment. A high level of surgical care and extensive equipment are required to be a designated a trauma center [99;100]. Level I trauma centers have the highest level of capabilities and they are often attached to medical schools. These facilities have extensive equipment requirements and maintain an open operating room, a 24-hour in-house operating room staff, and an on-site surgical team [101]. A level II trauma facility is similar to the level I facility, but does not require surgical specialists to be in-house; however, surgeons are required to arrive at the hospital when the patient arrives [102]. Level

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III trauma centers serve as stabilizing facilities and individuals are transferred to Level I or II facilities if more acute care is required.

Case Definition

The Colorado Trauma Registry defines traumatic brain injury cases using the International Classification of Diseases, 9th Revision, Clinical Modification diagnostic codes: 800 – 801.9, 803 – 804.9, 850, 854.1, and 959.01. Individuals with a brain injury resulting from disease processes, such as tumors are excluded. Further, for this specific aim, cases with a prior history of head injury are excluded; it has been documented that individuals with a prior traumatic brain injury are at risk for a secondary head injury [103].

The state of Colorado mandates that each trauma center report trauma case information to the Colorado Trauma Registry no later than three months after patient discharge. Data collected includes, but is not limited to, demographic information, date and time of incident and injury severity measures, such as HAIS.

Variables of Interest

For this specific aim, the main variable of interest is HAIS. Each trauma facility maintains at least one in-house trauma registrar to abstract data from medical records and code HAIS. Data on the education and training background of the trauma registrar is unknown at the state level, but state officials report that a diverse group of nurses, trained medical technicians and lay people are responsible for coding HAIS.

As previously mentioned, HAIS scores are also collected for a sample of cases from the Colorado Traumatic Brain Injury Surveillance system. These scores are coded by a trained and credentialed coder employed by the Colorado Traumatic Brain Injury Surveillance system. The goal of inter-rater agreement was to compare HAIS scores from

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the Colorado Traumatic Brain Injury Surveillance system coder to HAIS scores coded by the trauma registrars in the Trauma Registry database. Cases from 2000 were used to assess inter-rater agreement.

Potential Confounders

Factors which may influence inter-rater agreement were chosen based on availability, previous literature in which there was an association between TBI and a factor, and a priori selection. These factors included demographic variables such as sex (male or female) [104-108]; age (0-14, 15-24, 25-44, 45-64 and 65 or more years of age) [10;108-110]; payment or insurance source (government (federal and state), private, or none) [107;111;112]; hospital trauma level designations (classified as levels I, II, III or undesignated) [33]; and, outcome (inpatient death or survival) [72;113].

Injury factors which may influence inter-rater agreement included injury mechanism, Glasgow Coma Scale, and International Classification of Disease, 9th Revision – Clinical Modification diagnostic codes. Injury mechanism was classified using ICD-9-CM External Cause of Injury codes into two categories, penetrating and blunt. Penetrating injuries included codes from: firearms (E922.0 – E 922.4, E922.8, E955, E965.0 – E965.4, E970); and, sharp objects (E920.0 – E920.9, E956, E966, E974). Blunt injuries included of all the remaining mechanisms (E810.0 – E825.9, E826, E827.0 – 848.9, E880.0 – 888.9, E916.0 – E917.9, E960.0 – E969.9 (excluding E965.0 – E965.4), E950.0 – 959.9 (excluding E955), E906.8, E907, E918 – E919, E928.9, E970, E988, E985) [10;108]. Glasgow Coma Scale scores were grouped as: coma (3 – 8); moderate TBI (9 – 12); normal or mild TBI (13 – 15); and, unknown [3]. ICD-9-CM diagnostic codes

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were dichotomized as either a specific diagnostic code for TBI (800 – 801.9, 803 – 804.9, and 850) or unspecified code (854 or 959.01) [10;114].

Inter-rater Agreement Data Analyses

Frequency distributions were used to describe demographic and injury characteristics across HAIS categories. Mantel-Haenszel chi-square test statistics were used to identify associations between potential confounders and rater HAIS scores. Statistical significance was determined as p-value < 0.05. To determine inter-rater agreement, HAIS scores from the Colorado TBI Surveillance system coder were compared to those generated by the trauma registrars. Weighted kappa statistics were used to assess inter-rater agreement. As seen in Table 4.1, Landis and Koch cut points were used for interpretation of kappa statistics [51]. Inter-rater agreement of HAIS was further assessed to determine if any demographic or injury factors affected agreement. Variables identified with agreement less than or equal to moderate agreement as defined by Landis and Koch (kappa statistics ≤ 0.59), were further assessed using Spearman correlation coefficients to determine if a relationship existed between selected variables; statistical significance was determined as p-value < 0.05. [98]. SAS 9.1 © was used for all statistical analyses.

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There are four steps for the inter-rater agreement process:

1. Using the existing Colorado TBI Surveillance database, identify the total number of TBI cases for 2000 (n ~ 4,000)
2. Identify sampled traumatic brain injury cases containing HAIS scores from the Colorado Traumatic Brain Injury Surveillance system (n ~ 800)
3. Select sampled cases containing HAIS scores from the Colorado Traumatic Brain Injury Surveillance system, 2000, and link cases by name, date of birth medical record number and hospital to the same brain injured cases in the Colorado Trauma Registry, 2000 (n ~ 800)
4. Assess the inter-rater agreement of cases obtained from data sets (n = 624)

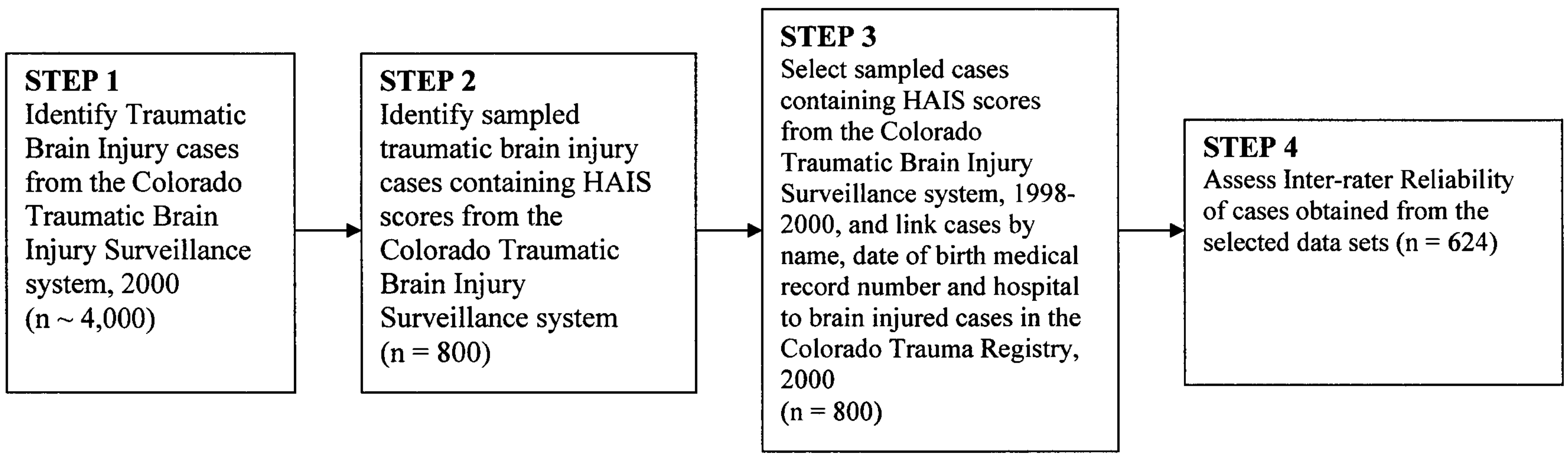

Figure 4.2: Inter-rater Agreement Methods using data from the Colorado Traumatic Brain Injury Surveillance system, 2000

Results

For intra-rater agreement, medical records were obtained for 248 out of 250 (95.0%) sampled hospitalized cases. Intra-rater agreement from time one to time two was 0.81 (0.76, 0.86). Based on Landis and Koch cut points, intra-rater agreement was interpreted as almost perfect [51].

For inter-rater agreement, approximately 800 hospitalized cases of TBI in Colorado were sampled in 2000. Of the eligible sampled hospitalized cases, 624 (78.0%) had HAIS scores available from both the Trauma Registry and the Colorado TBI Surveillance system.

As seen in Table 4.2, a majority of cases had an HAIS of two indicating moderate head injury. The majority survived (92.3%), were male (64.3%), had private insurance (63.5%), and were treated at a level II trauma facility in Colorado (49.2%). A majority of critical TBIs based on HAIS level were treated in Colorado hospitals designated as a level I and II facilities. By age, the largest percentages of head injured individuals were 25-44 years (31.8%) followed by individuals 15-24 years (24.0%). A statistically significant ($p < 0.05$) association was observed between all demographic characteristics and HAIS scores except for sex.

As seen in Table 4.3, a majority of head injured individuals had ICD-9-CM codes specific for head injuries (92.6%), suffered a blunt trauma (99.8%), and suffered from mild head injuries based on GCS scores done in emergency departments (64.2%). The proportion of cases with an unspecified ICD-9-CM code was highest among cases with moderate (HAIS = 2) and serious head injury (HAIS = 3). Among the individuals with mild TBI based on GCS, 112 out of 401 were identified as having a severe or critical

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head injury (HAIS scores > 4). Statistically significant ($p < 0.05$) associations were observed between HAIS scores and all diagnostic characteristics.

Weighted kappa statistics were used to assess the inter-rater agreement of HAIS scores between the coder at the Colorado TBI Surveillance system and the trauma registrars. As seen in Table 4.4, the overall proportion of agreement between the two raters was 70%. In Table 4.5, inter-rater agreement ranged from 0.17 to 0.79 and overall HAIS agreement was substantial (weighted kappa = 0.70 (0.66, 0.74)). For a majority of demographic and injury characteristics, weighted kappa statistics ranged between 0.60 – 0.79 indicating substantial agreement. Slight agreement (weighted kappa values ranging from 0.0 – 0.19) was observed among hospitalized cases who died. Moderate agreement (weighted kappa values ranging from 0.40 – 0.59) was observed among cases with unspecified ICD-9-CM diagnostic codes, hospitalized cases 0-14 years of age and 65 years of age and older, undesignated trauma facilities, and GCS scores indicating coma (GCS 3-8). It should be noted that although some factors were categorized with less than substantial agreement, that many of the upper confidence intervals overlapped with substantial agreement suggesting that the true values could fall in the substantial agreement category.

Discussion

Revisions of AIS occurred in 1980 (AIS-80), 1985 (AIS-85), 1990 (AIS-90) and 2005 (AIS-05) [37]. Of these, the AIS-90 has been used by hospitals, clinicians, and injury epidemiologists around the world to accurately characterize injury severity and identify trends over time. Compared to its predecessors, AIS-90 is considered to best represent head injury severity [39]. Changes to the 1990 revision included an expansion of medical

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descriptors to better characterize head injury. Such descriptors include but are not limited to describing brain contusions by size, specifying the location and number of lesions, quantifying the volume and size of hematomas, and adding a section on intracranial vessels and cranial nerves [37]. Regardless of revisions, one key principle of AIS has remained the same - the ability for AIS scores to be generated independently for each body region [36]. This principle provided a unique opportunity to assess the inter- and intra-rater agreement of AIS scores for the head region (HAIS) and the purpose of this study was to directly assess HAIS scores among individuals with TBI using AIS-90.

Study results indicate that the intra-rater agreement of HAIS scores was almost perfect. This finding suggests that a trained and credentialed coder can reliably assess medical record charts for injury severity measures. By comparing HAIS scores of the trained state coder to scores coded by trauma registrars at acute care facilities throughout the state of Colorado, this study found inter-rater agreement of HAIS to be substantial. Factors hypothesized to affect HAIS inter-rater agreement included demographic and injury characteristics. These factors were chosen based on past literature in which there is an established association with TBI or factors were selected a priori.

Factors that were hypothesized to influence inter-rater agreement were found not to affect agreement. For example, substantial agreement was observed for the varying payment/insurance categories. Another factor hypothesized to influence agreement was hospital trauma designation status. Because the state requires hospitals to send severely injured TBI individuals to level I hospitals, inter-rater reliability between the state coder and the trauma registrars at level I hospitals was expected to be higher compared to other hospitals. Weighted kappa values among Level I, II, and III hospital facilities were

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approximately the same. However, among undesignated hospitals, inter-rater agreement was reduced. These results suggest that although hospital trauma designation does not affect coding agreement, the lack of coding resources in undesignated hospitals may affect the accuracy of injury characterization.

In this study, age was tested to determine if it influenced inter-rater agreement. It is well established that young and older adults are at greatest risk for sustaining a TBI compared to all other age groups [2;115]. Often, young adults are at greatest risk for sustaining severe multi-system injuries due to high energy mechanisms while older adults are often affected by secondary and tertiary co-morbid conditions [2;115]. But, do these age groups influence inter-rater agreement of HAIS scores? Study results indicate moderate agreement in HAIS scores for the very young (0 – 14 years of age) and adults 65 years of age and older. Although these results may stem from small sample sizes it may suggest that inter-rater agreement may be complicated by co-morbid factors. For example, older adults using pharmaceutical agents such as the anti-coagulant warfarin (known as coumadin) are more likely to die from a TBI or suffer adverse outcomes compared to individuals not taking warfarin [116]. Coding HAIS among older adults with TBI may be difficult if an interaction exists between the primary injury and a secondary illness.

Less than substantial inter-rater agreement was observed among TBI individuals who died, were in comas, and had unspecified ICD-9-CM TBI diagnostic codes. Although low inter-rater agreement among these groups may reflect severe injury and/or the presence of other comorbid illnesses, other plausible explanations include poor medical record documentation, a need for expanding the injury descriptors to describe head injury, and small sample sizes. For example, unspecified ICD-9-CM diagnostic

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codes may indicate poor medical record documentation, thus making it difficult to assign HAIS scores. Or, low inter-rater agreement may stem from small sample size. For example, slight agreement was observed among the TBI individuals who died; however only 48 cases were used to test agreement.

Overall, this study concluded that inter-rater agreement between one trained state coder and trauma registrars at facilities throughout Colorado was substantial. Factors that may explain the observed differences between coders include differences among trauma registrars in regards to education and training, experience, use and knowledge of database systems, and multiple individuals entering data. Injury factors that potentially influence agreement include multi-system trauma, pharmaceutical drug usage, and use of personal protective equipment such as helmets. These factors would have been important for identifying their effect on inter-rater agreement of HAIS scores, but they are often not routinely collected or reported by acute care facilities. Lastly, medical record documentation factors such as radiological results, history and physical reports, and inaccurate hospital documentation may directly influence inter-rater agreement.

Although this study excluded pre-hospital deaths, and individuals with an HAIS score of six (virtually unsurvivable injury), the strength of this study is the availability of HAIS scores from two independent coding sources for the same patient. Study results indicate that when comparing HAIS scores between hospital trauma registrars and a state coder, the inter-rater agreement was substantial. Future studies should include a replication of this study using the newer version, AIS-05, to identify if expansion of head injury descriptors increase overall agreement. Additional studies should be conducted to

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identify agreement as hospitals move away from paper documentation and toward electronic health records.

Conclusion

Although scores from the Abbreviated Injury Scale are routinely used to assess injury, including head injury, no studies have directly assessed HAIS reliability. This study found almost perfect intra-rater reliability and substantial inter-rater reliability of HAIS scores among hospitalized TBI cases in Colorado, 1998 – 2000. Further, this study found that inter-rater agreement was associated with head injury severity, the more severe the TBI, the more difficult it is to provide a reliable HAIS score. Future studies are needed to identify factors associated with HAIS scoring variability among TBI individuals with severe head injury.

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Table 4.1: Kappa statistic cut points and interpretation, Landis and Koch (1977)

Kappa Value Range	Interpretation
0.80 – 1.0	Almost Perfect
0.60 – 0.79	Substantial
0.40 – 0.59	Moderate
0.20 – 0.39	Fair
0.00 – 0.19	Slight
-1.0 – -0.99	Poor

Table 4.2: Number and percent distribution of hospitalized traumatic brain injury cases by year and demographic characteristics, Colorado, 1998-2000, (n = 624).

Demographic Characteristics	HAIS = 2 moderate 221 (35.4%)	HAIS = 3 serious 154 (24.6%)	HAIS = 4 severe 124 (20.0%)	HAIS = 5 critical 125 (20.0%)	Total 624 (100.0%)
Outcome					
Survived	221 (100.0)	152 (98.7)	120 (96.7)	83 (66.4)	576 (92.3)
Died	0 (0.0)	2 (1.3)	4 (3.2)	42 (33.6)	48 (7.7)*
Sex					
Male	146 (66.0)	94 (61.0)	77 (62.1)	84 (67.2)	401 (64.3)
Female	75 (34.0)	60 (39.0)	47 (37.9)	41 (32.8)	223 (32.2)
Age Group (in years)					
0-14	31 (14.0)	15 (9.7)	17 (13.7)	14 (11.2)	77 (12.5)
15-24	66 (29.8)	36 (23.4)	23 (18.5)	25 (20.0)	150 (24.0)
25-44	69 (31.2)	60 (38.9)	30 (24.2)	40 (32.0)	199 (31.8)
45-64	43 (19.6)	27 (17.5)	22 (17.7)	19 (15.2)	111 (17.8)
≥ 65	12 (5.4)	16 (10.6)	32 (25.9)	27 (21.6)	87 (13.9)*
Payment/Insurance					
Private[§]	153 (69.3)	99 (64.3)	78 (62.9)	66 (52.8)	369 (63.5)
Government	18 (8.1)	17 (11.0)	21 (16.9)	25 (20.0)	81 (12.9)
None	50 (22.6)	38 (24.7)	25 (20.2)	34 (27.2)	147 (23.6)*
Hospital Trauma Designation					
Level 1	47 (21.2)	52 (33.7)	42 (33.8)	58 (46.4)	199 (31.9)
Level 2	129 (58.4)	71 (46.1)	61 (49.2)	46 (36.8)	307 (49.2)
Level 3	34 (15.5)	23 (14.9)	17 (13.7)	15 (12.0)	89 (14.2)
Undesignated	11 (4.9)	8 (5.3)	4 (3.3)	6 (4.8)	29 (4.7)*

*Statistically Significant (p-value <0.05) differences between HAIS scores and risk factor

[§]Private payment/insurance categories included: government (Medicaid, Medicare, Champus, & other government); private (private health insurance, liability, & workers compensation); and, none (self-pay & medically indigent).

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Table 4.3: Number and percent distribution of hospitalized traumatic brain injury cases by year and diagnostic characteristics, Colorado, 2000 (n = 624).

Injury Characteristics	HAIS = 2 moderate 221 (35.4%)	HAIS = 3 serious 154 (24.6%)	HAIS = 4 severe 124 (20.0%)	HAIS = 5 critical 125 (20.0%)	Total 624 (100.0%)
ICD-9-CM[§]					
Specific ICD-9-CM Code	181 (81.9)	149 (96.7)	123 (99.1)	341 (100.0)	578 (92.6)
Unspecified ICD-9-CM Codes[+]	40 (18.1)	5 (3.3)	1 (0.9)	0 (0.0)	46 (7.4)*
Injury Mechanism[†]					
Blunt	221 (100.0)	154 (100.0)	124 (100.0)	124 (99.2)	623 (99.8)
Penetrating	0 (0.0)	0 (0.0)	0 (0.0)	1 (0.8)	1 (0.2)
Glasgow Coma Scale (GCS) Categories of TBI					
Mild TBI (GCS 13 – 15)	182 (82.4)	107 (69.5)	79 (63.7)	33 (26.4)	401 (64.2)
Moderate (GCS 9 – 12)	11 (5.0)	14 (9.1)	11 (8.8)	7 (5.6)	43 (6.9)
Coma (GCS 3 – 8)	4 (1.8)	11 (7.1)	19 (15.3)	60 (48.0)	94 (15.0)
Unknown	24 (10.8)	22 (14.3)	15 (12.2)	25 (20.0)	86 (13.9)

[§]International Classification of Disease 9th Revision – Clinical Modification (ICD-9-CM)
[+]Unspecified ICD-9-CM codes for TBI are 854 & 959.01
[†] Injury Mechanism is defined using the International Classification of Disease 9th Revision – Clinical Modification External Cause of Injury codes. Penetrating injuries include firearm injuries and piercing or cutting injuries from sharp objects while blunt injuries are all other remaining mechanisms.
*Statistically Significant (p-value <0.05) differences between HAIS scores and risk factor

Table 4.4: Overall agreement of Abbreviated Injury Severity scores for the head region between a traumatic brain injury medical record abstractor and the trauma registrar, Colorado, 2000 (n = 624).

		Trauma Registrars				
		AIS =2	AIS=3	AIS=4	AIS=5	Total
State Medical Record Abstractor	AIS=2	**194**	37	9	2	242
	AIS=3	20	**94**	22	14	150
	AIS=4	5	21	**77**	37	140
	AIS=5	2	2	16	**72**	92
	Total	221	154	124	125	624
Overall Agreement = 70%						

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Table 4.5: Agreement of Abbreviated Injury Severity scores for the head region (HAIS) between a traumatic brain injury medical record abstractor and the trauma registrar, Colorado, 2000 (n = 624).

Demographic & Diagnostic Characteristics	**Sample Size**	**Weighted Kappa Statistic (95% Confidence Interval)**	**Agreement Interpretation***
Overall Agreement	624	0.70 (0.66, 0.74)	Substantial
Outcome			
Survived	576	0.68 (0.63, 0.72)	Substantial
Died	48	0.17 (0.01, 0.43)	Slight
Sex			
Male	401	0.72 (0.67, 0.77)	Substantial
Female	223	0.67 (0.60, 0.74)	Substantial
Age Group (in years)			
0-14	77	0.58 (0.45, 0.73)	Moderate
15-24	150	0.77 (0.70, 0.85)	Substantial
25-44	199	0.71 (0.63, 0.77)	Substantial
45-64	111	0.76 (0.67, 0.85)	Substantial
≥ 65	87	0.57 (0.44, 0.69)	Moderate
Payment/Insurance			
Private	396	0.66 (0.63, 0.72)	Substantial
Government	81	0.71 (0.60, 0.82)	Substantial
None	147	0.79 (0.73, 0.85)	Substantial
Hospital Trauma Designation			
Level 1	199	0.64 (0.57, 0.73)	Substantial
Level 2	307	0.73 (0.67, 0.78)	Substantial
Level 3	89	0.74 (0.64, 0.81)	Substantial
Undesignated	29	0.54 (0.35, 0.73)	Moderate
ICD – 9 – CM[ʃ]			
Specific ICD-9-CM Codes	578	0.69 (0.65, 0.73)	Substantial
Unspecified ICD-9-CM Codes[ǂ]	46	0.53 (0.19, 0.95)	Moderate
Injury Mechanism[†]			
Blunt	623	0.71 (0.66, 0.75)	Substantial
Penetrating	1	Na	Na
Glasgow Coma Scale Categories (GCS)			
Mild TBI (GCS 13 – 15)	401	0.67 (0.61, 0.73)	Substantial
Moderate (GCS 9 – 12)	43	0.67 (0.49, 0.83)	Substantial
Coma (GCS 3 – 8)	94	0.48 (0.34, 0.63)	Moderate
Unknown	86	0.71 (0.60, 0.82)	Substantial

*Weighted kappa statistic interpretation is based on Landis & Koch cut points: almost perfect (1.0 – 0.80); substantial (0.79 – 0.60); moderate (0.59 – 0.40); fair (0.39 – 0.20); slight (0.19 – 0.0); and, poor (-0.99 – (-1.0)) [51;98].

ʃ ICD-9-CM is the International Classification of Disease 9th Revision – Clinical Modification

ǂ Unspecified ICD-9-CM codes for TBI are 854 & 959.01

† Injury Mechanism is defined using the International Classification of Disease 9th Revision – Clinical Modification External Cause of Injury codes. Penetrating injuries include firearm injuries and piercing or cutting injuries from sharp objects while blunt injuries are all other remaining mechanisms.

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CHAPTER 5

DISABILITY AND FUNCTIONAL STATUS ONE YEAR AFTER HOSPITALIZATION FOR TRAUMATIC BRAIN INJURY, COLORADO 1998-1999

Introduction

Each year in the United States, an estimated 1.4 million people sustain a traumatic brain injury (TBI). Among them, approximately 230,000 are hospitalized and an estimated 80,000 to 90,000 Americans are affected by long-term disability from TBI [1;2]. Current estimates suggest that approximately 5.3 million Americans (2% of the United States population) are living with a TBI-related disability [2]. Direct medical costs and indirect costs, such as a loss of productivity due to TBI, totaled Overall, an estimated 60 billion dollars in the US in 2000 [95]the current estimated cost to society for individuals living with TBI disabilities is 48.3 billion dollars per year [30].

In order to better understand health function and disability, the World Health Organization (WHO) developed the International Classification of Functioning, Disability and Health (ICF) [83]. The ICF is one of a group of international classification scales developed by WHO to provide a common language to communicate about health care [83]. Applied to a specific population such as individuals with TBI, the ICF enables researchers to assess TBI function and disability at many levels.

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As seen in Figure 5.1, there are two main parts to the ICF model: functioning and disability, and contextual factors [83]. Both parts help to conceptually define TBI multi-dimensionally. Within the functioning and disability parts are three domains, body functions and structures, activity, and societal participation [83]. The body functions and structures domain assesses disability at the organ level by characterizing physiological function [83]. The activities domain assesses disability by characterizing the ability of an individual to perform specific tasks [83]. The participation domain assesses disability by measuring involvement in life situations [83].

The environmental and personal factors domains are the contextual factors of ICF; these differ from the "performance" domains in functioning and disability [83]. For example, the environmental factor domain includes the physical, social and attitudinal environment in which people live [83]. Often, the environmental domain is further classified into two different levels, the individual, and the society in which they live. The personal domain includes a person's sex, race, age, fitness level, habits, education, and lifestyle[83].

In order to accurately assess function and disability following TBI, the severity of the TBI must be taken into account. Severity of TBI ranges from mild or having a brief change in mental status to severe or experiencing extended periods of unconsciousness [1]. Over the past 50 years, a number of scales for categorizing injury severity have been developed, but none have been as promising as the Abbreviated Injury Scale (AIS) [70;71;73]. Developed in 1969 by the Association for the Advancement of Automotive Medicine, AIS was initially used to provide a standard system for rating injury from motor vehicle crashes [7]. Since then, AIS has been revised to characterize injury severity among all

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types of injury mechanisms [36]. Although it was not developed to be a predictive measure, investigators have found that among individuals with TBI, the head injury component of the Abbreviated Injury Scale (HAIS) to be associated with Functional Independence Measures [72], scores from the Glasgow Outcome Scale [70;71], and TBI mortality [117].

Although studies have assessed the predictive ability of HAIS, none have been population-based. Past studies addressing long term outcomes from TBI relied on small selective groups of individuals, such as individuals in acute care facilities or in mild brain injury clinics, or individuals in transitional living programs [9;87;118]. The Colorado Traumatic Brain Injury Registry and Follow-up System (1996 – 1999) was the first statewide population-based study used to assess one-year outcomes using a number of outcome measures. The purpose of this study was to use the WHO ICF conceptual model to identify the strength of association between head injury severity, as measured by HAIS, and functional outcomes following TBI. The overall goal of this study was to identify factors which influence function and disability following TBI to help aid clinicians in the identification of individuals with specific rehabilitative needs to help target rehabilitative efforts.

Materials and Methods

The Colorado Traumatic Brain Injury Registry and Follow-up System (CTBIRFS) was a collaborative study conducted at the Colorado Department of Public Health and Environment in Denver, Colorado, and at Craig Rehabilitation Hospital located in Englewood, Colorado [9]. The purpose of the study was to "identify outcomes associated with traumatic brain injury including quality of life, reintegration into the community, return to work and school, functional status, service utilization and secondary

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complications (page 2)" [9]. The CTBIRFS was a telephone-based study in which individuals, discharged between January 1996 and June 1999 from acute care facilities throughout Colorado, were called annually and asked to report a number of different outcomes related to their injury [9].

Study Population

Records from the Colorado Traumatic Brain Injury Surveillance system at the Colorado Department of Public Health and Environment were used to identify Coloradoans 16 years of age and older discharged from an acute care facility in Colorado with one of the following TBI International Classification of Diseases – 9th Revision Clinical Modification (ICD-9CM) diagnostic codes: 800 – 801.9, 803 – 804.9, 850, 854.1, and/or 959.01. From approximately 3,500 brain injured Coloradoans whom annually met this case definition, a stratified random sample of hospitalized survivors was selected based on TBI severity. Severity scores were generated using ICD-Map, a computer software program developed to generate Abbreviated Injury Scale (AIS) scores for body regions using ICD-9CM diagnostic codes. For this study, AIS scores for the head region (HAIS) were used to select 80% of severe head injuries (defined as HAIS of 4 or greater) and 20% of mild head injuries (defined as HAIS < 4).

Methods

Data from medical records were abstracted including injury severity, pre-injury history, demographic data, and discharge disposition. During medical record data abstraction, HAIS scores were also calculated by a trained and credentialed coder employed by the Colorado TBI Surveillance system. Data were also obtained from a telephone interview with the individual with traumatic brain injury, a family member, or

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other proxy. Between 1996 and 1999, 2,771 individuals meeting the case definition were sampled. Among those individuals, 6.6% (184) were deceased at the time to follow-up; 21.1% (586) could not be interviewed due to incarceration or a language barrier; and, 14.8% (410) refused. Study participants included 1,591 individuals for an overall response rate of 57.4%. This study includes participants recruited between January 1, 1998 and June 1999. A weighting factor was applied to the study sample for cases enrolled between January 1, 1998 and June 1999 to ensure that the interviewed individuals accurately represented the Colorado TBI population. The weighting factor was 1.26 and the weighted sample size was 1,802.

For this study, the exposure variable of interest was HAIS scores based on HAIS scores generated by the trained coder at the Colorado Department of Public Health and Environment. HAIS scores range from one to six with one representing minor head injury and six representing a virtually unsurvivable head injury. HAIS scores were grouped and categorized as: minor head injury (HAIS 1&2); moderate head injury (HAIS 3&4); and, severe head injury (HAIS 5&6).

The outcome variables of interest for this study were derived from survey responses to questions representing the different levels of function and disability at the organ, individual, and societal levels, as defined by the 2001 WHO ICF classification. The body functions and structures domain assessed TBI at the tissue/organ level. The main assessment tool for this domain was the Alertness Behavior subscale of the Sickness Impact Profile. This focused on cognitive symptoms and questions assess confusion and attention. Scores ranged from 0 to 100 with a higher score indicating greater dysfunction.

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The activities domain assessed physical limitation in regard to performing specific individual activities. Two assessment tools were used, the Activities of Daily Living and the Instrumental Activities of Daily Living. The Activities of Daily Living assesses needing help with personal care tasks such as: bathing or showering; dressing; eating; getting in and out of a bed or chair; walking; and, toileting. The responses are categorized as yes, no, or unknown. The Instrumental Activities of Daily Living assesses whether an individual needs aid with factors associated with independent living, such as: preparing meals; shopping for grocery or personal items; and, managing money.

The participation domain measures societal participation. The main assessment tool used for this domain was the Craig Handicap Assessment and Reporting Technique – Short Form comprised of 19 questions. Scores range from 0 to 600. Individuals are classified as diminished societal participation (< 450) and the same level of participation as observed in a non-disabled person (≥ 450). Testing of CHART-SF revealed that this instrument is not reliable when administered by proxy, therefore, cases in which CHART-SF was completed by proxy, were excluded from analyses [9].

Potential explanatory variables included both environmental and personal factors such as demographic, pre-injury and diagnostic variables. Demographic variables were classified as: sex (male, female); age (at time of injury) group in years (16-24, 25-44, 45-64, and 65+ years of age); race (white, non-white or unknown) and ethnicity (Hispanic, non-Hispanic, or unknown); insurance (government, private, other, or unknown); pre-injury education (no high school diploma/high school diploma or GED, trade-school/some college/bachelor's degree/graduate degree, or unknown); and, survey by proxy (yes, no, or unknown). Pre-injury variables were derived from survey responses

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one year-post injury and were classified as: self-reported prior history of neurological pathology such as stroke or seizure (yes, no, or unknown); psychiatric disorder or drug and alcohol problems (yes, no, or unknown); learning disability (yes, no, or unknown); and, prior history of TBI (yes, no, or unknown). Diagnostic variables were classified as: length of stay in hospital in days (0 – 2, 3 – 5, or 6 or more days); radiological test results (normal, abnormal, unknown); discharge disposition from the hospital (transfer to a facility, home, or unknown); and, rehabilitation during the one year following brain injury (yes or no).

Analyses

Descriptive statistics were used to characterize the data. Frequencies and percent distributions were calculated to describe HAIS scores by demographic, pre-injury, diagnostic, and outcome variables. Mantel-Haenszel chi-square tests were used to evaluate the difference between HAIS groups for each characteristic. Unknown categories were excluded from Mantel-Haenszel chi-square calculations. T-tests were used to determine if a difference in means existed between HAIS group 1&2 and HAIS groups 3&4 and 5&6 in the Alertness Behavior subscale of the Sickness Impact Profile. Statistical significance was set at 95% ($p < 0.05$).

Four models were built to determine if HAIS grouped scores were predictive of the outcomes of interest. Three models used logistic regression modeling and one model used linear regression. Multiple linear regression was used to determine the association between HAIS grouped scores and the Alertness Behavior subscale of the Sickness Impact Profile. The model was built using forward stepwise selection in which variables were chosen based on biological and statistical significance ($p< 0.05$). Each variable was

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added to the model based on its contribution to the reduction of residual error accounting for the other variables already selected. All excluded variables were assessed as potential effect modifiers or confounding variables; and, lastly, the model was tested for independence, normality, linearity, and homoscedasticity.

Logistic regression models were used to determine the association between TBI severity categories (HAIS) and one-year activity and participation outcomes, as measured by the Activities of Daily Living, Instrumental Activities of Daily Living, and the Craig Handicap Assessment and Reporting Technique – Short Form (CHART-SF). Models were built using five steps of purposeful selection as outlined by Hosmer and Lemeshow (1999) [119]. The five steps of purposeful selection were: 1) test for univariate significance ($p<0.25$); 2) insert variables into the multivariate model and retain those that were statistically significant ($p<0.05$) and/or biologically important; 3) test for confounding among excluded variables and include variables that change the odds ratio of a model variable by more than 10%; 4) assess continuous variables; and, 5) test for effect modification and include interaction terms that are statistically significant ($p < 0.05$) and biologically important in the multivariate model [119]. Missing data were excluded during analyses. SAS 9.1 © was used for all statistical analyses.

Results

Between 1998 and 1999, 1,802 individuals participated in the CTBIRFS. HAIS scores were grouped as minor head injury (HAIS 1&2), moderate head injury (HAIS 3&4), and, severe head injury (HAIS 5&6). As seen in Table 5.1, a majority of the survey respondents had moderate TBI (45.2%) followed by mild TBI (32.8%) and severe TBI (22.0%).

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The majority of respondents were male (70%). On average, survey respondents were 41 years old with ages ranging from 16 – 94. By age group, a majority of respondents were 25 – 44 years of age (35.7%), followed by individuals 16 – 24 years of age (28.3%), 45 – 64 years of age (19.5%), and 65 years of age and older (16.5%). A majority of respondents were white (80.0%). Approximately 60% of survey respondents were non-Hispanic, 12.8% reported being of Hispanic ethnicity, and 30% were unknown. Insurance was obtained from the CO TBI Registry and was categorized as private (13.9%), government (9.1%), other (including no charge for services, self-pay, and other insurance) (0.7%), or unknown (76.3%). Approximately half of survey respondents reported having a high school education. A majority of survey respondents were interviewed without the help of a proxy (62.5%). The majority of patients did not report receiving rehabilitation in the year following brain injury (76.0%). No statistically significant differences were observed across HAIS categories for sex or ethnicity. Statistically significant differences ($p<0.05$) were observed across the HAIS categories for age groups, race, insurance status, education, proxy status, and rehabilitation.

Table 5.2 provides the frequency distribution across the three HAIS categories for pre-injury and diagnostic variables. A majority of survey respondents reported not having a history of neurological pathology (96.4%), psychiatric disorder (90.0%), or learning disability (90.2%) prior to the injury. The average hospital length of stay was 6.8 days with lengths of stay ranging from less than 24 hours (noted as 0 days) to 63 days. The percentages of individuals with a hospital length of stay were 34.5% for those staying 0 – 2 days; 29.5% for those staying 3 – 5 days; and, 36.0% for respondents with six or more days. A majority (95.8%) did not have documented evidence of a history of TBI. The

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percentage of respondents with an abnormal radiological result was 55%, 41% had normal results. A majority of individuals were discharged home following injury (95.8%) while a minority (3.3%) was discharged to a facility for continued care. No statistically significant differences were observed across HAIS categories for history of learning disability and prior history of TBI. Statistically significant differences ($p<0.05$) were observed across the HAIS categories history of neurological pathology, history of psychiatric disorder or drug abuse, length of stay, radiological test result, and hospital discharge disposition.

Outcome variables were assessed across the three HAIS categories (Table 5.3). No statistically significant differences were observed when comparing the means across the HAIS categories. Among those reporting on Activities of Daily Living, a greater proportion of individuals reported did not need any aid (84.7%) as compared to those who did need aid (15.0%). Similarly, a greater proportion of respondents did not need aid with Instrumental Activities of Daily Living (78.8%) as compared to those who did (20.8%). A majority of respondents reported diminished societal participation (71.1%). Compared to mild TBI, there no statistically significant differences were observed between means for moderate and severe TBI HAIS categories. Statistically significant differences ($p<0.05$) were observed across the HAIS categories for Activities of Daily Living, Instrumental Activities of Daily Living, and CHART-SF outcomes.

Table 5.4 contains the results of three logistic regression models used to determine the strength of association between HAIS and function and disability one-year post-injury. Because missing data was excluded from analyses, 857 cases were used for the Activities of Daily Living and the Instrumental Activities of Daily Living models, and

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860 cases were used to build the Craig Handicap Assessment and Reporting Technique – Short Form model.

Adjusting for age, race, Hispanic ethnicity, education, survey proxy status, history of neurological pathology, and prior TBI, subjects with moderate and severe TBI were more than four times as likely to report needing help with Activities of Daily Living throughout the study period as compared to those with mild TBI. The odds ratios for moderate and severe TBI were 5.04 [95% confidence interval (1.67, 15.6)] and 4.08 [95% confidence interval (1.29, 12.7)], respectively. Identified confounders included Hispanic ethnicity and prior TBI. During the study period systematic increases for needing help with Activities of Daily Living were observed for individuals 25 years of age and older, with high school education, individuals responding by proxy, and those with a history of neurological pathology.

Adjusting for age, race, Hispanic ethnicity, education, survey proxy status, history of neurological pathology, history of psychiatric pathology, and hospital length of stay, subjects with moderate and severe TBI were more than 60% as likely to report needing help with Instrumental Activities of Daily Living throughout the study period as compared to those with mild TBI. The odds ratios for moderate and severe TBI were 1.90 [95% confidence interval (1.01, 3.57)] and 1.62 [95% confidence interval (0.81, 3.26)], respectively. Systematic increases in risk for needing help with Instrumental Activities of Daily Living were observed among individuals 45 years of age and older, with high school education, responding by proxy, with a history of neurological and psychiatric pathology, and those with a hospital length of stay greater than six days. Hispanic

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ethnicity was identified to confound the relationship between HAIS and Instrumental Activities of Daily Living; no significant interactions were identified.

The Craig Handicap Assessment and Reporting Technique – Short Form was used to identify respondents participation in society. Adjusting for age, Hispanic ethnicity, education, history of neurological pathology, history of learning disability, and hospital length of stay, subjects with moderate and severe TBI were 40% as likely to report diminished participation throughout the study period as compared to those with mild TBI. The odds ratios for moderate and severe TBI were 1.72 [95% confidence interval (1.18, 2.51)] and 1.58 [95% confidence interval (1.01, 2.47)], respectively. Hispanic ethnicity confounded the relationship between HAIS and the Craig Handicap Assessment and Reporting Technique – Short Form; however, no significant interactions were identified. A systematic increase in risk for diminished participation was observed among individuals 25 years of age and older, Hispanic ethnicity, high school education, those with a history of neurological pathology and learning disability, and those with a hospital length of stay greater than six days.

To better assess and understand the role of rehabilitation on the association between HAIS and TBI outcomes relating to the activities and instrumental activities of daily living and participation in society, logistic regression models were re-run stratifying by whether an individual attended rehabilitation. As seen in Table 5.5, among individuals that attended rehabilitation, no association was observed between TBI patients with moderate and severe TBI and activities and instrumental activities of daily living. However, among those attending rehabilitation, individuals with severe TBI were 13 times as likely to report diminished societal participation as compared to individuals with

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mild TBI, after adjusting for identified confounding variables. Conversely, as seen in Table 5.6, individuals with moderate and severe TBI that did not attend rehabilitation were more than seven times as likely to report needing help with activities of daily living as compared to individuals with mild TBI. The odds ratios for moderate and severe TBI were 8.62 [95% confidence interval (1.94, 38.3)] and 7.89 [95% confidence interval (1.58, 39.3)], respectively. Individuals with moderate TBI who attended rehabilitation were two times as likely to reporting needing help with instrumental activities of daily living as compared to individuals with mild TBI [(OR=2.38), 95% confidence interval (1.21, 4.69)]. Similarly, individuals with moderate TBI who attended rehabilitation were 85% as likely to report diminished societal participation as compared to individuals with mild TBI [(OR=1.85), 95% confidence interval (1.24, 2.75)].

Multiple linear regression was used to determine the association between HAIS and the Alertness Behavior Subscale of the Sickness Impact Profile (Table 5.7). Adjusting for age, Hispanic ethnicity, education level, survey by proxy status, psychiatric pathology, and prior history of learning disability, moderate and severe TBI were associated with cognitive dysfunction. The model was found to meet the assumptions of independence, normality, linearity, and homoscedasticity. However, the square of the correlation coefficient was 0.123; meaning, only 12.3% of the variance of the Alertness Behavior Subscale of the Sickness Impact Profile was explained by the predictors in the model.

Discussion

Over the years, researchers have evaluated individuals with TBI using the Glasgow Coma Scale and the Abbreviated Injury Scale. Because Glasgow Coma Scale

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scores are routinely collected during hospitalization, they are often more available for research as compared to the Abbreviated Injury Scale. However, Glasgow Coma Scale scores have been found to be a poor predictor of one-year morbidity outcomes from TBI [4;61-63;120]. For example, Zafonte et al. (1996) studied the association between Glasgow Coma Scale scores and Functional Independence Measures among individuals admitted for TBI rehabilitation and found that Glasgow Coma Scale scores provided little predictive value [64]. Initial studies assessing the predictive abilities of the Abbreviated Injury Scale found brain injury to be the major determinant of overall severity and that body-specific Abbreviated Injury Scale scores, such as the one for the head region (HAIS), were more useful for predicting functional deficits than overall Injury Severity Scores [55].

Using an AIS score for a single body region is feasible, i.e. head AIS (HAIS) since each AIS score is treated independently for each body region. Ross et al. (1992) evaluated HAIS as a prognostic tool for functional outcome among individuals at the New Jersey Trauma Center, 1986-1988. The results indicated a statistically significant ($p < 0.001$) association between HAIS and scores from the Glasgow Outcome Scale [70]. Walder et al. (1995) had similar findings when comparing HAIS scores to six month scores from the Glasgow Outcome Scale among British individuals at the Queen's Medical Center, 1986-1988 [71]. Recently, Demetriades et al. (2004) assessed HAIS as predictor of TBI mortality among 7,764 individuals from two local Los Angeles hospitals [121]. HAIS was significantly associated with mortality, specifically when adjusting by age (≤ 65 years old and ≥ 65 years old) and the type of injury mechanism (blunt versus penetrating) [122]. Lower morbidity was predicted by lower HAIS severity scores [71]. The

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advent of improved imaging capabilities such as computed tomography has enhanced the ability to anatomically describe head injury and has aided in the coding of HAIS [4]. As more individuals survive head injuries, it has become increasingly important to identify rehabilitation needs to reduce the long-term health outcomes associated with TBI.

The results of this study indicate that HAIS is a good predictor of function and disability at the individual and societal levels, as measured by the activities and participation domains. Specifically, this study identified an association between having a moderate to severe TBI (as measured by HAIS scores > 3) and a self-reported need for help with activities of daily living and societal participation. The study failed to find an association between HAIS and cognitive disability as measured by the Alertness Behavior Subscale of the Sickness Impact Profile. This finding may be the result of one of two factors. First, the Alertness Behavior Subscale of the Sickness Impact Profile may assess TBI in terms of physiology rather than anatomy, suggesting that physiological measures may be better at predicting this outcome; however, when Glasgow Coma Scale scores were introduced into the model, it failed to provide any significant improvement. Second, the lack of association between the HAIS and cognitive function may be due to the instrument used. The Alertness Behavior Subscale is only one of 12 subscales of the Sickness Impact Profile. Future studies are needed to determine if HAIS is associated with the Sickness Impact Profile rather than one subscale.

Activities were assessed using two instruments, the Activities of Daily Living and the Instrumental Activities of Daily Living. Although both measurements are similar, each instrument assesses a different aspect of physical activities following TBI. While the Activities of Daily Living assesses whether an individual needs help with performing

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personal care tasks, the Instrumental Activities of Daily Living assesses whether an individual needs help living independently. The results of this study indicate that moderate and severe TBI, as measured by HAIS, was associated with needing help with activities.

Both activities models indicated an association between needing help with daily activities and older age. Age is directly related to increased mortality and decreased morbidity following TBI [123] and often affects an older individual's ability to perform personal care tasks and live independently[115]. Often it is not age itself, but the co-morbidities that accompany age which affect older individuals need for help with daily activities. For example, older individuals with cardiovascular disease are often placed on anti-coagulant agents such as the pharmaceutical drug Warfarin (also known as Coumadin) [116]. Researchers have observed a significant increase in the risk of death among individuals taking this medication as compared to individuals not taking the drug [116]. As the population of the United States matures with a subsequent increase in the number of individuals 65 years of age and older, it will become increasingly important to provide physical help for this population following TBI. This study supports the need for targeting rehabilitative efforts for certain groups, such as older individuals. Further, future studies targeting older TBI individuals are needed to identify the role of comorbid conditions and treatments for these conditions as potential effect modifiers for one-year outcomes following TBI.

The instrument used to assess societal participation was the Craig Handicap Assessment and Reporting Technique – Short Form. Developed in 1992, the short form consists of 19 questions assessing the various roles of social integration following TBI [80].

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Results of this study suggest that individuals with moderate to severe head injury were more likely to report less societal participation as compared to individuals with mild head injury. Individuals 45 years of age and older, Hispanic, having a high school education, and history of psychiatric or drug use pathology, history of a learning disability, and an overall length of stay greater than or equal to six days were more likely to report diminished societal participation. The findings suggest that societal participation for individuals with a moderate to severe head injury is diminished. Future research is needed to identify the effectiveness of rehabilitative services for increasing societal participation among these vulnerable populations.

For individuals with TBI, attending rehabilitation is often vital for improving function, independence, and quality of life [76]. The main goal of rehabilitation is for individuals and their families to work in conjunction with rehabilitation experts to set and obtain realistic functional goals [76]. However, not all individuals attend rehabilitation after hospital discharge. For example, among persons hospitalized with TBI in Colorado, researchers found that only one-third (353) of 1059 identified cases had received extra rehabilitation services following discharge from acute care facilities [77]. By not attending rehabilitation, individuals miss opportunities to gain independence, increase functional abilities and improve quality of life [76;124]. By stratifying by rehabilitation, the results of this study indicate that the relationship between HAIS and adverse outcomes one year following TBI are significantly reduced. The results further suggest a positive association between moderate and severe TBI and adverse outcomes among those that did not attend rehabilitation. These study results further support the need for individuals with a

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moderate and severe TBI (HAIS score greater than three) to participate in some form of rehabilitation to increase function and reduce disability following TBI.

There were limitations in this study. Approximately 54% of cases sampled for the CTBIRFS participated during the four year study. Because many individuals refused to participate or were excluded due to incarceration or a language barrier one-year post injury, study results are only generalizable to English speaking individuals who were not incarcerated. Individuals who did not participate may have been significantly different than individuals who did participate. This may have affected the effect estimations observed in this study. A majority of cases had unknown insurance status. Insurance status is important because little is known about the association between HAIS and one-year outcomes following TBI relative to the type of insurance. Rehabilitation services may be provided based on insurance coverage. Future studies are needed to determine the magnitude of effect that insurance status has on one-year outcomes following TBI.

Despite the limitations, moderate and severe TBI, as measured by HAIS, was associated with daily activities and societal participation one-year after hospital discharge. The WHO ICF conceptual model of function and disability provided a multi-dimensional approach for identifying the complexities of TBI. One aspect missing from this conceptual model was a quality of life measurement. Subjective in nature, quality of life following TBI may provide insight not captured in the other domains of the ICF. These findings also support the need for an inter-disciplinary group of epidemiologists, clinicians and rehabilitation experts to work together to identify barriers to rehabilitation such as cost, availability of resources, and support from family and friends.

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Conclusion

The purpose of this study was to determine the association between HAIS scores and function and disability one year after hospitalization for TBI. Using population-based data from the CTBIRFS, 1998-1999, this study found that HAIS scores greater than three predicted function and disability at the individual and societal levels. These findings suggest that HAIS scores can be used to predict the need for rehabilitation following TBI in order to reduce disability and increase function.

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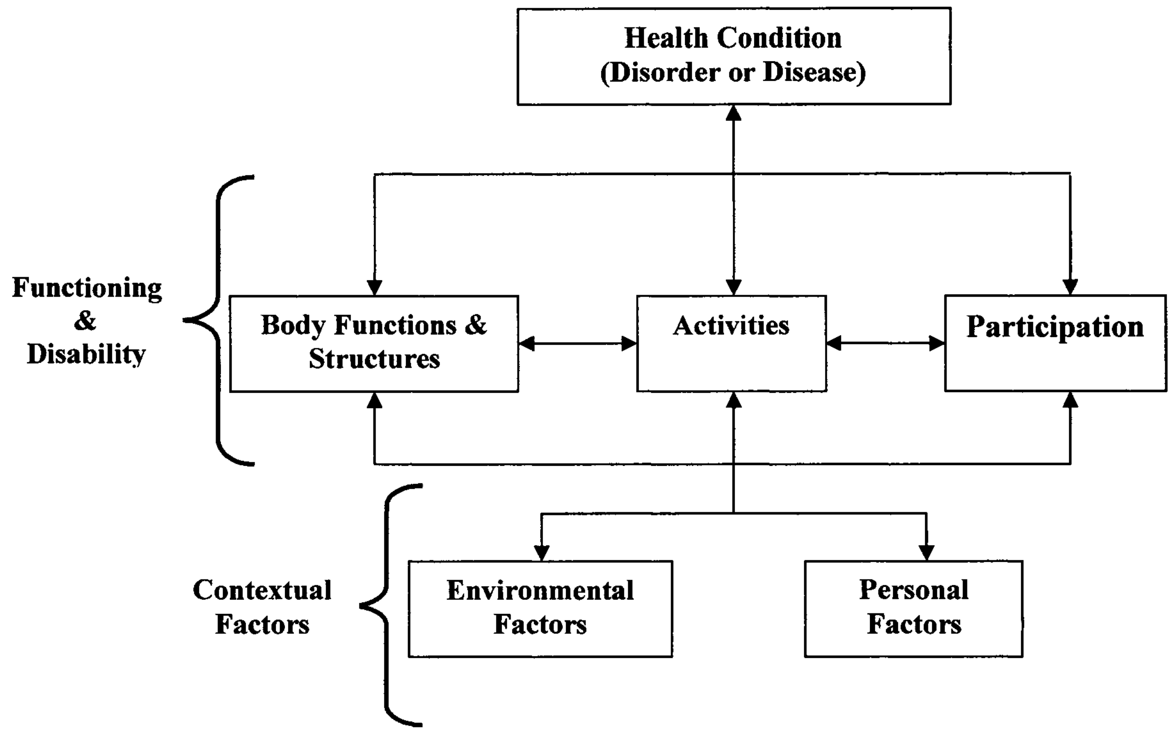

Figure 5.1: Interactions between the components of the International Classification of Functioning, Disability and Health (World Health Organization 2001 p. 18)

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Table 5.1: Number and percent distribution of hospitalized traumatic brain injury cases for select demographic characteristics by Abbreviated Injury Scale for the Head (HAIS), Colorado Traumatic Brain Injury Registry and Follow-up System, Colorado, 1998-1999 (n = 1,802)

Characteristics	**Mild TBI (HAIS 1& 2)**	**Moderate TBI (HAIS 3 & 4)**	**Severe TBI (HAIS 5 & 6)**	**Total (HAIS 1 – 6)**	**Chi-Square Value§**
Demographic	**(n = 590) (32.8%)**	**(n = 814) (45.2%)**	**(n = 398) (22.0%)**	**(n = 1802) (100%)**	
Sex					
Male	406 (68.8)	572 (70.2)	284 (71.5)	1282 (70.0)	
Female	184 (31.2)	242 (29.8)	114 (28.5)	540 (30.0)	0.9
Age Groups					
16-24	193 (32.7)	216 (26.5)	102 (25.7)	511 (28.3)	
25-44	226 (38.3)	275 (33.7)	142 (35.7)	643 (35.7)	
45-64	105 (17.8)	187 (23.0)	59 (14.8)	351 (19.5)	
≥65	66 (11.2)	136 (16.8)	95 (23.8)	297 (16.5)	17.7*
Race					
White	494 (83.7)	652 (80.2)	295 (74.3)	1441 (80.0)	
Non-White†	24 (4.1)	23 (2.7)	28 (6.8)	75 (4.0)	4.3*
Unknown	72 (12.2)	139 (17.1)	75 (18.9)	286 (16.0)	
Ethnicity					
Non-Hispanic	372 (63.0)	427 (52.5)	236 (59.2)	1035 (57.4)	
Hispanic	84 (14.4)	95 (11.7)	51 (12.9)	230 (12.8)	0.05
Unknown	133 (22.6)	292 (35.8)	111 (27.9)	536 (29.8)	
Insurance					
Private	85 (14.4)	105 (13.0)	60 (15.0)	250 (13.9)	
Government	37 (6.3)	62 (7.6)	65 (16.4)	164 (9.1)	7.9*
Other^J^	0 (0.0)	11 (1.3)	2 (0.6)	13 (0.7)	
Unknown	468 (79.3)	636 (78.1)	271 (68.0)	1375 (76.3)	
Education					
High School Diploma/GED‡	262 (44.4)	393 (48.3)	203 (51.0)	858 (47.6)	
College+	328 (55.6)	418 (51.3)	190 (47.5)	936 (52.0)	5.32*
Unknown	0 (0.0)	3 (0.4)	5 (1.5)	8 (0.4)	
Survey by Proxy					
No	359 (60.7)	540 (66.3)	228 (57.3)	1126 (62.5)	
Yes	9 (1.6)	42 (5.2)	71 (17.7)	122 (6.8)	78.6*
Unknown	222 (37.7)	232 (28.5)	100 (25.0)	554 (30.7)	
Rehabilitation					
No	560 (95.0)	630 (77.0)	190 (47.7)	1380 (76.0)	278.8*
Yes	30 (5.0)	184 (23.0)	208 (52.3)	422 (24.0)	

§Unknown categories were excluded from Mantel-Haenszel Chi-Square calculations
*Statistically Significant (p-value <0.05) differences between AIS groups
†Non-white includes all other races
‡High School Diploma/GED category includes individuals with less than a high school degree
^J^Other includes no charge for services, self-pay, and other insurance
+College includes individuals who had trade-school experience, college, and graduate education

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Table 5.2: Number and percent distribution of hospitalized traumatic brain injury cases for select pre-injury and diagnostic variables by Abbreviated Injury Scale for the Head, Colorado Traumatic Brain Injury Registry and Follow-up System, Colorado, 1998-1999 (n =1,802).

Characteristics	**Mild TBI (HAIS 1& 2)**	**Moderate TBI (HAIS 3 & 4)**	**Severe TBI (HAIS 5 & 6)**	**Total (HAIS 1 – 6)**	**Chi-Square Value[§]**
	(n = 590) (32.8%)	**(n = 814) (45.2%)**	**(n = 398) (22.0%)**	**(n = 1802) (100%)**	
History of Neurological Pathology (seizure/stroke)					
No	590 (34.0)	772 (44.4)	376 (21.6)	1738 (96.4)	
Yes	0 (0.0)	40 (64.0)	22 (36.0)	64 (3.50)	26.2*
Unknown	0 (0.0)	2 (100.0)	0 (0.0)	2 (0.1)	
History of Psychiatric Disorder or Drug Abuse					
No	521 (32.1)	735 (45.4)	366 (22.5)	1622 (90.0)	
Yes	69 (39.0)	76 (43.0)	32 (18.0)	177 (9.8)	3.7*
Unknown	0 (0.0)	3 (100.0)	0 (0.0)	3 (0.2)	
History of Learning Disability					
No	521 (32.0)	739 (45.5)	366 (22.5)	1626 (90.2)	
Yes	67 (40.0)	71 (41.5)	32 (18.5)	170 (9.4)	3.4
Unknown	2 (29.0)	4 (71.0)	0 (0.0)	6 (0.4)	
Length of Stay					
0 – 2 Days	339 (57.3)	245 (30.0)	39 (9.8)	623 (34.5)	
3 – 5 Days	182 (30.8)	254 (31.2)	95 (23.9)	531 (29.5)	
≥ 6 Days	69 (11.9)	315 (38.8)	264 (66.3)	648 (36.0)	360.8*
Prior TBI					
No	568 (96.3)	782 (96.1)	376 (94.4)	1726 (95.8)	
Yes	22 (3.7)	24 (2.9)	13 (3.4)	59 (3.3)	0.11
Unknown	0 (0.0)	8 (1.0)	9 (2.2)	17 (0.9)	
Radiological Test Result					
Normal	543 (92.0)	184 (22.5)	13 (3.3)	740 (41.0)	
Abnormal	11 (1.9)	610 (75.0)	380 (95.5)	1001 (55.5)	934.5*
Unknown	36 (6.1)	20 (2.5)	5 (1.2)	61 (3.5)	
Hospital Discharge Disposition					
Home	587 (99.5)	763 (94.0)	378 (95.0)	1728 (95.8)	
Facility	0 (0.0)	41 (5.0)	17 (4.4)	58 (3.3)	18.4*
Unknown	3 (0.5)	10 (1.0)	3 (0.6)	16 (0.9)	

[§]Unknown categories were excluded from Mantel-Haenszel Chi-Square calculations
*Statistically Significant (p-value <0.05) differences between AIS groups

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Table 5.3: Characterization and statistical significance* of traumatic brain injury outcome measures by Abbreviated Injury Scale for the Head, Colorado Traumatic Brain Injury Registry and Follow-up System, Colorado, 1998-1999

Outcomes	**Mild TBI (HAIS 1& 2)**	**Moderate TBI (HAIS 3 & 4)**	**Severe TBI (HAIS 5 & 6)**	**Total (HAIS 1 – 6)**
	(n = 590) (32.8%)	**(n = 814) (45.2%)**	**(n = 398) (22.0%)**	**(n = 1802) (100%)**
Alertness Behavior Subscale				
Mean (Standard Deviation)	27.1 (70.0)	32.7 (54.8)	33.1 (53.0)	31.6 (32.1)
Activities of Daily Living+				
Aid Needed	32 (5.5)	126 (15.5)	111(28.0)	269 (15.0)
No Aid Needed	556 (94.1)	686 (84.3)	285 (71.5)	1527 (84.7)*
Unknown	2 (0.4)	2 (0.2)	2 (0.5)	6 (0.3)
Instrumental Activities of Daily Living†				
Aid Needed	63 (10.6)	166 (20.4)	147 (36.8)	376 (20.8)
No Aid Needed	525 (88.9)	646 (79.4)	249 (63.0)	1420 (78.8)*
Unknown	2 (0.5)	2 (0.2)	2(0.2)	6 (0.4)
CHART – SF				
Diminished Participation (<450)	475 (80.0)	580 (71.3)	226 (57.0)	1281 (71.1)
No Diminished Participation (≥ 450)ʃ	115 (20.0)	234 (28.7)	171 (43.0)	521 (28.9)*

*Mantel – Haenszel Chi-Square (p<0.0001) – unknowns excluded

+Activities of Daily Living – needing help with one or more of the following activities: bathing/showering, dressing, eating, getting in and out of a bed or chair, walking, and, toileting.

†Instrumental Activities of Daily Living – needing help with one or more of the following activities: preparing meals, shopping for grocery or personal items, and managing money.

ʃCraig Handicap Assessment and Reporting Technique – Short Form scores ≥ 450 indicate the same level of participation as observed in a non-disabled person.

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Table 5.4: Adjusted† odds ratios and 95% confidence intervals obtained from Logistic regression models one-year following traumatic brain injury by World Health Organization (WHO) ICF° Activity and Participation Domains, Colorado Traumatic Brain Injury Registry and Follow-up System, Colorado, 1998-1999.

DOMAINS	**ACTIVITY**	**ACTIVITY**	**PARTICIPATION**
MODEL CHARACTERISTICS	**Activities of Daily Living†§ (N=857)**	**Instrumental Activities of Daily Living †§ (N=857)**	**Craig Handicap Assessment & Reporting Technique Short Form†§ (N=1,253)**
HAIS Groups			
HAIS 1&2 (Mild TBI)	**Referent**	**Referent**	**Referent**
HAIS 3&4 (Moderate TBI)	5.04 (1.67, 15.6)	1.90 (1.01, 3.57)	1.72 (1.18, 2.51)
HAIS 5&6 (Severe TBI)	4.08 (1.29, 12.7)	1.62 (0.81, 3.26)	1.58 (1.01, 2.47)
Age Groups			
16-24	**Referent**	**Referent**	**Referent**
25-44	1.49 (0.48, 4.61)	0.68 (0.36, 1.29)	1.11 (0.74, 1.66)
45-64	14.8 (5.25, 41.7)	1.97 (1.05, 3.71)	1.80 (1.15, 2.84)
≥65	19.8 (6.84, 57.2)	12.9 (6.43, 25.9)	12.9 (8.23, 20.2)
Race			
White	**Referent**	**Referent**	
Non-White†	0.07 (0.02, 0.37)	0.11 (0.03, 0.42)	
Hispanic Ethnicity			
Non-Hispanic	**Referent**		**Referent**
Hispanic	0.67 (0.29, 1.58)	1.11 (0.60, 2.05)	2.19 (1.51, 3.18)
Education			
College†	**Referent**	**Referent**	
High School Diploma/GED‡	4.86 (2.56, 9.21)	1.71 (1.05, 2.76)	2.68 (1.96, 3.66)
Survey by Proxy			
No	**Referent**	**Referent**	
Yes	15.7 (6.45, 38.5)	7.20 (3.03, 17.1)	
Neurological Disorder Pathology			
No	**Referent**	**Referent**	**Referent**
Yes	5.84 (1.91, 17.9)	4.13 (1.63, 10.50)	4.68 (1.98, 11.1)
Psychiatric/Drug Use Pathology			
No		**Referent**	
Yes		3.44(1.87, 6.34)	
Learning Disability Pathology			
No			**Referent**
Yes			3.45 (2.18, 5.45)
Length of Stay			
0 – 2 Days		**Referent**	**Referent**
3 – 5 Days		0.86 (0.45, 1.68)	0.77 (0.52, 1.15)
≥ 6 Days		2.28 (1.19, 4.38)	1.91 (1.27, 2.86)
Prior TBI			
No	**Referent**		
Yes	3.98 (0.88, 17.8)		
Rehabilitation			
No	**Referent**	**Referent**	**Referent**
Yes	4.53 (2.39, 8.59)	3.01 (1.79, 5.04)	1.87 (1.28, 2.75)

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† Controlling for all other variables in the model
° International Classification of Function and Disability and Health
+Activities of Daily Living – needing help with one or more of the following activities: bathing/showering, dressing, eating, getting in and out of a bed or chair, walking, and, toileting.
†Instrumental Activities of Daily Living – needing help with one or more of the following activities: preparing meals, shopping for grocery or personal items, and managing money.
ʃCraig Handicap Assessment and Reporting Technique – Short Form scores ≥ 450 indicate the same level of participation as observed in a non-disabled person.
§ Hosmer-Lemeshow Goodness of Fit Tests: ADL ($p = 0.68$); IADL ($p = 0.41$); CHART ($p=0.11$)
Receiver Operating Characteristic Curves: ADL ($c = 0.91$); IADL ($c = 0.84$); CHART ($c = 0.79$)
†Non-white includes all other races
‡High School Diploma/GED category includes individuals with less than a high school degree
+College includes individuals who had trade-school experience, college, and graduate education

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Table 5.5: Adjusted† odds ratios and 95% confidence intervals obtained from Logistic regression models for individuals that attended rehabilitation within one-year following traumatic brain injury by World Health Organization ICF° Activity and Participation Domains, Colorado Traumatic Brain Injury Registry and Follow-up System, Colorado, 1998-1999.

LOGISTIC REGRESSION MODELS FOR PATIENTS THAT ATTENDED REHABILITATION			
DOMAINS	**ACTIVITY**	**ACTIVITY**	**PARTICIPATION**
MODEL CHARACTERISTICS	**Activities of Daily Living†§ (N=857)**	**Instrumental Activities of Daily Living †§ (N=857)**	**Craig Handicap Assessment & Reporting Technique Short Form †§ (N=1,253)**
HAIS Groups			
HAIS 1&2 (Mild TBI)	**Referent**	**Referent**	**Referent**
HAIS 3&4 (Moderate TBI)	0.27 (0.04, 1.96)	1.68 (0.19, 14.3)	5.52 (0.91, 33.5)
HAIS 5&6 (Severe TBI)	0.16 (0.02, 1.42)	1.79 (0.22, 14.8)	13.3 (2.09, 84.4)
Age Groups			
16-24	**Referent**	**Referent**	**Referent**
25-44	1.35 (0.21, 8.60)	0.86 (0.23, 3.30)	12.2 (4.48, 33.2)
45-64	11.4 (1.51, 85.6)	4.49 (1.05, 19.3)	12.2 (3.30, 45.1)
≥65	90.2 (9.94, 819)	--------------	257 (52.9, >999)
Race			
White	**Referent**	**Referent**	
Non-White†	--------------	0.18 (0.02, 1.35)	
Hispanic Ethnicity			
Non-Hispanic	**Referent**		**Referent**
Hispanic	0.91 (0.18, 4.61)	0.28 (0.48, 1.82)	1.78 (0.67, 4.71)
Education			
College†	**Referent**	**Referent**	
High School Diploma/GED‡	4.70 (1.29, 16.9)	1.01 (0.32, 3.22)	5.19 (2.26, 11.9)
Survey by Proxy			
No	**Referent**	**Referent**	
Yes	60.1 (9.11, 396)	--------------	
Neurological Disorder Pathology			
No	**Referent**	**Referent**	**Referent**
Yes	3.72 (0.34, 41.3)	7.33 (1.17, 45.6)	5.92 (0.96, 36.4)
Psychiatric/Drug Use Pathology			
No		**Referent**	
Yes		41.3 (5.25, 323)	
Learning Disability Pathology			
No			**Referent**
Yes			0.75 (0.24, 2.38)
Length of Stay			
0 – 2 Days		**Referent**	**Referent**
3 – 5 Days		--------------	1.44 (0.27, 7.78)
≥ 6 Days		--------------	7.09 (1.68, 29.9)
Prior TBI			
No	**Referent**		
Yes	-------------		

† Controlling for all other variables in the model
° International Classification of Function and Disability and Health

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+Activities of Daily Living – needing help with one or more of the following activities: bathing/showering, dressing, eating, getting in and out of a bed or chair, walking, and, toileting.
†Instrumental Activities of Daily Living – needing help with one or more of the following activities: preparing meals, shopping for grocery or personal items, and managing money.
|Craig Handicap Assessment and Reporting Technique – Short Form scores ≥ 450 indicate the same level of participation as observed in a non-disabled person.
§ Hosmer-Lemeshow Goodness of Fit Tests: ADL ($p = 0.05$); IADL ($p = 0.95$); CHART ($p=0.06$)
Receiver Operating Characteristic Curves: ADL ($c = 0.94$); IADL ($c = 0.85$); CHART ($c = 0.87$)
†Non-white includes all other races
‡High School Diploma/GED category includes individuals with less than a high school degree
+College includes individuals who had trade-school experience, college, and graduate education

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Table 5.6: Adjusted† odds ratios and 95% confidence intervals obtained from Logistic regression models for individuals that did not attend rehabilitation one-year following traumatic brain injury by World Health Organization ICF° Activity and Participation Domains, Colorado Traumatic Brain Injury Registry and Follow-up System, Colorado, 1998-1999.

LOGISTIC REGRESSION MODELS FOR PATIENTS THAT DID NOT ATTEND REHABILITATION			
DOMAINS	**ACTIVITY**	**ACTIVITY**	**PARTICIPATION**
MODEL CHARACTERISTICS	**Activities of Daily Living†§ (N=683)**	**Instrumental Activities of Daily Living †§ (N=857)**	**Craig Handicap Assessment & Reporting Technique Short Form†§ (N=1,253)**
HAIS Groups			
HAIS 1&2 (Mild TBI)	**Referent**	**Referent**	**Referent**
HAIS 3&4 (Moderate TBI)	8.62 (1.94, 38.3)	2.38 (1.21, 4.69)	1.85 (1.24, 2.75)
HAIS 5&6 (Severe TBI)	7.89 (1.58, 39.3)	0.94 (0.39, 2.21)	1.11 (0.65, 1.89)
Age Groups			
16-24	**Referent**	**Referent**	**Referent**
25-44	0.95 (0.11, 7.83)	0.46 (0.18, 1.15)	0.52 (0.31, 0.87)
45-64	22.3 (5.05, 99.1)	1.66 (0.77, 3.56)	1.23 (0.74, 2.05)
≥65	26.7 (5.82, 122)	20.5 (8.81, 47.9)	9.43 (5.70, 15.5)
Race			
White	**Referent**	**Referent**	
Non-White†	0.16 (0.01, 1.87)	1.73 (0.30, 9.95)	
Hispanic Ethnicity			
Non-Hispanic	**Referent**		**Referent**
Hispanic	0.44 (0.13, 1.50)	1.33 (0.65, 2.75)	2.03 (1.33, 3.10)
Education			
College†	**Referent**	**Referent**	
High School Diploma/GED‡	5.64 (2.47, 12.8)	1.82 (0.99, 3.33)	2.29 (1.58, 3.23)
Survey by Proxy			
No	**Referent**	**Referent**	
Yes	4.82 (1.42, 16.3)	2.09 (0.71, 6.21)	
Neurological Disorder Pathology			
No	**Referent**	**Referent**	**Referent**
Yes	13.2 (2.36, 73.4)	5.16 (1.45, 18.4)	3.81 (1.22, 11.8)
Psychiatric/Drug Use Pathology			
No		**Referent**	
Yes		3.74 (1.77, 7.90)	
Learning Disability Pathology			
No			**Referent**
Yes			5.22 (3.12, 8.72)
Length of Stay			
0 – 2 Days		**Referent**	**Referent**
3 – 5 Days		0.73 (0.37, 1.44)	0.75 (0.49, 1.14)
≥ 6 Days		1.12 (0.53, 2.36)	1.75 (1.12, 2.75)
Prior TBI			
No	**Referent**		
Yes	14.0 (2.38, 83.7)		

† Controlling for all other variables in the model
° International Classification of Function and Disability and Health

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+Activities of Daily Living – needing help with one or more of the following activities: bathing/showering, dressing, eating, getting in and out of a bed or chair, walking, and, toileting.
†Instrumental Activities of Daily Living – needing help with one or more of the following activities: preparing meals, shopping for grocery or personal items, and managing money.
'Craig Handicap Assessment and Reporting Technique – Short Form scores ≥ 450 indicate the same level of participation as observed in a non-disabled person.
§ Hosmer-Lemeshow Goodness of Fit Tests: ADL (p = 0.94); IADL (p = 0.82); CHART (p=0.10)
Receiver Operating Characteristic Curves: ADL (c = 0.91); IADL (c = 0.83); CHART (c = 0.78)
†Non-white includes all other races
‡High School Diploma/GED category includes individuals with less than a high school degree
+College includes individuals who had trade-school experience, college, and graduate education

Table 5.7: Linear regression analysis of factors associated with the Alertness Behavior Subscale of the Sickness Impact Profile among individuals with Traumatic Brain Injury, Colorado Traumatic Brain Injury Registry and Follow-up System, Colorado, 1998-1999 (n = 1,802).

Characteristic	**Standardized Coefficient & P-value**
HAIS Groups	
HAIS 1&2 (Mild TBI)	**Referent**
HAIS 3&4 (Moderate TBI)	10.6 (p = 0.025)*
HAIS 5&6 (Severe TBI)	13.2 (p = 0.019)*
Age Groups	
16-24	**Referent**
25-44	11.0 (p = 0.032)*
45-64	10.4 (p = 0.081)*
≥65	6.26 (p = 0.420)
Hispanic Ethnicity	
Non-Hispanic	**Referent**
Hispanic	9.19 (p = 0.133)
Education	
College+	**Referent**
High School Diploma/GED‡	4.49 (p = 0.315)
Survey by Proxy	
No	**Referent**
Yes	-26.3 (p = 0.412)
Psychiatric/Drug Use Pathology	
No	**Referent**
Yes	-47.6 (p = 0.070)*
Learning Disability Pathology	
No	**Referent**
Yes	69.9 (p = 0.009)*
F-Test Statistic = 2.95 (p = 0.001)	
R^2 Value = 0.123	

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CHAPTER 6

SUMMARY OF STUDY RESULTS

The epidemiology of TBI has been characterized and risk factors for sustaining a traumatic brain injury have been identified; however, less is known about outcomes following TBI. This is most likely due to the difficulties in collecting prospective data, such as study costs and attrition. One study that successfully identified one-year outcomes following TBI was the Colorado (CO) Traumatic Brain Injury Registry and Follow-up System (CTBIRFS). Working in conjunction with the CO TBI surveillance system at the Colorado Department of Public Health and Environment (CDPHE), the CTBIRFS identified and followed TBI individuals in CO from 1996 – 1999. The objective of this study was to use data from the CTBIRFS and the CO TBI Surveillance system to expand upon the literature regarding outcomes following TBI. Specifically, the purpose of this study was to increase understanding of the Abbreviated Injury Scale for the head (HAIS) – an anatomical scoring system that potentially could be a predictor for one-year outcomes following TBI. Thus, the specific aims of this study were to 1) to describe the intra-rater agreement of HAIS scores by having a trained coder employed by the CDPHE recode HAIS scores for traumatic brain injured cases from the CO TBI surveillance system for years 1999-2000; 2) to describe the inter-rater agreement of HAIS scores by comparing HAIS scores from cases in the CO TBI surveillance system

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for years 1998-2000 to HAIS scores from trauma registrars at hospitals throughout CO; and, 3) to use HAIS scores to evaluate functional outcomes of TBI individuals in CO who were enrolled between 1998 and 1999 in the CTBIRFS.

To assess both intra-rater and inter-rater agreement, data from both the CTBIRFS and the CO TBI surveillance system were used. To assess intra-rater agreement, a sub-sample of the sampled records for years 1999-2000 were selected and recoded and scores from the original HAIS were compared to recoded HAIS scores to determine the agreement based on coding by the same individual. To assess inter-rater agreement, HAIS scores from the sampled cases in the CO Traumatic Brain Injury Surveillance system were used to compare HAIS scores from TBI cases in the CO Trauma Registry for years 1998-2000. The CO Trauma Registry is a population-based statewide mandatory reporting system of trauma cases (including traumatic brain injury) from all hospitals in CO. To determine inter-rater agreement, Trauma Registry records were linked to CO Traumatic Brain Injury Surveillance system records by name and date of birth and sampled cases from the CO Traumatic Brain Injury Surveillance system were used to compare to HAIS scores for the same case derived from trauma registry personnel.

The results of the intra- and inter-rater study found almost perfect intra-rater agreement and substantial inter-rater reliability of HAIS scores among hospitalized TBI cases in CO, 1998 – 2000. Inter-rater agreement was associated with head injury severity, the more severe the TBI, the more difficult it was to provide a reliable HAIS score. Factors that may explain the observed differences between coders included differences among trauma registrars in regards to education and training, experience, use

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and knowledge of database systems, and multiple individuals entering data. Injury factors that may influence agreement include multi-system trauma, pharmaceutical drug usage, and use of personal protective equipment such as helmets. These factors would have been important for identifying their effect on inter-rater agreement of HAIS scores, but they are often not routinely collected or reported by acute care facilities. Lastly, medical record documentation factors such as radiological results, history and physical reports, and inaccurate hospital documentation may directly influence inter-rater agreement. Future studies are needed to identify factors associated with HAIS scoring variability among TBI individuals with severe head injury. Further, replication of this study using the newer version, AIS-05, is needed to identify if expansion of head injury descriptors increases overall intra- and inter-rater agreement.

Data from the CTBIFRS (1998 – 1999) was used to evaluate the predictive ability of HAIS in determining functional outcomes following TBI. Outcomes of interest included measures at the organ, individual, and societal levels. To better understand the role of HAIS in predicting one-year outcomes, outcome data from the CTBIFRS were used to assess the predictive ability of HAIS while adjusting for known morbidity and mortality risk factors such as age and sex.

The results of this study indicate that HAIS is a good predictor of function and disability at the individual and societal levels, but the model assessing the organ level failed to predict disability. Assessing quality of life, both pre-injury and post-injury factors were associated with poor physical and mental health one year after hospital discharge with TBI. The identification of important potential confounders such as age, education status, and prior history of a neurological pathology help to identify which

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individuals will be in need of aid following a TBI. To reduce the burden of injury among TBI individuals, clinicians and rehabilitation experts must work together to identify individuals in need of tertiary prevention to improve the quality of life for these individuals. Further, as a society, we need to identify barriers to rehabilitation such as resource availability and cost in order to improve the life of those affected by TBI.

The results of these studies contribute to the body of knowledge regarding TBI outcomes because they are the first of their kind to test for associations between HAIS and one-year outcomes following TBI. These studies lend credence to the usage of the HAIS. In particular, this study found that individuals with moderate to severe brain injury are in need rehabilitation following a TBI. The field of TBI rehabilitation is a new one and future studies are needed to identify barriers to rehabilitation, such as cost and access to care, and to assess the role of rehabilitation on quality of life following TBI.

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