A SECONDARY ANALYSIS TO INFORM A CLINICAL DECISION RULE FOR PREDICTING SKULL FRACTURE AND INTRACRANIAL INJURY IN CHILDREN UNDER AGE TWO

by

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The purpose of the current study was to identify the variables associated with the risk of closed head injury (CHI) in children under age two with suspected *minor* head injuries based on age-appropriate, or near age-appropriate, mental status on exam, as defined by a Glascow Coma Score (GCS) of 15 or 14, respectively. The goal was to propose a set of variables that, when considered together, have a high degree of predictive accuracy in identifying CHI in this population. This set of variables could eventually be used to inform a clinical decision rule which may help triage nurses make acuity decisions in a more evidence-based manner. The study was guided by Donabedian's Structure, Process, Outcome model that allows for the assessment of the various factors that inform and influence the ED triage process.

The current study was a secondary data analysis of the public-use dataset from the largest prospective, multi-center pediatric head injury study found in the current literature. As part of the secondary analysis, an existing clinical decision rule by Greenes and Schutzman (2001) (Greenes and Schutzman Risk Scoring System [the Scalp Score]), was examined using a sample of 3,329 children under age two to determine whether it, or the individual variables within it, could be utilized alone, or in conjunction with other variables to accurately predict the risk of underlying CHI in this population.

In consideration of the factors related to best practice for clinical decision rule development, the optimal set of variables for a clinical decision rule to predict CHI in

children under age two would include the following variables: age in months, a composite variable representing hematoma presence/size, and location; and severity of injury mechanism. An evidence-based, nurse-driven clinical decision rule designed as a risk scoring system could serve to improve the "structure" of ED triage. Such a resource could influence the "process" of the triage assessment and acuity assignation to be more accurate, ultimately also optimizing the primary "outcome" of triage accuracy for children under age two with CHIs. Such a tool could help overcome inconsistencies in triage acuity decisions due to variation in knowledge, thereby improving triage accuracy and consistency for children under age two who present for evaluation of suspected minor head injuries. The results of this study could also be used to inform more age-specific recommendations for children under age two in triage and educational resources and in national trauma criteria.

The findings from this study add to the body of knowledge regarding what variables are, and are not, associated with CHI in children under age two with suspected minor head injuries. The key to an accurate triage assessment for children under age two with suspected minor head injuries includes familiarity with the main regions of the skull, being able to assess for the presence and size of any scalp hematoma and having access to accurate information regarding the child's age and the details of the injury mechanism.

Dedicated to my first nurse scientist mentor, and dear friend,
Dr. Elizabeth “Betty” K. Woodard

APPROVAL PAGE

This dissertation, written by Elizabeth L. Stone, has been approved by the following committee of the Faculty of The Graduate School at The University of North Carolina at Greensboro.

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CHAPTER I

INTRODUCTION

In most western countries, whether a patient arrives ambulatory or by ambulance, once they enter an emergency department (ED) they are usually subject to triage prior to being seen by a medical provider (a physician, physician's assistant, or a nurse practitioner). The term *triage*, which means "to sort," was originally used in the 1700s to refer to the organization of patient care in mass casualty situations (Robertson-Steel, 2006). The term was later adopted by the healthcare profession to refer to the process that takes place when the first healthcare professional, typically a registered nurse, prioritizes patients presenting to an ED for care. The triage nurse's acuity, or risk level, decision is the major factor that determines which patients are examined by a medical provider first versus which other patients must wait to be seen (Gilboy, Tanabe, Travers, Rosenau, & Eitel, 2012). For these reasons, the ED triage nurse is often considered the gatekeeper of the ED.

Emergency Department Triage

The ED triage nurse is tasked with conducting a focused initial patient assessment based on the patient's chief complaint; obtaining a history including pertinent subjective and objective data; assigning an acuity, or risk, level to the patient based on a valid and reliable triage scale; implementing appropriate initial care according to established protocols, documenting relevant data, and communicating significant findings to healthcare team members (Stone & Wolf, 2017). Triage acuity decisions are typically made in time sensitive situations with limited data and are often influenced by external factors such as the number of patients, or degree of "crowding," in the ED (Stone & Wolf, 2017). When the ED is crowded, and several patients are waiting to be triaged, the triage nurse has the additional pressure to make more timely decisions so that, ideally, they can assess every patient in the waiting room before any patient deteriorates clinically.

The Triage Acuity Scale

The acuity level assigned by the ED triage nurse serves as a proxy measure for how long the patient can safely wait to be examined and treated by a medical provider, also known as the patient's risk of clinical deterioration (Gilboy et al., 2012). An accurate acuity level decision by the triage nurse can be crucial to expediting care and optimizing outcomes for a patient at high risk of clinical deterioration. Several validated triage scales are utilized globally by the triage nurse to sort and rank patients according to acuity, including the Emergency Severity Index (ESI), Manchester Triage Scale (MTS), Australian Triage Scale (ATS), and the Canadian Triage Acuity Scale (CTAS). The predominant acuity scale utilized in the United States at this time is the ESI (Worth, 2017). Regardless of the acuity scale utilized, or the order of the numbers used in the scale, "high acuity" refers to an urgent patient at high-risk for clinical deterioration, and "low acuity" refers to a non-urgent patient at low-risk for clinical deterioration.

According to the ESI Handbook, an acuity level of "1" represents a life-threatening or critical condition that should be treated immediately; "2" represents an emergent condition that should “get the next available bed,” and “3” through “5” represent less urgent conditions which are further differentiated by the number of expected resources needed to examine and treat the patient (Gilboy et al., 2012). While the ESI does not prescribe specific acceptable wait times for each acuity level, institution policies typically do. For example, ESI level 1 patients are generally seen immediately, ESI level 2 patients are generally seen within 15-30 minutes of triage, and ESI level 3 through 5 patients may wait for several hours after triage to be seen by a medical provider. Some facilities have policies that instruct triage nurses to reassess patients who are waiting to be seen by a medical provider at regular intervals, but in a busy ED with limited resources, this may or may not always occur. When patients are left in a crowded ED waiting room, clinical deterioration can go undetected. In addition, some patients will leave without being seen by a medical provider.

Triage Accuracy

While there is no universal standard for defining, or measuring, triage accuracy (Ekins & Morphet, 2015; Hansoti et al., 2017), studies of triage accuracy typically define accuracy as the assignation of an appropriate acuity level to a patient based on the presenting complaint and clinical condition, utilizing a validated triage scale, such as ESI (Allen, Spittal, Nicolas, Oakley, & Freed, 2015; Bonsi et al., 2014; Brosinski, Riddell, & Valdez, 2017; Ekins & Morphet, 2015; Sanders & DeVon, 2016; Seiger, van Veen, Steyerberg, van der Lei, & Moll, 2013). Regardless of the illness or injury, the risk of unidentified clinical deterioration increases when the patient is in the waiting room for a prolonged time, especially when a high-risk condition was not properly identified by the triage nurse and the patient was assigned an inappropriately low, or non-urgent, acuity level. This can happen for example if the triage nurse is not aware of the variables that represent a moderate to high risk of CHI in children under age two, and can be compounded by the fact that many of these children remain clinically asymptomatic with only a scalp hematoma as an outward sign of the injury.

Inaccurate, or "Mis"-Triage

Two types of inaccurate triage, also referred to as "mis-triage," exist: over-triage and under-triage. Over-triage occurs when a patient is assigned a higher acuity level than what is deemed appropriate for the given presentation. This might happen, for example, if the triage nurse lacks experience in assessing injured infants and decides that "all infants who come to the ED after a head injury should be assigned an ESI-2 (urgent acuity level)" rendering more expedited triage care. However, an ESI-2 acuity level automatically being assigned might be inappropriate if the infant had sustained a witnessed, very low impact injury according to a validated resource (deeming a lower acuity level). Assigning that infant an inappropriately high ESI level would mean that the infant's care might be expedited at the expense of other patients who might have more serious illnesses or injuries. Emergency department resource allocation tends to be concentrated, at least initially, towards the patients assigned higher acuity levels often resulting in delays in care for other patients of high acuity that have to wait longer to be seen by a medical provider (Allen et al., 2015; Brosinski et al., 2017).

In contrast to the above situation, under-triage might occur if a patient arrives with subtle, or atypical, symptoms, inconsistent with textbook versions of an illness or injury. An example of under-triage would be if a two-month old who had fallen more than three feet from an unbuckled car-seat and was clinically asymptomatic were assigned a low acuity level such as ESI-4, representing a "non-urgent" status. In this situation, other patients who were assigned higher acuity levels would likely be taken to treatment rooms for medical assessments first and the infant may be left in the waiting room for hours awaiting a medical assessment. Under-triage can easily lead to delays in care for the patient assigned the inappropriately low acuity level (Allen et al., 2015; Brosinski et al., 2017). Under-triage has multiple impacts to the patient that can include the type of medical provider who eventually assesses them, delayed identification of illness or injury, delayed treatment, and poorer outcomes.

Impacts of mis-triage. Emergency department charge nurses rely largely on acuity levels assigned at triage to help them determine the order of patients they, or other staff members, take from the ED waiting room to treatment rooms to be seen by a medical provider. Some EDs have separate areas that are designated for the examination of patients assigned non-urgent acuity levels; these patients are often seen by physician assistants or nurse practitioners in order to reserve physicians' time with the more urgent patients. Regardless of where the patients are roomed in the ED for a medical examination, when several patients are in treatment rooms awaiting medical examinations, medical providers rely largely on acuity levels assigned by the triage nurse to prioritize which patient they should see first. Therefore the impact of the triage acuity decision on the patients can include, but is not limited to, the time they wait to be placed in a treatment room for an assessment by a medical provider, their treatment room placement within the ED, the type of medical provider that will assess them, and their ultimate health-related outcome if there are delays in needed care. If the acuity level assigned at triage does not accurately reflect the patient's risk level, a high-risk patient may wait several hours to be seen, or a low risk patient may be expedited to a medical assessment unnecessarily.

Mis-triage is a global problem which poses a significant threat to patient safety and outcomes (Ekins & Morphet, 2015; Stone & Wolf, 2017) and has implications for healthcare policy and funding when quality standards are tied to ED acuity levels (Allen et al., 2015). Mis-triage and its consequences have received increased attention since the 2000's when the Centers for Medicare and Medicaid Services began incentivizing institutions for improvements in healthcare quality and outcomes such as reduced delays in care. The CMS Hospital Outpatient Quality Reporting Program requires hospitals to submit specific data on their quality of care measures; if they fail to report the data as mandated, or fail to meet certain benchmarks, there is a financial penalty in the form of a reduced hospital payment (Centers for Medicare and Medicaid Services, 2018). Three quality measures that are required to be reported by EDs are: OP-18: Medium Time from ED Arrival to ED Departure for Discharged ED Patients; OP-20: Door to Diagnostic Evaluation by a Qualified Medical Professional; and OP-22: [Patients Who] Left Without Being Seen [by a Medical Provider]. The ED triage acuity decision could clearly have implications for all three of these ED quality measures, since the acuity level for each patient is the major factor guiding initial prioritization and care.

A study by Yurkova and Wolf (2011) examined the factors involved in delays in transfer of critically ill patients from the ED to the intensive care unit (ICU) of a community hospital in the U.S. Of 75 total charts reviewed, 44 (58.7%) of the patients spent over four hours in the ED prior to transfer to the ICU, which was considered "delayed status" per the study protocol (measured from time to triage to time to inpatient ICU bed). A significant negative correlation ($r = -.339$, $P = .004$) was demonstrated between a "delayed status" and an ESI designation of 3 (considered a non-urgent acuity level). In other words, patients assigned lower acuity scores experienced longer treatment delays. Patients with sepsis and female patients were more likely than patients with other conditions and of the male gender to be delayed; 11/17 patients (64.7%) diagnosed with sepsis were delayed, and a total of 70.4% of female patients were delayed, compared with 52.1% of male patients. A limitation of this study was that the reason for the "delays" in transfer were unclear. For instance, one might assume that the patients deemed to be the sickest were transferred first, and those deemed to be more stable were transferred last. The time of the admission (to ICU) decision was not reported by the authors. However, a key finding of Yurkova and Wolf (2011) supported a later point by Levin et al. (2018): The ESI level of 3, considered a "middle ground" acuity level, is frequently over-utilized in practice.

Complex and Ambiguous Triage Situations

Emergency department triage nurses utilize a combination of expert knowledge and gut instinct to identify high-risk situations (Gilboy et al., 2012). Unfortunately, not every high-risk situation is easy to identify. Researchers have demonstrated that certain patient populations such as with pediatric patients (Escobar & Morris, 2016; Griffin, Lippmann, Travers, & Woodard, 2014), children with chronic illnesses (Seiger et al., 2013), females, and the elderly with acute myocardial infarction (Atzema, Austin, Tu, & Schull, 2010; Ryan et al., 2016) are particularly challenging to triage due to atypical or subtle presentations for more acute or life-threatening conditions. High risk conditions, such as acute myocardial infarction (Atzema et al., 2010) and sepsis (Frazier et al., 2015), which are known for their sometimes-subtle presentations, are often the subjects of accuracy studies due to international interest in early identification of these conditions to support optimal patient outcomes. The development and use of clinical decision support systems, such as nurse-driven clinical decision rules or risk assessment tools, for such conditions or populations could contribute to improving triage accuracy in these patients.

The triage of pediatric patients (age 0 to 17 years), requires knowledge of normal growth and development as well as any anatomical, physiological, and developmental characteristics unique to each major age group within the specialty population. Pediatric triage also requires the ability to obtain a pertinent and thorough history from the parent or caregiver, since many pediatric patients are unable to provide complete information first-hand. In addition to having atypical or subtle presentations for high-risk situations, children under age two can be especially difficult to triage due to the fact that they have limited verbal ability to explain what happened, a developmentally appropriate stranger anxiety, and a tendency to sleep more than older children. Thus, triage nurses often find themselves in the situation of evaluating ill or injured children who are anxious, crying, or very tired children with an illness or injury. These situations require a keen ability of the triage nurse to differentiate concerning signs and symptoms from expected “normal” pediatric behaviors.

Head Injury Triage in Children Under Age Two

Children under age four represent approximately 10% of overall ED visits in the U.S. (Rui, Kang, & Albert, 2014). In particular, this population sustains head trauma at a higher rate than any other age group (Quayle, 2014). Assessing suspected minor head injuries in children under age 2 and determining their risk of underlying skull fracture and/or intracranial injury based on their clinical presentation and the information available in triage is a specific challenge (Griffin et al., 2014). Consistent with the medical literature, children with suspected “minor head injuries” typically refers to children who appear “well” based on an age-appropriate or close to age-appropriate mental status on presentation to the ED.

Regardless of their method for arrival at the ED, children whose injuries meet national trauma criteria (Sasser, Hunt, & Faul, 2012) (Figure 1), based on mechanism or other factors, are excluded from the category of those with suspected *minor* head injuries. These children usually arrive via emergency medical services and are identified in the pre-hospital environment; they receive automatic “urgent” or “critical”- status acuity levels to reflect their high risk for serious injury and are not typically subjected to the traditional triage process prior to treatment.

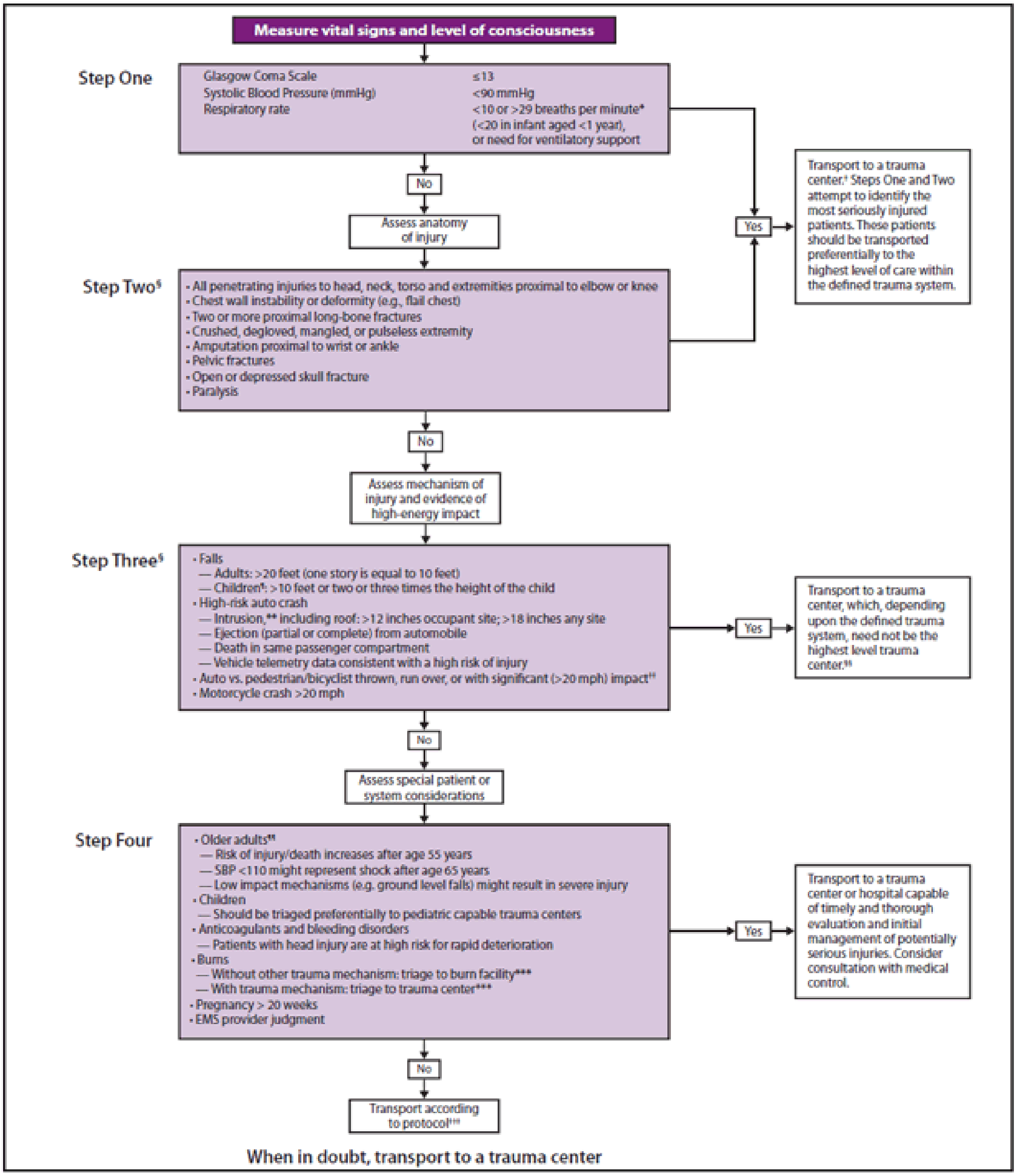


Figure 1. Guidelines for Field Triage of Injured Patients – United States, 2011. Source: Sasser, S., Hunt, R., & Faul, M. (2012). Guidelines for Field Triage of Injured Patients: Recommendations of the National Expert Panel on Field Triage. Morbidity and Mortality Weekly Report. *Recommendations and Reports, 61*(RR-1), 1–20. Retrieved from https://www.cdc.gov/mmwr/preview/mmwrhtml/rr6101al.htm

Due to several anatomical and physiological differences, children under age two are the most susceptible to underlying skull fracture and/or intracranial injury (also referred to as closed head injury [CHI]) secondary to suspected minor head trauma (Mahajan, 2014; Quayle, 2014; Powell et al., 2015; Shiomi, Hino, Hashimoto, & Yamaki, 2016). This age group is also the most difficult to assess of the pediatric population (Mahajan, 2014). In fact, many children under age two who sustain an underlying CHI are actually considered clinically asymptomatic (Bin, Schutzman, & Greenes, 2010; Griffin et al., 2014; Quayle, 2014).

Factors That Contribute to the Challenge

Due to developmental limitations, including limited, if any, verbal ability, classic head injury symptoms such as altered mental status, pain, and amnesia are difficult, if not impossible, to assess in children under age two. Most children under age two who present to triage for evaluation of a head injury act appropriately for their age, with few, if any, symptoms of injury other than a skull hematoma. Children under age two may appear sleepy, but this symptom may be confounded by their age because most nap regularly, which is more than other age groups. Injuries that are not witnessed and where incomplete information is available by the caregiver are often assessed based on estimates (e.g., height of fall).

Several factors contribute to the magnitude of the head injury assessment challenge: the time-pressured environment of the ED in which there are typically more patients then there are beds, less distinct symptoms exhibited by children under age two, a lack of awareness by the triage nurse of specific anatomical, physiological, and mechanism of head injury characteristics, and a lack of clinical decision rules specific to head injuries to guide the triage nurse's assessment. While several clinical decision rules developed for medical providers identify significant factors associated with the risk of underlying CHI in children under age two with suspected minor head injuries, the data have not been widely disseminated to the nursing profession (Griffin et al., 2014).

An Opportunity for Clinical Decision Support

The unique environment of the ED makes it fertile ground for unrecognized clinical deterioration, especially in patients with vague or atypical presentations for their illness or injury. Suggestions for more widespread use of clinical decision support systems, such as clinical decision rules embedded into the electronic health record and used by healthcare professionals in the ED, are abundant in the literature. In today's healthcare environment rich with accessible data and the latest evidence, it is increasingly suggested that clinical decision support systems be used to translate evidence into practice; this may be especially useful for certain "high risk" conditions that can be difficult to identify or assess such as acute coronary syndrome, sepsis, syncope, and pediatric head injuries. For example, Patel (Patel, Gutnik, Karlin, & Pusic, 2008) suggests that as medicine evolves, clinical decision support in the form of updated clinical guidelines easily accessible at the point of care in the ED could help mitigate inconsistencies in acuity ratings.

Purpose of the Study

The purpose of the current study was to identify the variables associated with the risk of CHI in children under age two with suspected *minor* head injuries based on age-appropriate, or near age-appropriate, mental status on exam. The goal was to propose a set of variables that, when considered together, have a high degree of predictive accuracy in identifying CHI in this population. This set of variables could eventually be used to inform a clinical decision rule designed as a risk scoring system which may help triage nurses make acuity decisions in a more evidence-based manner.

The current study was a secondary data analysis of the public-use dataset from the largest prospective, multi-center pediatric head injury study found in the current literature. As part of the secondary analysis, the *Clinical Scoring System to Assess the Risk of Skull Fracture*, an existing clinical decision rule by Greenes and Schutzman (2001), was tested using a sample of 3,329 children under age two to determine whether it, or the variables within it, could be utilized alone, or in conjunction with, other variables to accurately predict the risk of underlying CHI in this population. The initial validation study of this clinical scoring system was published by Bin et al. in 2010. It is important to note that the sample of 3,329 CT-imaged children used in the current study is considerably larger than the samples of 172 and 203 CT-imaged children used for the derivation study (Greenes & Schutzman, 2001) and validation study (Bin et al., 2010) of the clinical scoring system by Greenes and Schutzman (2001). The current study tested the performance of this existing clinical decision rule to determine how it would perform in the much larger sample.

Donabedian's Structure, Process, Outcome Model

Donabedian's *Structure, Process, Outcome* model (1988) has been used to describe the three categories of care involved in improving the quality of medical care.

This model has been adopted for use in many domains of healthcare. Donabedian's model was founded on the understanding that assessing the quality of care is a multidimensional and multifactorial process. The process should examine more than the performance of practitioners; also considering the contributions of patients and of the health care system. The model has been proposed as a framework that can be applied to clinical decision-making processes and healthcare process improvement initiatives (Cornwell, Chang, Phillips, & Campbell, 2003; Donabedian, 1988), including ED triage (Sammons, 2012). See Figure 2.

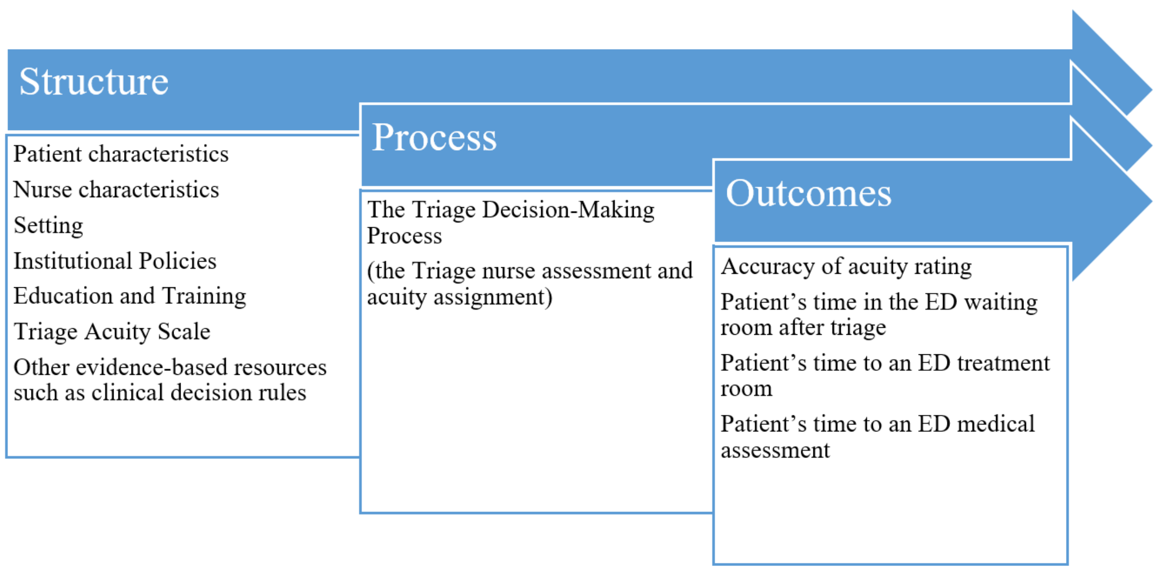


Figure 2. Model Representing Emergency Department Triage Framed within Donabedian's Model.

Applying Donabedian's Model to the current study. Framed within Donabedian's model (Figure 2), the triage acuity decision is the process that will ultimately influence the outcomes (the accuracy of the acuity decision being the primary outcome with additional outcomes that are influenced by its accuracy being the secondary outcomes). Secondary outcomes include, but are not limited to, the patient's time to medical assessment and treatment, their room placement within the ED, and their medical provider as well as their ultimate health-related outcome. Framed within Donabedian's model, the acuity rating system, such as ESI, and any clinical decision rule which helps to inform triage decisions, is be considered part of the structure of triage.

Chapter Summary

The purpose of the current study was to identify the variables associated with the risk of CHI in children under age two with suspected *minor* head injuries based on age-appropriate, or near age-appropriate, mental status on exam. The goal was to propose a set of variables that, when considered together, have a high degree of predictive accuracy in identifying CHI in this population. This set of variables could eventually be used to inform a clinical decision rule that may help triage nurses make acuity decisions in a more evidence-based manner. An evidence-based, nurse-driven assessment tool based on objective data (such as mechanism of injury, age of the child and skull region of injury—all validated risk factors for underlying CHI from the medical literature) may serve to improve the structure of ED triage. Such a resource could influence the "process" of the triage assessment and acuity assignation to be more accurate, ultimately also optimizing the primary outcome of triage accuracy for children under age two with CHIs. Such a tool could help overcome inconsistencies in triage acuity decisions due to variation in knowledge, thereby improving triage accuracy and consistency of triage decisions for children under age two who present with suspected minor head injuries.

CHAPTER II

LITERATURE REVIEW

Head injuries are a frequent reason for pediatric emergency department (ED) visits (Burns et al., 2016; Kuppermann et al., 2009), and children under age two account for approximately 25% of these visits (Dayan et al., 2014). While most children who present to the ED for evaluation of their head injury have not sustained an underlying skull fracture or intracranial injury (closed head injury [CHI]), identifying those who *may* have a CHI is important because secondary injuries such as increased bleeding or swelling of the brain are more likely to occur when primary injuries are not identified. Unlike many other injuries, CHIs cannot be identified by visual inspection alone.

Problem

Assessing the risk of an underlying CHI in a child under age two who has presented to the ED for evaluation of a head injury can be very challenging for nurses and medical providers alike, especially when the child is not yet verbal (Griffin, 2011; Griffin et al., 2014).

The Triage of Head Injuries in Children Under Age Two

Children under age two who have sustained suspected minor head injuries pose a major challenge to ED triage nurses. While the terminology and definitions for what is considered “minor head injury” vary within the literature and across studies, the definition used for the purposes of this paper is consistent with the definition used by

Kuppermann et al. (2009). "Minor head injury" refers to a head injury that occurred in the past 24 hours in a child with a Glascow Coma Score (GCS) of 14-15, indicating a fully appropriate (15) or just slightly altered (14) mental status on exam.

At the time of ED triage for children under age two with a suspected minor head injury, the variation in signs and symptoms for this age group and the challenges of assessing patients who are nonverbal or not fully verbal make risk stratification and acuity assignment difficult.

Purpose

The purpose of this paper was to review the literature for patient- and injury-specific variables that have been shown to be associated with underlying CHI in children under age two with suspected minor head injuries. This information may be used to help inform an ED triage clinical decision rule designed as a risk assessment tool for children under age two who present to the ED for evaluation of suspected *minor* head injuries. Children whose injuries meet national trauma criteria (Sasser et al., 2012), regardless of how they arrive to the ED and how well they appear, are not included in those considered to have "suspected minor head injuries," because national trauma criteria independently delineate the necessity of specialized, immediate care for patients who have sustained certain types of injuries known to carry high risks of loss to life or limb (Sasser et al., 2012).

Background

Secondary brain injury can occur for approximately 3 to 5 days following a single head trauma due to the brain's temporary state of increased vulnerability (Mahajan, 2014). Proper identification of the risk for underlying CHI at the point of triage, the point of the initial ED assessment and prioritization, helps reduce the risk of secondary injury while also aiding in the identification of inflicted injuries in children when the mechanism and injury characteristics do not clinically align (Quayle, 2014). Notably, children under age two are the most frequent victims of inflicted injury (Mahajan, 2014), and many of these children are brought to the ED with a false history of having fallen (Haney, Starling, Heisler, & Okwara, 2010). In children under age two, especially in those who are nonverbal, hidden injuries including some caused by physical abuse are more likely to be missed due to their age-appropriate developmental and physiological limitations.

Many children under age two who present to EDs for the evaluation of a suspected minor head injury are clinically asymptomatic, yet some of these children have sustained an underlying CHI (Bin et al., 2010; Griffin et al., 2014). Nationwide, about half of the children under age 2 who present to emergency departments (EDs) for evaluation of their head injury receive neuroimaging (e.g., computed tomography (CT) scan), of which approximately 10% have some degree of documented underlying CHI (Mahajan, 2014). Only about 1% of children under age two who have sustained a head injury will have an underlying CHI requiring a life-saving intervention; this increases to 4% for children of any age with altered mental status and/or a known skull fracture (Kuppermann et al., 2009).

Prior studies have shown that the risk of underlying CHI in a child under age two varies based on variables that include the child's age in months, the severity of the injury mechanism, the region of skull injured, and the presence and size of hematoma if present (Kuppermann et al., 2009; Bin et al., 2010; Burns et al., 2016). These risk factors are included in validated clinical decision rules created to help medical providers assess pediatric patients with a history of blunt head trauma, but the rules vary considerably in their terminology, the ages of their subjects, their outcomes of interest, and their overall aims. Most validated clinical decision rules are focused on guiding the neuroimaging decision and identifying injuries that require life-saving or surgical intervention. This focus may in large part be due to a global effort to reduce unnecessary CT scanning, which is known to be responsible for some radiation-induced malignancies in children (Burns et al., 2016; Dayan et al., 2014). None of the current clinical decision rules are designed to aid the ED triage nurse in their assessment or their acuity decision. This is a problem because the ED triage nurse is typically the first healthcare professional to assess patients who present to an ED for evaluation and is tasked with the initial prioritization of patient care.

The Goal of Triage

While some injuries are visible and obvious, injuries to the skull and brain are often difficult, if not impossible, to identify without radiographic imaging. When assessing children under age 2 with head injuries, one of the main goals of triage nurses is to identify which children are at a moderate to high risk of having sustained *any* underlying CHI from their injury. Those children with a moderate to high risk of having sustained underlying CHIs should be assigned acuity levels that reflect this risk so that their medical assessment and care, including radiographic imaging, can occur quickly, minimizing the risk of secondary injury and clinical deterioration.

The Triage Challenge

Emergency department triage nurses utilize a combination of expert knowledge and gut instinct to identify high-risk situations (Gilboy et al., 2012). Unfortunately, not every high-risk situation is easy to identify, and gut instinct can be wrong when the patient is a well-appearing child under age two. Pediatric patients are particularly challenging to triage due to often atypical or subtle presentations for high-risk situations (Escobar & Morris, 2016; Griffin et al., 2014); CHIs represent one of these high-risk situations. For example, the authors of one cohort study collected acuity level information for 200 head-injured children age 0-17 in one southeastern pediatric emergency department (Griffin et al., 2014). Of the 100 children who sustained a skull fracture and/or intracranial injury, only 42 (42%) were assigned an acuity level considered "accurate," indicating at least an "urgent" risk status, while most of the children who were considered clinically asymptomatic (20/35, 57%) were under age 2 (Griffin et al., 2014). The results of this study highlighted the fact that nurses who triage children need more evidence-based data at the point of care to help guide their assessments, risk stratification and acuity decisions for head injuries, especially for this age group.

Methods

A literature search was conducted on head injury assessment for children under age two. Databases used included PUBMED, CINAHL, The Cochrane Library, Web of

Science and Google Scholar. Primary keyword searches included pediatric head injury, assessment, triage, emergency department and nursing. Limits were placed to narrow the search to 2007-2017. However, an article by Greenes and Schutzman (2001) was included because it was an original derivation study for a clinical decision rule. Articles selected for final inclusion addressed head trauma in children under age two.

Results

Types of Head Injuries

Children under age four present to EDs in the United States for evaluation of head injuries at a higher rate than any other age group (CDC, 2016). Head injuries in young children are caused by accidents such as falls, motor vehicle crashes and unwitnessed injuries as well as by non-accidental trauma (such as by being shaken by a caregiver or other adult). These injuries include concussions (injuries not typically visible on CT scan, but which result in temporary changes in mental status) (CDC, 2016), as well as mechanical injuries such as skull fractures and intracranial bleeding which *are* visible on CT scan (referred to collectively as CHIs for the purposes of this paper). While some of these mechanical injuries resolve on their own with close observation and medical follow up, others lead to long term disability or death if not identified early.

Etiology of Head Injuries

Falls are the most common mechanism of head injuries for children assessed in EDs (Quayle, 2014; Hawley et al., 2013) and are responsible for up to 80% of head injuries in children under age two (Hawley et al., 2013; Powell et al., 2015). Common falls in children under age two include being dropped from a caregiver's arms, falling out of an unsecured car set, falling off a bed, and falling out of a shopping cart (Griffin et al., 2014; Haney et al., 2010). These common falls can range in height from less than three feet (for a typical bed or couch height) to over three feet (being dropped by an adult, falling out of a shopping cart, or falling off a changing table) (see Table 1). Some falls are unwitnessed, which may contribute to delays in seeking care.

Table 1

Average Heights of Common Falls in Children Under Age Two

Fall Surface	**Approximate Height in Inches/Feet**	**Approximate Height in Meters**
Sofa	18-20 inches (1.5 feet)	0.5 meter
Bed	18-36 inches (1.5 feet-3 feet)	0.5 – 1 meter
Changing Table	36-43 inches (3 feet – 3.5 feet)	0.5 – 1 meter
Counter	36 inches (3 feet)	1 meter
Shopping Carts	36-42 inches (3 feet – 3.5 feet)	0.5 – 1 meter
Caregiver's Arms	4-5 feet depending on height of the adult	1.2 meters – 1.5 meters

Severity of the Injury Mechanism

Head injuries in children that require medical or surgical intervention are most often caused by "severe" injury mechanisms, such as certain motor vehicle crashes (MVCs), bicycle accidents and assaults, including child abuse (Quayle, 2014). Many of the children with these life-threatening injuries are brought to EDs by emergency medical services from accident scenes and receive expedited care because they meet national trauma criteria (Sasser et al., 2012), a national reference which delineates which patients should receive the most emergent care due to very severe injury mechanisms or other factors. For those who do not meet national trauma criteria, other resources exist which define “mild,” “moderate” and “severe” mechanisms of injury based on the risk of underlying skull fracture and/or intracranial injury. One resource for severity of injury that is widely used in EDs in the United States is the criteria used by Kuppermann et al. (2009) in their pediatric head injury research study. Table 2 contains a description of the three severity of injury categories from this study, which is the parent study for the current study.

Table 2

Injury Severity Categories and Associated Injury Mechanisms for Children Under Age 2 According to the Pediatric Emergency Care Applied Research Network (PECARN) Study (Kuppermann et al., 2009)

Injury Severity Category	Injury Mechanism
Severe	Motor vehicle crash with patient ejection, death of another passenger, or rollover; pedestrian or bicyclist without helmet struck by a motorized vehicle; falls of more than 1.5 m (5 feet) for children aged 2 years and older and more than 0.9 m (3 feet) for those younger than 2 years; or head struck by a high-impact object.
Moderate	Any injury mechanism that does not fall into the "severe" or "mild" category
Mild	Ground-level falls or running into stationary objects

Despite having resources which define injury severity, assessing the severity of the injury mechanism is challenging when a child has been injured as the result of a fall, because the risk varies in relation to the child’s height and in relation to the height of the fall, both are which are typically reported as estimates by caregivers. Children under age two typically lack the developmental ability to provide a detailed history of the fall and of their symptoms following the fall. Some of these children have fallen from a height considered to be a severe mechanism of injury based on major emergency medicine resources. However, this fact can be easily missed when the history and details of the fall are vague. In children under age two, falls from over 3 feet represent a severe mechanism of injury based on major medical studies, representing the most common severe mechanism of injury in this age group (Kuppermann et al., 2009; Nigrovic et al., 2012).

Anatomical and Physiological Differences

Due to several anatomical and physiological differences, children under age two have a higher risk for sustaining an underlying CHI secondary to minor head trauma (Mahajan, 2014; Powell et al., 2015; Quayle, 2014; Shiomi et al., 2016). The heads of children under age two are proportionately larger than the rest of their bodies, their neck muscles are weaker and their motor abilities are underdeveloped, all which contribute to a higher incidence of skull fracture in the first year of life when compared to older children (Powell et al., 2015; Shiomi et al., 2016). As a result, their heads are more likely to hit surfaces when they fall, and their ability to change positions during falls or brace the falls is limited. The younger the child, the higher their risk of underlying CHI (Bin et al., 2010; Griffin et al., 2014; Kuppermann et al., 2009; Powell et al., 2015).

The skull. Some differences in risk for CHI exist based on the skull region injured, regardless of the child’s age. For example, the frontal region has the lowest incidence of CHI as compared to other regions in children age 0-17 (Kuppermann et al., 2009). The temporal and parietal regions are often combined and referred to as the "temporal-parietal region" as compared to other regions of the skull, for identification purposes due to their close proximity. The temporal-parietal region is in closer proximity to the middle meningeal artery, which is the major artery that perfuses the brain. Thus, for patients of all ages, an injury to the temporal-parietal region is more likely to result in significant intracranial bleeding than an injury to another region. The temporal region, in particular, includes an area near the ear that is the thinnest area of the skull (Ma, Baillie, & Stringer, 2012) and more likely to contribute to a higher incidence of fracture with blunt force impact such as by a baseball that hits the child's head.

Risks specific to infants. Infants, generally considered to be children less than 12 months of age, are at particularly high-risk for certain hematomas and diffuse brain injury and swelling due to loose connections among the soft tissues of their heads (Shiomi et al., 2016). The softer and more pliable skulls, compared to those of older children and adults, also puts infants at higher risk of depressed skull fractures (Mahajan, 2014; Shiomi et al., 2016). Depressed skull fractures are more severe than linear and nondisplaced fractures because the bone displacement can cause secondary trauma in the form of brain tissue or vessel injury.

Signs and Symptoms

Children under age two who have sustained underlying CHIs are often clinically asymptomatic, meaning that they do not have any obvious altered mental status or other clinical signs or symptoms of injury other than, in some cases, a hematoma (Bin et al., 2010; Dayan et al., 2016; Griffin et al., 2014; Quayle, 2014). Many "classic" symptoms of underlying CHIs in adults and older children, such as increased sleepiness, vomiting and behavioral changes, can be normal assessment findings in children under age 2 based on developmental age (Conforto & Claudius, 2016; Griffin et al., 2014). Obtunded, or truly lethargic children under age two should be relatively easy for any triage nurse to identify, deemed as an inappropriate presentation due to minimal responsiveness to stimulation and/or pain. However, subtle alterations in mental status may be very challenging to identify in young children. Children under age two, when compared to older children, are the most susceptible to underlying CHI, yet they are also the most difficult to assess (Mahajan, 2014; Powell et al., 2015).

While the results of prior studies are fairly consistent in showing that a loss of consciousness (LOC) and repeated vomiting are predictors of underlying CHI in children over age two, data are mixed on their significance in children under age two. A well-validated study of pediatric head injuries by the Pediatric Emergency Care Advanced Research Network ([PECARN] (Kuppermann et al., 2009), as well as some of its secondary analyses, have produced data that also challenge classic head injury assumptions such as the importance of vomiting and loss of consciousness (LOC) in children under age two. The PECARN study reported "3 or more episodes of vomiting" as a predictor for clinically important traumatic brain injury for children age 2-17, yet did not report vomiting as a predictor at all in children under age two (Kuppermann et al., 2009). One possible explanation for this is that an isolated episode of vomiting can be considered a "normal" response to a head injury, occurring approximately 14% of the time (Mahajan, 2014). While vomiting could be a sign of increased intracranial pressure and a history of vomiting after head trauma does increase the risk of intracranial injury to some degree (Mahajan, 2014), it can also be difficult to differentiate from the normal "spitting up" of some infants unless it is projectile vomiting.

Neurological symptoms, such as headache, altered mental status and amnesia, can be subtle, overlooked, or impossible to fully assess in children under age two by both caregivers and medical professionals. However, among those children under age 2 with a suspected minor head injury based on an alert mental status or normal neurologic exam as assessed by a medical provider, it is estimated that 3-10% of them have sustained an underlying CHI (Quayle, 2014). Even linear skull fractures, the simplest, nondisplaced skull fractures, result in an underlying intracranial injury in about 15-30% of cases (Mahajan, 2014).

Skull Fracture Versus Intracranial Injury

While the presence of a skull fracture is a known predictor of an intracranialor brain injury (Bin et al., 2010), skull fractures and intracranial injuries may also occur independently of one another. Signs of a possible underlying skull fracture that can be seen objectively by caregivers or health care providers assessing a head injury include lacerations and hematomas of the scalp. A scalp hematoma is often the *only* clinical sign of an underlying skull fracture in children under age 2 with head injuries (Bin et al., 2010). In children under age two, the larger the hematoma, the higher the risk of an underlying skull fracture (Bin et al., 2010; Burns et al., 2016; Kuppermann et al., 2009). Furthermore, the risk of skull fracture also increases if the hematoma is located on the temporal/parietal or occipital region of the scalp (Bin et al., 2010; Burns et al., 2016; Hughes, Maguire, Jones, Theobald, & Kemp, 2016; Kuppermann et al., 2009).

Existing Clinical Decision Rules for Pediatric Head Injury

Several pediatric clinical decision rules for head injury have been developed to assist medical providers in identifying risk factors for underlying CHIs. These decision rules vary considerably in their terminology, the ages of their subjects, their outcomes of interest and their overall aims. However, most clinical decision rules are geared towards goals such as guiding the neuroimaging decision. No clinical decision rules exist in the current literature to guide triage nurses in an age specific assessment and triage acuity decision for children under age two (Griffin et al., 2014).

For example, the *Clinical Score to Assess Risk of Skull Fracture and Associated Intracranial Injury*, a clinical decision rule published in 2001 by Greenes and Schutzman, was developed to help identify skull fracture and associated intracranial injury in head-injured infants 0-24 months of age. This clinical decision rule was created using a prospective cohort study of 422 infants age 0-24 months, of which 172 had received CT imaging (Greenes & Schutzman, 2001). The decision rule was subsequently validated by Bin et al. in 2010. The validation study was conducted using 203 children under age two who presented to one U.S. emergency department with a chief complaint or final diagnosis of head trauma, and who had either CT imaging or an x-ray of the skull. The results of the 2010 validation study indicated that a clinical score of 4 or greater identified 90% of the children with underlying skull fracture with a sensitivity of .90 and a specificity of .78. The results of the validation study also indicated that a clinical score of 4 or greater identified 93% of those with an underlying intracranial injury with a sensitivity of .93 and a specificity of .42. A score of 3 or greater identified 100% of intracranial injury among the children considered asymptomatic (Bin et al., 2010).

The *PECARN pediatric head injury study* by Kuppermann et al. (2009) included the derivation and validation of two clinical decision rules designed to help providers rule out "clinically important traumatic brain injuries" (ciTBIs) in children age 0-17 so that CT imaging could be avoided in these children. One clinical decision rule was designed for children under age 2, and a separate decision rule was designed for children age 2-17. This multi-center prospective study, the largest prospective study of pediatric head injuries found in the current literature, included over 40,000 children age 0-17. The following six variables were found to be predictive of ciTBIs (the most serious, life-threatening CHIs which require medical or surgical intervention) in children under age two: alert mental status on exam, non-frontal scalp hematoma, a history of a loss of consciousness for 5 seconds or more following the injury, severe injury mechanism, palpable skull fracture, or not acting normally according to parent. The predictor variable of "not acting normally according to parent" is unique to the PECARN decision rule and serves as a proxy for altered mental status by caregiver opinion. This decision rule for ciTBIs indicates that in children under age two, caregiver report regarding their opinion of the child's mental status should be considered. While the PECARN head injury study also collected information on other less severe outcome variables such as "linear skull fracture" and "any traumatic brain injury on CT scan," the investigators did not report these results or the predictor variables for these alternate outcomes. These alternate outcomes used by the PECARN study and their associated data would be useful to triage nurses who aim to "capture," or help identify, the children at a moderate to high risk for underlying CHI.

The Significance of Fall Characteristics

Since falls represent the most common mechanism of head injuries in children, several studies have sought specifically to examine falls to ascertain which ones pose higher risks for sustaining an underlying CHI in infants and young children (Burrows et al., 2015; Haney et al., 2010; Hughes et al., 2016). Haney et al. (2010) conducted anonymous surveys of 307 parents of children under age five at a primary care clinic in the southeastern U.S., asking questions regarding any falls their children had sustained prior to the age of two. They examined characteristics of falls and associated risks related to head injuries in children under age two, concluding that children who fell on hard surfaces were 6 times more likely to sustain injuries compared with those who fell onto soft surfaces. The results of the study have limited implications or generalizability because this study defined "injury" very broadly, ranging from a bruise or abrasion to a skull fracture or intracranial injury. However, this article was unique in that it discussed specific heights for common falls. This information is useful to the triage nurse because it suggests that information regarding fall surface and estimated fall height may be helpful to collect as part of the assessment of children under age two with head injuries.

Many children under age two "fall" because they are actually dropped by a caregiver. In a United Kingdom (U.K.) study of 1,775 children under age six with head trauma, being dropped by caregivers was the mechanism of injury responsible for the most underlying CHIs (Burrows et al., 2015). What can easily go unnoticed by the triage nurse is that many of these falls are from heights of three feet or higher, considered a "severe" or high-risk injury mechanism for children under age two (Kuppermann et al., 2009).

Another study done in the United Kingdom collected data on the fall *surface*. A case control study of skull fractures and intracranial injuries in children age two and under evaluated in a U.K. hospital who had fallen from less than 3 meters (approximately 10 feet) was conducted by Hughes et al. (2016). Authors compared 47 children who had sustained an underlying CHI with 416 controls who had not (Hughes et al., 2016). Data were collected on the mechanism of injury, the surface of impact, the region of impact to the head, and the fall height. The results of this study indicated that children 12 months and under were more likely to a sustain an underlying CHI from being dropped by a caregiver (especially when on stairs), from falling onto wood surfaces, and from impacts to a non-frontal region of the scalp. Falls onto concrete surfaces were more frequently reported than falls onto wooden surfaces, but the investigators noted that the falls onto concrete in this particular study usually involved an impact to the forehead, which overlies the frontal region of the skull. Also notable from this study was the fact that no significant difference was found between the mean fall heights of children who had sustained a simple skull fracture (n=17) versus those who had sustained a more complex, higher risk skull fracture (n=30). Results from this study included: a fall threshold of 0.6 meters (2 feet) based on the height of the "head centre of gravity," an age of less than 12 months, an impact to a non-frontal area of the scalp, a fall from a caregiver's arms, and a fall onto a wood surface were all significantly associated with the risk of skull fracture and/or intracranial injury. However, a limitation of this study was that fall heights were only documented in 133 (29%) of the 463 total cases.

Authors of a cross-sectional study of children younger than age 6 admitted to U.K. hospitals (Burrows et al., 2015) collected data on 1,175 children with a median age of 18 months who had sustained head injuries from falls. The injury according to CT scan, the object fallen from and the Glascow Coma Score (GCS) or other neurological assessment data were collected on each patient enrolled. A total of 58 (16.9%) had sustained isolated skull fractures, 47 (13.7%) had sustained an intracranial injury, and 23 (49%) of those with intracranial injury had an associated skull fracture. While the authors reported that those with an intracranial injury were more likely to have altered mental status, 12% of the children with a mental status assessed as normal for their age by a medical provider actually had sustained an intracranial injury. The mean age of children who sustained a skull fracture and/or intracranial injury from being dropped by a caregiver was one year and falls from an elevated height were responsible for 74.5% (1322/1775) of the injuries. Results showed that infants under six months of age were more likely to sustain an underlying CHI than older children, and falling from a caregiver's arms was the most likely mechanism associated with these injuries in infants.

A retrospective review by Mulligan, Adams, Tzioumi, and Brown (2017) examined injury characteristics and hospital admissions in children under one year of age who presented after a fall to an Australian pediatric trauma center for evaluation. A total of 916 infants were included in the analysis, and head injury was the most common reason for admission. Outcome data included the specific type of injury sustained: skull fracture, intracranial bleed, and/or soft tissue injury. The authors of this study found that there was no difference in head injury severity by mechanism of the fall, a point that highlights the significance of the age-specific risks for skull fracture and/or intracranial injury in infants. Overall, the literature regarding fall heights and surfaces indicates that falls, including being dropped by a caregiver, are responsible for 70-80% of CHIs in children under age 2, many of whom have few if any symptoms of injury. The literature also indicates that age in months, especially for children under 12 months, is a major factor to consider when predicting risk of underlying CHI. While the research is limited regarding specific fall surfaces, hard surfaces also seem to be associated with higher risk of CHI in children under age 2.

The Significance of an Isolated Loss of Consciousness

Some studies questioned the significance of an isolated LOC, typically defined as a LOC of less than 5 seconds following the injury, in children under age two (Griffin et al., 2014; Lee et al., 2014). A secondary analysis of the PECARN study by Lee et al. (2014) found that an isolated LOC following blunt head trauma does not represent a significant risk factor for clinically important traumatic brain injury in children under age two. Whether this is because a brief LOC can be more difficult to identify in children under age two, or because LOC does not occur as frequently in this age group, is unclear. A limitation of this study is that the outcome measured was ciTBIs, which were only the most severe, life-threatening injuries. This contrasts with the circumstances most triage nurses are confronted with; they are challenged with identifying patients at moderate to high-risk for any underlying CHI, not just the patients at risk for life-threatening injuries.

Discussion and Implications for Nursing Practice

Based on the literature reviewed, variables that suggest a higher risk of underlying CHI in children under age two who have sustained a head injury include: younger age (with 2-3 months and under considered the highest risk age group), injuries to a non-frontal area of the scalp with the temporal-parietal region of the scalp with the highest risk, and the presence of any scalp hematoma and the size of any hematoma, with large or "boggy" hematomas representing the highest risk for underlying CHI (according to the studies which collected that detail) (Atbaki, 2016; Bin et al., 2010; Dayan et al., 2015; Kuppermann et al., 2009). One point that varied among studies, the fall height, represented a higher degree of risk for having sustained an underlying CHI for children under age two. Current clinical decision rules for pediatric head injuries tend to use criteria ranging from "greater than 2 feet (0.6 m)" to "greater than 3 feet (0.9 m)" to describe the fall height considered a "severe mechanism of injury" for children under age 2.

Nurses who triage children under age two with suspected minor head injuries should be familiar with the risks unique to this age group so that an accurate assessment of risk for underlying CHI can be conducted. Several objective variables that are relatively easy to assess and are associated with the risk of underlying CHI in children under age two are the presence of any hematoma on the scalp, the size of the hematoma, and the region of the hematoma. Since falls are the most common mechanism of head injury in children under age two, it is imperative that nurses who triage these children be familiar with the heights of common falls in this age group so a more accurate determination of severity of injury mechanism can be assessed. The results of prior studies show that information regarding the approximate height of the fall and the fall surface should be collected when obtaining the history of the injury to help determine the child's risk for CHI.

Conclusion

A gap exists in the literature regarding the best practice triage assessment of children under age two who have sustained suspected minor head injuries. While several studies in the past decade have identified significant factors associated with the risk of underlying CHI in children under age two who have sustained suspected minor head injuries and some have culminated in the development of clinical decision rules, none of the currently available clinical decision rules are designed to assist the triage nurse at the point of care.

Emergency department triage is a pivotal point in patient care; the decisions made by the triage nurse inform patient prioritization and ultimately affect patient outcomes. Evidence-based clinical decision rules that help support accurate assessments, risk stratification, and appropriate prioritization and treatment are needed. An evidence-based approach to the triage assessment of children under age two who have sustained suspected minor head injuries that would inform accurate and consistent triage acuity decision reflective of the child's degree of risk for underlying CHI would be useful to nurses who triage children in the ED setting. A nurse-driven clinical decision rule that could score the child under age two's risk of any underlying CHI could be developed according to variables stratified by several age- associated risk cut-points and suggest an acuity level based on the child's total risk score. Such a clinical decision rule would be a valuable addition to the existing resources for ED triage and could potentially increase both the accuracy and consistency of triage decisions for children under age two who present with suspected minor head injuries.

CHAPTER III

METHODOLOGY

This study was a secondary data analysis of the public-use dataset from the largest prospective, multi-center pediatric head injury study found in the current literature. The purpose of the current study was to identify the variables associated with the risk of CHI in children under age 2 with suspected *minor* head injuries based on age-appropriate, or near age-appropriate, mental status on exam. The goal was to propose a set of variables that, when considered together, have a high degree of predictive accuracy in identifying CHI in this population. This set of variables could eventually be used to inform a clinical decision rule designed as a risk scoring system which may help triage nurses make acuity decisions in an evidence-based manner.

Setting and Sample

The PECARN Traumatic Brain Injury study (*parent study*) was a federally funded, multicenter, prospective cohort study of children under 18 years of age who had sustained head trauma within the prior 24 hours and presented to 25 EDs in the United States within a pediatric research network between 2004 and 2006 (Kuppermann et al., 2009). These EDs were from 13 states, plus the District of Columbia, and represented a combination of academic, urban and children's hospitals.

The parent study enrolled 43,904 children (Kuppermann et al., 2009). After applying inclusion and exclusion criteria, 42,412 children age 0-17 with a GCS of 14-15 were retained for the parent study. The parent study included separate prospective derivation and validation phases; these phases were defined by specific time lines and included continuous sets of patients per best practice recommendations for the development of clinical decision rules (Stiell & Wells, 1999). Eighty percent (33,785/42,412) of the children represented the derivation sample, and 20% (8,627/42,212) of the children represented the validation sample. Of the total sample, 25% (10,718/42,412) were under age two, and of those, 31% (3,329/10,718) had a CT scan done to evaluate their head injury. The parent study culminated in the creation of two prediction rules designed to identify children at very low risk of clinically important traumatic brain injuries (ciTBI) for whom CT scan might be unnecessary. One decision rule was designed to be used for children under age two and a separate decision rule was designed to be used for children age 2-17.

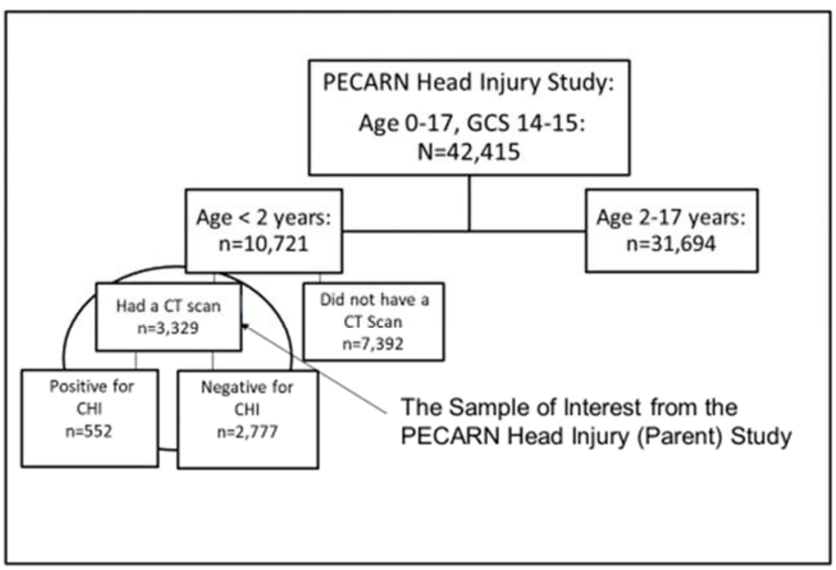
The sample of interest for the current study was the 3,329 children under age two from the parent study who had a CT scan performed for evaluation of their head injury (Figure 3). Only the children with CT imaging were included in the current study because CT is the "gold standard" diagnostic test for identifying CHIs. This inclusion criterion represents a limitation of the study and will be further addressed in Chapter Five. The purpose of the *parent* study was to derive and validate prediction rules for ciTBI, defined *a priori* as a traumatic brain injury that directly resulted in death, required neurosurgery, required intubation for over 24 hours, or resulted in hospital admission of 2 nights or more secondary to a traumatic brain injury found on CT scan (Kuppermann et al., 2009). In contrast, the purpose of the *current* study was to identify the variables associated with the risk of *any* underlying skull fracture or intracranial injury ("closed head injury" [CHI]) in children under age 2 with suspected minor head injuries (those who appear neurologically appropriate or close to neurologically appropriate on their initial presentation to the ED). The goal of the current study was to present a framework for a clinical decision rule that may help triage nurses make decisions to optimize evidence-based decision making.

Inclusion and Exclusion Criteria

The inclusion criteria for the parent study were children age 0-17 years presenting to the ED within 24 hours of head trauma and with a suspected minor head injury, as defined by children with a GCS of 14-15, considered normal or very close to normal neurological status. The sample for the parent study was determined by the medical provider assessment. A GCS score below 14 reflects an obvious alteration in mental status; patients who have obvious altered mental status do not typically require a clinical decision rule to assist with their evaluation because they typically have their medical care expedited due to their mental status alone. The current study included only the children who were under age two from this original sample. Exclusion criteria for the parent study (and therefore also the current study) were children who had been injured by "trivial" injury mechanisms (ground level falls or walking or running into stationary objects and no signs or symptoms of head trauma other than scalp abrasions or lacerations), and children with penetrating trauma (known brain tumors, pre-existing neurological disorders) that complicated the assessment, or neuroimaging at an outside facility for the injury (Kuppermann et al., 2009).

Sample Size

Based on Vittinghoff and McCulloch's (2007) recommendation for the minimum number of subjects to include in logistic regression analysis, the sample size of 3,329 for the current study more than exceeds the minimal size needed to review the potential factors associated with the outcome of CHI. Vittinghoff and McCulloch (2007) recommended 5-9 events per predictor variable be utilized for logistic regression. There are well over 5-9 events per predictor variable for all independent variables considered in the logistic regression analysis. The independent variables investigated included: age in months, size and location of hematoma (a composite variable), severity of injury mechanism, any suspected or actual loss of consciousness, any parental concern of not acting normally, any altered mental status on exam, and any vomiting since the injury.



Kuppermann N, Holmes J, Dayan P, Hoyle J, Atabaki S, Holubkov R, ... Dean J, Wootton-Gorges S; Pediatric Emergency Care Applied Research Network (PECARN) (2009). Identification of children at very low risk of clinically-important brain injuries after head trauma: a prospective cohort study. *Lancet*. 374(9696):1160-70. doi: 10.1016/S0140-6736(09)61558-0.

Figure 3. Derivation of the Sample.

Data Collection

This study was a secondary analysis of existing, public use, de-identified patient data already housed on the secured network at the University of North Carolina at Greensboro. No new data were collected for the current study, and no interventions were performed.

Human Subjects Protection

The doctoral student, who served as the Principle Investigator (P.I.), received exempt Institutional Review Board Approval from the University of North Carolina at Greensboro in 2018 to conduct a secondary analysis on the PECARN Traumatic Brain Injury public use dataset.

Data Analysis

Dependent Variable

The outcome of interest in this study was broader than the outcome used in the PECARN parent study. The dependent variable for the current study was a variable representing *any* CHI found on CT scan. This variable was a composite variable that included the parent study's variables of traumatic brain injury (which included intracranial bleeding or swelling as well as some complex or depressed skull fractures) and linear skull fracture (which included the simpler and non-displaced skull fractures). The dependent variable for the current study was chosen because the goal of the current study was to collect data that would aid the ED triage nurse in identifying the risk of *any* CHI in children under age two, in contrast to only the most life-threatening CHIs, which was the dependent variable in the parent study.

Independent Variables

Independent variables for the secondary analysis were chosen based primarily on the prior research by Greenes and Schutzman (1999, 2001), Bin et al. (2010), and Kuppermann et al. (2009), and from 15 years plus of observational experience of the P.I. as a pediatric emergency nurse. The three variables (age in months, hematoma size and hematoma location) identified by Greenes and Schutzman (2001) in their clinical scoring system as predictors of (any) skull fracture in children 0-24 months (Figure 4) were also identified as predictors of the more severe outcome of ciTBI in children under age 2 by the PECARN Traumatic Brain Injury parent study. These three variables were analyzed in the current study both individually and in composite form (the composite score representing the total risk score according to the existing scoring system by Greenes and Schutzman (2001) (referred to in this paper as the Scalp Score).

Risk points	**Patient Age**	**Hematoma size**	**Hematoma location**
0	>12 months	None	Frontal
1	6-11 months	Small (barely palpable)	Occipital
2	3-5 months	Medium (easily palpable)	Temporal/Parietal
3	0-2 months	Large (boggy consistency)	

Note. Total scores can range from 0-8 points, with 0 representing the lowest risk and 8 representing the highest risk. Used with permission by Dr. David Greenes.

Figure 4. Clinical Scoring System to Assess the Risk of Skull Fracture and Associated Intracranial Injury (Scalp Score).

The PECARN Traumatic Brain Injury Study (*parent study*) found two *additional* variables to be predictive of their outcome, ciTBI, in children under age 2: “severe injury mechanism” defined *a priori* by their research (see Table 1) and “parental concern of not acting normally.” These variables, as well as other variables based on classic assumptions regarding symptoms of head injuries such as “any vomiting after the injury” were also examined in the current study. The variables ultimately tested for independent associations with the dependent variable of “any CHI” in the current study were, 1) the child’s composite risk score according to the Scalp Score; 2) the child’s age in months as a continuous variable; 3) a composite variable that contained nine categories representing the presence of a scalp hematoma, the size of any scalp hematoma, and the location of any scalp hematoma; 4) the mechanism of injury severity; 5) the presence of any vomiting after the injury; 6) any suspected or actual loss of consciousness following the injury 7) altered mental status on ED examination (based on medical provider assessment); and 8) parental concern for not acting normally, a proxy for altered mental status according to the parent or caregiver.

Table 3

Injury Severity Categories and Associated Injury Mechanisms for Children Under Age 2 According to the Pediatric Emergency Care Applied Research Network (PECARN) Study

Injury Severity Category	Injury Mechanism
Severe	Motor vehicle crash with patient ejection, death of another passenger, or rollover; pedestrian or bicyclist without helmet struck by a motorized vehicle; falls of more than 1.5 m (5 feet) for children aged 2 years and older and more than 0.9 m (3 feet) for those younger than 2 years; or head struck by a high-impact object.
Moderate	Any injury mechanism that does not fall into the “severe” or “mild” category.
Mild	Ground-level falls or running into stationary objects.

Reliability and Validity

Because this was a secondary analysis, the reliability and validity of the parent study's measures were considered. Data for the parent study were collected on standardized data forms by trained site investigators and other ED physicians without knowledge of the results of any imaging if imaging was performed. Quality assurance practices also included annual site monitoring visits and random double or triple data entry. Approximately 4% of patients at each site had double ED assessments performed by two different ED physicians within 60 minutes of one another to assess inter-rater reliability of patient characteristics and exam findings (Kuppermann et al., 2009; Gorelick et al., 2008).

Agreement between paired assessments was slightly higher when the time that had elapsed between assessments was less than 30 minutes (Gorelick et al., 2008). Overall, data for 27 (84%) of 32 variables collected by the parent study had acceptable agreement per the parent study's interrater reliability criteria which used a *kappa* of >0.40. While κ=.41 is the threshold for what Cohen considered "acceptable" agreement (Cohen, 1960), an author of contemporary literature regarding the use of *kappa* have suggested that higher thresholds may be more appropriate in healthcare studies (McHugh, 2012). According to McHugh's (2012) recommendations for interrater agreement in healthcare studies, the variables analyzed in the current study demonstrated the following interobserver agreement in children under age two: the presence or absence of scalp hematoma demonstrated moderate agreement at κ=0.66; scalp hematoma location demonstrated strong agreement at κ=.87; scalp hematoma size demonstrated moderate agreement at κ=.74; the three levels of mechanism of injury severity demonstrated strong agreement ranging from κ=.83 - .87; a composite variable of GCS < 15 that included several specific indicators of altered mental status demonstrated weak agreement at κ=0.53; a history of any vomiting since the injury demonstrated almost perfect agreement at κ=.94; and parental concern of not acting normally demonstrated weak agreement at κ=.54 (Gorelick et al., 2008). One reason for the lower agreement on the variable of "parental concern of not acting normally" may have been the time that elapsed between the interobserver assessments; if a child began to feel better after the initial assessment, their behavior may have been closer to baseline by the time of the second assessment.

Research Questions

The research questions for the current study were focused on the ED triage nurse assessment and acuity decision. The three questions were:

1. Of the eight variables identified *a priori* based on the literature and the P.I.'s prior experience, which are significantly associated with the risk of underlying CHI in children under age 2 with suspected minor head injuries?
2. What is the optimal age "cut point" in months which represents the most accurate dichotomy to predict CHI in children under age 2 with suspected minor head injuries?
3. Does the *Clinical Scoring System to Assess the Risk of Skull Fracture* by Greenes and Schutzman (2001) (the Scalp Score) contain the optimal combination of variables, in the optimal format, to accurately identify the risk

of underlying CHI in children under age two presenting for evaluation of a suspected minor head injury?

Data Analysis

Descriptive statistics and univariate analysis were completed, and the results given to describe the sample participants. Statistical analyses performed for the current study included Chi-square tests of independence, Fischer's exact tests when necessary, and logistic regression using the Statistical Package for the Social Sciences (SPSS v. 25; IBM Corp., Armonk, NY). Selected variables from the PECARN TBI public use dataset were analyzed to determine whether they had any association with CHI in children under age 2 with suspected minor head injuries. "Risk scores" based on an existing, validated clinical decision rule created by Greenes and Schutzman (2001) (Figure 2) were also analyzed for their performance in identifying CHI in the sample of 3,329, individually and with additional variables. Notably, the clinical decision rule by Greenes and Schutzman (2001) was created to help medical providers predict the risk of skull fracture and underlying intracranial injury in children under age 2 by considering objective data stratified by age- associated risk cut-points.

The main assumptions inherent to logistic regression are: only meaningful variables are included in the model, signifying optimal "goodness of fit"; the effects of the IVs on the log-odds of the dependent variable are linear; a large sample size is utilized; the observations or subjects are independent; and there is little to no multicollinearity of variables (Polit, 2010). The current study involved a large sample size of 3,329. Multicollinearity of three variables: hematoma presence, hematoma size, and hematoma location was present, and was addressed by re-coding these three variables into one composite variable for the regression analysis. This composite variable was the categorical variable of “Hematoma Location and Size” and had 10 categories: none (no hematoma present), frontal small, frontal medium, frontal large, occipital small, occipital medium, occipital large, temporal/parietal small, temporal/parietal medium, and temporal/parietal large.

The missing data were assessed for all analysis variables because the number and patterns of missing data can influence the results of any given study. All variables included in the regression analysis had under 10% missing data, and most had under 5% missing data. The variables of “any suspected or reported loss of consciousness since the injury” and “any parental concern of not acting normally” had the highest amounts of missing data of the variables included in the regression analysis, ranging from 6% to just under 10%. The only independent variable in the descriptive analysis which had a high degree of missing data was “ethnicity,” with data missing for over 41% of the children. One reason for this may be that questions regarding specific ethnicity are not always part of the standard ED history data collection; this was a variable specific to the study data collection. This variable was not included in the regression analysis. The following data analyses were performed for each research question.

Research Question 1

Research Question 1 was answered by completing descriptive statistics and univariate and bivariate analysis for the eight different independent variables of interest, then using multivariable logistic regression to analyze the relationship of six different combinations of independent variables with the dependent variable. Step one of the descriptive analysis involved computing frequencies and measures of central tendency for the independent variables. Measures of central tendency were computed for the independent variable "age in months," which was the only continuous variable used in the current study. The number (*n*) and percent (%) of patients in the sample of *n*=3,329 who had any of the other independent variables present were presented in total and according to their outcome. Frequencies and percentages were also presented according to outcome (CHI versus no CHI) for each of the 9 different Scalp Score risk scores which ranged from zero points (lowest risk) to 8 points (highest risk). Step two of the descriptive analysis involved computing crosstabulations using Chi-square analysis (or Fishers exact tests when necessary) to evaluate the individual relationships between the independent variables and the dependent variable.

Multivariable logistic regression was then used to examine the relationship of various combinations of the eight independent variables with the composite outcome of CHI in the sample of 3,329 children under age 2 who had a CT done from the parent study. Step one of the logistic regression analysis involved computing statistics to examine the performance of the GSRSS in identifying CHI in the sample of 3,329 children under age 2. A composite variable which represented the risk score according to the Scalp Score was created to allow for an examination of the risk scoring system's performance with the current sample, which is considerably larger than the samples used to initially derive and validate the Scalp Score. In the logistic regression analysis for the current study, the independent performance of the Scalp Score in identifying CHI was examined, then additional variables were added to this model to evaluate how they affected accuracy in identifying CHI in the sample of 3,329. In total, three regression models (Models 1, 2, and 3) included the Scalp Score as a composite independent variable and three subsequent models (Models 4, 5, and 6) did not include the GSRSS composite independent variable. However, Models 4, 5, and 6 included the "components" of the Scalp Score: the same variables within the Scalp Score of age in months, hematoma size and hematoma location were considered individually and with age as a continuous variable instead of a categorical variable. Odds ratios were used to describe the strength of associations within the six regression models.

Model building for the logistic regression was done in two stages and using a hierarchical fashion for both stages. Model 1 included only one composite variable: the total composite risk score according to the Scalp Score (Greenes & Schutzman, 2001), to examine the accuracy of the Scalp Score in predicting CHI. Model 2 built upon Model 1 by adding an additional independent variable, severity of injury mechanism. Model 3 added four additional independent variables: any suspected or reported vomiting, any loss of consciousness since the injury, any parental report of child not acting normally, and altered mental status on exam to observe any additional effects on the performance of the regression model.

Model 4 was then built using the *components* of Model Zero as opposed to its composite (total risk score) variable, so that the individual components of the Scalp Score (Greenes and Schutzman, 2001) could be analyzed independently and with age as a continuous variable. Finally, Models 5 and 6 built upon Model 4, adding the same additional independent variables that were added for Models 2 and 3, respectively. Model 4 included the independent variables of age in months, and a composite variable which combined hematoma size and location, when present; representing the three "components" of the Scalp Score in independent form. The composite variable combining hematoma size and location was created to avoid multicollinearity and meet the assumptions of logistic regression. Model 5 added the variable representing severity of injury mechanism to observe any additional effect. Model 6 added the remaining independent variables: any suspected or reported vomiting, any loss of consciousness since the injury, any parental report of child not acting normally, and altered mental status on exam to observe any additional effects on the performance of the regression model.

The receiver operating curve was produced by plotting each regression model's estimated sensitivity against 1-specificity. An advantage of receiver operating curve analysis is that the accuracy indices produced by this analysis are not subject to bias or influence (Hajian-Tilaki, 2013). Analyzing the area under the receiver operating curve can be used to compare more than one diagnostic test (or, in this case, potential clinical decision rule) in identifying a dichotomous outcome (Hajian-Tilaki, 2013).

The overall predictive accuracy of the six models for identifying CHI was compared by estimating the AUC for each model according to best practice for evaluating a diagnostic test with a dichotomous outcome (Hajian-Tilaki, K., 2013) and examining the 95% Cis for each AUC. The goal of the receiver operating curve analysis was to identify the model with the AUC closest to 1.0 that contained a set of independent variables which maximized predictive value for CHI while remaining parsimonious. A two-sided *p*-value <0.05 was considered statistically significant. The Hosmer-Lemeshow test was used to assess the goodness of fit of the overall models according to best practices for logistic regression (Polit, 2010).

Research Question 2

Research Question 2 was answered in three steps:

1. By creating 23 indicator variables representing the 23 different ages of the sample ranging from zero months to 23 months. Bivariate analysis was conducted by examining crosstabulations for each indicator variable's dichotomy with CHI to investigate sensitivity and specificity performance.
2. To examine overall accuracy as a measure of sensitivity plotted against 1-specificity for 23 original age in month categories, a receiver operating curve was constructed based on a regression model which used the continuous variable of age in months as the sole independent variable.
3. The coordinates for the receiver operating curve were used to calculate the age that corresponded to each predicted probability, then Youden's index was used to identify the cut-point of maximum overall accuracy in identifying CHI.

Research Question 3

Research Question 3 was answered in two parts:

1. By comparing Models 1, 2, and 3 to Models 4, 5, and 6 to determine whether the Scalp Score had better performance using its composite summative score

or using its component variables independently. The areas under the curve for the three models built around the Scalp Score composite score were compared to the areas under the curve for the models built using its individual components as separate independent variables. This analysis helped demonstrated whether the Scalp Score could be used as an adjunct to the ED triage nurse, either alone or with additional variables to increase the predictive accuracy for CHI.

2. By examining the overall performance of each regression model as a potential clinical decision rule according to the *Methodologic Standards for the Development of Clinical Decision Rules in Emergency Medicine* (Stiell & Wells, 1999). All six models were assessed to determine which combination of independent variables resulted in a model with maximum predictive accuracy for CHI while having goodness of fit and remaining parsimonious. Retaining only the number of clinical variables necessary in the model, without retaining variables of minimal value in additional predictive accuracy for CHI, would typically inform a clinical decision rule that is more likely to be considered sensible and acceptable by healthcare professionals (Stiell & Wells, 2012).

Summary

The purpose of the current study was to identify the variables associated with the risk of CHI in children under age 2 with suspected *minor* head injuries based on age-appropriate, or near age-appropriate, mental status on exam. The goal was to propose a set of variables that, when considered together, have a high degree of predictive accuracy in identifying CHI in this population. The secondary analysis of the PECARN Traumatic Brain Injury Study (parent study) used a public-use dataset to explore and describe the variables that were significantly associated with the risk of underlying CHI in children under age 2 with a suspected minor head injury.

The statistical analysis included comparing the performance of a logistic regression model representing the composite risk score from an existing clinical decision rule, the Scalp Score, with other potential models that contained additional variables and/or variables in different format (such as continuous versus categorical) in the sample of 3,329 from the parent study. The research study sought to answer the questions: 1) Which variables identified *a priori* by the P.I. were significantly associated with the risk of underlying CHIs in children under age 2 who present with suspected minor head injuries; 2) What is the optimal age "cut point" in months which represents the most accurate dichotomy to predict CHI in children under age 2 who present with suspected minor head injuries? And 3) Could the *Clinical Scoring System to Assess the Risk of Skull Fracture* by Greenes and Schutzman (2001) (Scalp Score) be utilized by the ED triage nurse to accurately identify the risk of underlying CHI in children under age two presenting for evaluation of a suspected minor head injury? Donabedian's Structure, Process, Outcome model was used to frame the process of ED triage, the process that the P.I. is trying to improve with the results of this study.

Data analyses included descriptive statistics, chi-square tests of independence and Fischer's exact tests to examine relationships between independent variables and the dependent variable (CHI), and logistic regression. Odds ratios were used to describe the strength of associations. The AUC for each of the six regression models was analyzed to determine which of the six models had the highest degree of predictive accuracy for CHI in children under age two.

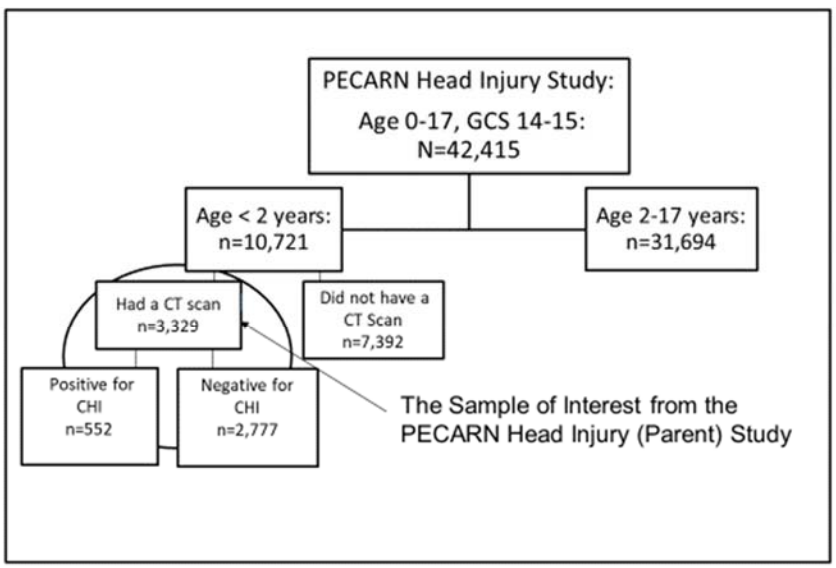
CHAPTER IV

RESULTS

This study was a secondary analysis of an existing public-use dataset from the largest prospective study of pediatric head injuries found in the current literature, the Pediatric Emergency Care Advanced Research Network (PECARN) Traumatic Brain Injury Study. The purpose of the current study was to identify the variables associated with the risk of CHI in children under age 2 with suspected *minor* head injuries based on age-appropriate, or near age-appropriate, mental status on exam. The goal was to propose a set of variables that, when considered together, have a high degree of predictive accuracy in identifying CHI in this population. This set of variables could eventually be used to inform a clinical decision rule designed as a risk scoring system which may help triage nurses make acuity decisions in a more evidence-based manner.

The study examined the relationship of age in months, injury characteristics, reported signs and symptoms and presenting signs and symptoms with the risk of a closed head injury (CHI) in children under age two that are evaluated for a suspected minor head injury. The study also examined the predictive accuracy of an existing clinical decision rule in identifying CHI in this population. In this chapter, the results of the study are presented.

While the terminology and definitions for what is considered "minor head injury" vary within the literature and across studies, the definition used for this secondary analysis study was consistent with its parent study. “Minor head injury” referred to a head injury that occurred within the past 24 hours in a child with a Glascow Coma Score (GCS) of 14-15, indicating a fully appropriate (15) or slightly altered (14) mental status on exam. Closed head injury was defined for the purposes of this study as the presence of any underlying skull fracture or intracranial injury within a closed skull vault that was visible on CT scan. Because CT scan is the diagnostic standard for skull fracture and intracranial injury, the children under age two who did not receive a CT scan were not included in the sample.



Kuppermann N, Holmes J, Dayan P, Hoyle J, Atabaki S, Holubkov R, ... Dean J, Wootton-Gorges S; Pediatric Emergency Care Applied Research Network (PECARN) (2009). Identification of children at very low risk of clinically-important brain injuries after head trauma: a prospective cohort study. *Lancet.* 374(9696):1160-70. doi: 10.1016/S0140-6736(09)61558-0.

Figure 5. Derivation of the Sample Revisited.

Sample Characteristics and Outcome Prevalence

The mean age for the 3,329 children included in this study was 9.4 months (*SD*=6.8) and a notable 669 (20%) of the children were under the age of three months. In total, 1,780 (54%) of the children were male, and 1,935 (58%) were White (Table 4). Injury mechanism data were collected according to 13 specific mechanism descriptions and categorized by three levels of severity (Table 5 and Table 6). Falls from an elevated height were responsible for 59% (*n*=1,944) of the injuries in the sample of 3,329 children under age two, which was over seven times the number injured than by any other mechanism (Table 5).

Table 4

Sample Demographics by CHI Status

Independent Variable	**Overall (*N*=3,329)**	**Positive for CHI (*n*=552) (17%)**	**Negative for CHI (*n*=2,777) (83%)**	***p*-value**
Age in months (*n*=3,329)	9.4 ±6.8 (0, 23)	6.5 ±6.1 (0, 23)	9.9 ±6.8 (0, 23)	<.001
Under 3 mos.	669 (20%)	179 (32%)	490 (18%)	<.001
3 mos. – 23 months	2,660 (80%)	373 (68%)	2,287 (82%)	
Missing	0	0	0	
Gender (*n*=3,329)				.016
Male	1,780 (54%)	321 (58%)	1,459 (52%)	
Female	1,549 (46%)	231 (42%)	1,318 (48%)	
Missing	0	0	0	
Ethnicity (*n*=1,955)				.439
Hispanic	483(15%)	76 (14%)	407 (15%)	
Non-Hispanic	1,472 (44%)	254 (46%)	1,218 (44%)	
Missing	1,374 (41%)	222 (40%)	1,152 (41%)	
Race (*n*=3,021)				.292
White	1,935 (58%)	337 (61%)	1,598 (58%)	
Black	877 (26%)	128 (23%)	749 (27%)	
Asian	75 (2%)	14 (3%)	61 (2%)	
American	6 (<1%)	0	6 (<1%)	
Indian/Alaskan Native	9 (<1%)	1 (<1%)	8 (<1%)	
Pacific Islander	119 (4%)	24 (4%)	95 (3%)	
Other	308 (9%)	48 (9%)	260 (9%)	
Missing				

Table 5

Specific Injury Mechanisms by CHI Status

Injury Mechanism	**Overall (*N*=3,329)**	**Positive for CHI (*n*=552; 17%)**	**Negative for CHI (*n*=2,777; 83%)**	***p*-value**
Motor Vehicle Crash	118 (4%)	20 (4%)	98 (4%)	.820
Pedestrian struck by moving vehicle	33 (1%)	5 (<1%)	28 (1%)	1.000
Bike rider struck by vehicle	1 (<1%)	0	1 (<1%)	1.000*
Bike collision / fall from bike while riding	5 (<1)	2 (<1%)	3 (<1%)	.187
Other wheeled transport crash	15 (<1%)	2 (<1%)	13 (<1%)	1.000
Fall to ground from standing/walking/running	242 (7%)	16 (3%)	226 (8%)	<.001
Walked or ran into stationary object	86 (3%)	4 (<1%)	82 (3%)	.003
Fall from an elevation	1,944 (58%)	361 (65%)	1,583 (57%)	<.001
Fall from stairs	406 (12%)	56 (10%)	350 (13%)	.161
Sports injury	2 (<1%)	0	2 (<1%)	1.000*
Assault	39 (1%)	6 (1%)	33 (1%)	.890
Object struck head by accident	127 (4%)	16 (3%)	111 (4%)	.262
Miscellaneous/other mechanism	249 (7%)	41 (7%)	208 (8%)	.903
Missing	62 (2%)	23 (4%)	39 (1%)	

Note. * *p*-values which were starred were calculated by Fisher's exact test due to small sample size. The remaining *p*-values were obtained by Pearson's Chi-square analysis.

Table 6

Severity of Injury Mechanism by CHI Status

Independent Variable	Overall (*N*=3,329)	Positive for CHI (*n*=552; 17%)	Negative for CHI (*n*=2,777; 83%)	*p*-value
Severity of injury mechanism* (*n*=3,266)				<.001
Low	328 (10%)	20 (4%)	308 (11%)	
Medium	1,856 (56%)	257 (47%)	1,599 (58%)	
High	1,082 (32%)	252 (46%)	830 (30%)	
Missing	63 (2%)	23 (4%)	40 (1%)	

Note. *Severity of injury mechanism defined as follows: **Mild**=fall from ground level (or fall to ground from standing, walking or running), **Moderate**=any mechanism that doesn't fall into "low" or "high" severity category, **Severe**=falls of > 3 feet for children < 2 years of age; head struck by high impact object (such as a baseball); motor vehicle collision with patient ejection, death of another passenger, or rollover; pedestrian or bicyclist without helmet struck by motorized vehicle (Kuppermann et al., 2009)

Sixty-six percent (361/552) of the children who sustained CHIs had been injured as the result of a fall from an elevated height, compared to 57% (1,583/2,777) of those without a CHI. In total, 17% (552) of the 3,329 children who received a CT scan had sustained a CHI (95% C.I. = [.15, .18]). A total of 18% (98/552) of the children with CHIs had sustained a *clinically important* traumatic brain injury (ciTBI), the outcome of the parent study. The term ciTBI was a composite variable defined *a priori* as a traumatic brain injury which directly resulted in death, required neurosurgery, required intubation for over 24 hours, or resulted in hospital admission of two nights or more secondary to a traumatic brain injury found on CT scan (Kuppermann et al., 2009). The remaining 82% (454/552) of the children with CHIs had sustained less complex or life-threatening injuries.

Research Question 1

The first research question was: Of the eight variables identified *a priori* based on the literature and the P.I.'s prior experience, which are significantly associated with the risk of underlying CHI in children under age 2 with suspected minor head injuries? These included variables that were based on the characteristics of the child, the history of the injury, the characteristics of the injury, and the child's signs and symptoms. Age in months, presence of scalp hematoma, scalp hematoma size, scalp hematoma location, and severity of injury mechanism all demonstrated statistically significant bivariate associations with CHI in children under age two (Tables 4, 6, 7, and 8).

Table 7

Scalp Score Composite Risk Score by CHI Status

Independent Variable	**Overall (*N*=3,329)**	**Positive for CHI (*n*=552) (17%)**	**Negative for CHI (*n*=2,777) (83%)**	***p*-value**
Greenes & Schutzman	2.64 ±2.06	4.69 ± 2.26	2.23 ± 1.76	
(2001) Scalp Score	(0, 8)	(0,8)	(0,8)	<.001
(*n*=3,225)	604 (18%)	29 (5%)	575 (21%)	
0 points	463 (14%)	31 (6%)	432 (16%)	
1 point	528 (16%)	39 (7%)	489 (18%)	
2 points	750 (23%)	78 (14%)	672 (24%)	
3 points	267 (8%)	37 (7%)	230 (8%)	
4 points	245 (7%)	82 (15%)	163 (6%)	
5 points	180 (5%)	102 (18%)	78 (3%)	
6 points	137 (4%)	92 (17%)	45 (2%)	
7 points	51 (2%)	42 (7%)	9 (<1%)	
8 points	104 (3%)	20 (4%)	84 (3%)	
Missing				

Table 8

Hematoma Characteristics by CHI Status

Independent Variable	Overall (*N*=3,329)	Positive for CHI (*n*=552; 17%)	Negative for CHI (*n*=2,777; 83%)	*p*-value
Presence of a Scalp Hematoma (*n*=3,310)				<.001
Yes	1,632 (49%)	420 (76%)	1,212 (44%)	
No	1,678 (50%)	130 (24%)	1,548 (56%)	
Missing	19 (1%)	2 (<1%)	17 (1%)	
Hematoma Location and Size (*n*=3,225)				<.001
None	1,697 (50%)	132 (24%)	1,565 (56%)	
Frontal Small	131 (4%)	8 (1%)	123 (4%)	
Frontal Medium	427 (13%)	29 (5%)	398 (14%)	
Frontal Large	165 (5%)	14 (3%)	151 (5%)	
Occipital Small	52 (2%)	4 (<1%)	48 (2%)	
Occipital Medium	130 (4%)	36 (7%)	94 (3%)	
Occipital Large	37 (1%)	25 (5%)	12 (.4%)	
Temporal/Parietal Small	86 (3%)	26 (5%)	60 (2%)	
Temporal/Parietal Medium	275 (8%)	109 (20%)	166 (6%)	
Temporal/Parietal Large	225 (7%)	149 (27%)	76 (27%)	
Missing	104 (3%)	20 (4%)	84 (3%)	

Bivariate Analysis

Relationship of the Composite Risk Score to CHI Status. The first independent variable analyzed for its relationship with CHI was a composite variable, the "Composite Risk Score" for each subject according to the existing *Clinical Scoring System to Assess the Risk of Skull Fracture and Associated Intracranial Injury* ("Greenes and Schutzman Risk Scoring System" [Scalp Score]) (Greenes & Schutzman, 2001) (Table 7). This scoring system was designed to grade the risk of skull fracture and associated intracranial injury in children under age 2 using a scoring scheme that identifies various levels of risk for four categories of age in months, four categories of hematoma size, and three categories of hematoma location. The total risk score ranges from 0 (lowest risk) to 8 (highest risk). For those *with* CHI, of those with sufficient data to produce a Scalp Score composite risk score (n=532), 40% (214/532) had a Scalp Score composite risk score of 4 points or less, and 60% (318/532) had a Scalp Score composite risk score of 5-8 points. In comparison, for those *without* CHI, of those with sufficient data to produce a Scalp Score composite risk score (n=2,693), 89% (2,390/2,693) had a Scalp Score composite risk score of 4 points or less, and 11% (295/2,693) had a composite risk score of 5-8 points. A composite risk score of "6" was the most frequent score in those *with* CHIs, representing 19% (102/532) of the scores for children with CHIs. In comparison, a score of "3" was the most frequent score in those *without* CHIs, representing 25% (672/2,693) of the scores for children without CHIs. There were incomplete data to determine the Scalp Score composite risk score for 3% (104) of the 3,329 study subjects; 19% (20/104) of the subjects with missing data had a CHI.

Relationship of patient age and gender with CHI. A total of 32% (179/552) of the children who had sustained a CHI were under the age of 3 months compared to 18% (490/2,777) of those without CHI (p<.001). As a continuous variable ranging from 0-23, age in months also demonstrated a statistically significant association with CHI (mean age with CHI 6.5 months (SD=6.1) vs. mean age with no CHI of 9.9 months (SD=6.8). There were no statistically significant associations found between the presence of CHI with any other demographic characteristics, but male children were more likely to have sustained CHI than female subjects (*p*=.016) (Table 4). A two-sided *p*-value <.05 was considered statistically significant.

Relationship of scalp hematoma presence and region with CHI. Of the 3,329 children under age two who had a CT scan, most (76%) of those who had sustained a CHI had a scalp hematoma, while only 24% of those who were negative for CHI had a scalp hematoma (*p*<.001) (Table 8). More than half (51%, *n*=284) of the 552 CHIs resulted from injuries to the temporal/parietal region of the skull. Injuries to the occipital and frontal regions represented considerably fewer CHIs, at 12% (*n*=65) and 9.2% (*n*=51), respectively. There were incomplete data to determine the region or size of hematoma for 3% (*n*=104) of the 3,329 study subjects.

Relationship of severity of injury mechanism with CHI Status. Almost equal proportions of children with and without CHI were injured by medium or high severity injury mechanisms: ninety-six percent (509/532) of the children who had sustained a CHI had been injured by a medium or high severity injury mechanism compared to 89% (2,429/2,737) of those without CHI (Table 6). Falls from greater than three feet represented the most frequent high severity mechanism. The injury mechanisms which demonstrated statistically significant associations with CHI status were “fall to ground from standing/walking/running” and “fall from an elevation” (both *p*<.001). The mechanism “fall from an elevation” did not include falls from stairs as they were separately reported. The observed difference in the percentage of children with and without CHI who were injured by the mechanism “fall from an elevation” was the only difference considered both statistically significant and clinically significant. However, the observed differences in the percentage of children with and without CHI injured by other mechanisms such as "motor vehicle crash" and "pedestrian struck by moving vehicle" may not have reached statistical significance due to small numbers of cases for these mechanisms in the parent study. There were incomplete data to determine the severity of injury mechanism for 2% (*n*=63) of the 3,329 study subjects.

Relationship of other clinical variables to CHI. The variables of *any suspected or reported loss of consciousness following the injury*, *GCS < 15 or other signs of altered mental status* (which represented a GCS of 14 or other signs of altered mental status in the current study because children with GCS of less than 14 were excluded), *any vomiting since the injury, and parental concern of child not acting normally* all demonstrated associations with CHI, and all except for *suspected or reported loss of consciousness following the injury* were statistically significant at $p<.001$ (Table 9). However, it is important to note that none of these associations were considered clinically significant because the associations for all these variables were negative. Possible reasons for these unexpected results will be discussed in more detail later in Chapter V and include issues with missing data for some variables, developmental and physiological differences in this age group, and global challenges with the neurologic assessment of infants and young children.

Table 9

Variables Analyzed Based on "Classic Assumptions" by CHI Status

Independent Variable	Overall (N=3,329)	Positive for CHI (n=552; 17%)	Negative for CHI (n=2,777; 83%)	p-value
Any vomiting since the injury (n=3,289)				<.001
Yes	851 (26%)	86 (16%)	765 (28%)	
No	2,438 (73%)	457 (82%)	1,981 (71%)	
Missing	40 (1%)	9 (2%)	31 (1%)	
Any reported or suspected LOC since the injury (n=3,054)				.006
Yes (Reported)	248 (7%)	27 (5%)	221 (8%)	
Suspected	130 (4%)	40 (7%)	117 (4%)	
Suspected *or* Yes	378 (11%)	13 (2%)	338 (12%)	.479
No	2,676 (81%)	457 (83%)	2,219 (80%)	
Missing	275 (8%)	55 (10%)	220 (8%)	
GCS = 14 or other signs of altered mental status (agitated, sleepy, slow to respond) (n=3,309)				<.001
Yes	922 (28%)	186 (34%)	736 (26%)	
No	2,387 (72%)	361 (65%)	2,026 (73%)	
Missing	20 (<1%)	5 (1%)	15 (<1%)	
Parental concern of child not acting normally/like themselves (n=3,108)				.194
Yes	982 (29%)	145 (26%)	837 (30%)	
No	2,126 (64%)	353 (64%)	1,773 (64%)	
Missing	221 (7%)	54 (10%)	167 (6%)	

Note. * "Any TBI on CT" includes complex and depressed skull fractures but does not include linear skull fractures.

Multivariable Analysis

Regression Models 1, 2, and 3: The Scalp Score Models. Models 1, 2, and 3 are presented in Table 10. Model 1 included only the Scalp Score's composite risk score. For each additional unit increase in the composite risk score, the odds of having a CHI increased by 82% (AOR=1.82, 95% CI= [1.73, 1.92], p<.001).

Table 10

Hierarchical Multivariable Logistic Regression Models 1, 2, and 3

Independent variable AOR, (95% CI), P-value	**Model 1 (*n*=3,325)**	**Model 2 (*n*=3,164)**	**Model 3 (*n*=2,747)**
Scalp Score's Composite Risk Score* for age in months, hematoma location and hematoma size	1.87 (1.73, 1.92), <.001	1.82 (1.72, 1.93), <.001	1.90 (1.78, 2.03), <.001
Severity of injury mechanism**		< .001 (*df* = 2)	< .001 (*df* = 2)
Mild (RC)	-	-	-
Moderate	-	1.51 (.91, 2.50), .108	1.52 (.88, 2.64), .134
Severe	-	2.82 (1.70, 4.69), <.001	2.86 (1.64, 4.98), <.001
Any vomiting since the injury	-	-	.83 (.61, 1.14), .252
Any suspected or actual loss of consciousness since the injury	-	-	1.24 (.80, 1.20), .342
Parental concern of child not acting normally	-	-	.95 (.70, 1.30), .747
GCS of 14 or other signs of altered mental status (agitated, sleepy, slow to respond)	-	-	1.62 (1.19, 2.19), .002
Area under the ROC curve 95% CI for AUC	.792 (.769, .816)	.804 (.781, .828)	.824 (.800, .847)

Note. * "Composite Risk Score" according to the existing "Clinical scoring system to assess the risk of skull fracture and associated intracranial injury" [Scalp Score] (Greenes & Schutzman, 2001).
Severity of injury mechanism defined as follows: **Mild=fall from ground level (or fall to ground from standing, walking or running), **Moderate**=any mechanism that doesn't fall into "low" or "high" severity category, **Severe**=falls of > 3 feet for children < 2 years of age; head struck by high impact object (such as a baseball); motor vehicle collision with patient ejection, death of another passenger, or rollover; pedestrian or bicyclist without helmet struck by motorized vehicle (Kuppermann et al., 2009)

Model 2 added the variable "severity of injury mechanism," with a reference category of "low." After adjusting for the effect of severity of injury, the AOR of the Scalp Score's composite Score remained identical, with every unit increase in total score increasing the odds of having sustained a CHI by 82% (AOR=1.82, 95% CI=[1.72, 1.93], *p*<.001). Having sustained a medium severity injury as opposed to a low severity injury increased the odds of a CHI by 51% (AOR = 1.51, 95% CI=[.91, 2.50], *p*=.108) and having sustained a high severity injury as opposed to a low severity injury increased the odds of a CHI by 182% (AOR=2.82, 95% C.I.=[1.70, 4.69], *p*<.001).

Model 3 added the remaining four independent variables of "any vomiting since the injury," "any reported or suspected loss of consciousness since the injury," "any parental report of child not acting normally" and "any altered mental status on exam" to Model 2. After adjusting for the effects of the four new variables in Model 3, the total Scalp Score's composite Risk Score demonstrated a slightly increased impact, as with every additional unit increase in total score the odds of having sustained a CHI increased by 190% (AOR=2.90, 95% CI=[1.78, 2.03], *p*<.001). Having been injured by a high-severity mechanism as compared to a low severity mechanism was the only additional risk factor that demonstrated a statistically significant increase in the odds of CHI (AOR=3.86, 95% CI=[1.64, 4.98], *p*<001). Vomiting since the injury and parental concern of not acting normally both demonstrated AORs which demonstrated minimal to no association with CHI; and neither association was statistically significant.

Regression Models 4, 5, and 6: The Scalp Score's Component Models. The results of Models 4, 5, and 6 are presented in Table 11. The reference category for the "Hematoma Location and Size" variable was "no hematoma." In Model 4, each additional month of age decreased the odds of having sustained a CHI by 8.0%, adjusting for hematoma size and location (AOR=.92, 95% CI=[.904, .937], *p*<.001).

Table 11

Hierarchical Multivariable Logistic Regression Models 4, 5, and 6

Independent variable **AOR, 95% CI, P-value**	**Model 4** **(*n*=3,325)**	**Model 5** **(*n*=3,164)**	**Model 6** **(*n*=2,747)**
Age in months	.92 (.90, .94), <.001	.93 (.91, 94), <.001	.91 (.89, .93), <.001
Hematoma Location and Size (combined variable)	<.001 (df = 9)	<.001 (df = 9)	<.001 (df = 9)
None (RC)	-	-	-
Frontal Small	.78 (.37, 1.63), .506	.82 (.39, 1.74), .610	.55 (.20, 1.53), .248
Frontal Medium	.99 (.65, 1.52), .977	1.01 (.66, 1.64), .977	.835 (.50, 1.40), .492
Frontal Large	1.67 (.93, 3.01), .087	1.608 (.87, 2.97), .129	1.89 (.96, 3.72), .064
Occipital Small	1.12 (.39, 3.18), .834	1.22 (.43, 3.49), .707	1.30 (.39, 4.34), .672
Occipital Medium	5.47 (3.54, 8.46), <.001	5.43 (3.46, 8.52), <.001	7.033 (4.30, 11.51), <.001
Occipital Large	28.66 (13.71, 59.94), <.001	29.55 (13.85, 63.03), <.001	32.01 (14.41, 71.12), <.001
Temporal/Par Small	4.74 (2.86, 7.86), <.001	5.02 (2.98, 8.43), <.001	5.71 (3.20, 10.21), <001
Temp/Par Medium	7.69 (5.656 10.46), <.001	8.015 (5.85, 10.98), <.001	9.52 (6.73, 13.46), <.001
Temp/Par Large	23.30 (16.63, 32.66), <.001	24.47 (17.13, 34.96), <.001	24.98 (16.80, 37.14), <.001
Severity of injury mechanism*		< .001 (df = 2)	< .001 (df = 2)
Mild (RC)	-	-	-
Moderate	-	1.81 (1.06, 3.08), .029	1.73 (.97, 3.09), .063
Severe	-	3.31 (1.94, 5.66), <.001	3.165 (1.77, 5.67), <.001
Any vomiting since the injury	-	-	.82 (.60, 1.12), .216

Table 11

Cont.

Independent variable AOR, 95% CI, P-value	Model 4 (*n*=3,325)	Model 5 (*n*=3,164)	Model 6 (*n*=2,747)
Any suspected or actual loss of consciousness since the injury	-	-	1.32 (.84, 2.07), .234
Parental concern of child not acting normally	-	-	.94 (.68, 1.29), .697
GCS of 14 or other signs of altered mental status (agitated, sleepy, slow to respond)	-	-	1.66 (1.21, 2.28), .002
Area under the ROC 95% CI for AUC	.807 (.784, .830)	.817 (.794, .840)	.839 (.817, .862)

Note. * Severity of injury mechanism defined as follows: **Low**=fall from ground level (or fall to ground from standing, walking or running), **Medium**=any mechanism that doesn't fall into "low" or "high" severity category, **High**=falls of > 3 feet for children < 2 years of age; head struck by high impact object; motor vehicle collision with patient ejection, death of another passenger, or rollover; pedestrian or bicyclist without helmet struck by motorized vehicle.

The most notable result from Model 4 was that the presence of a large occipital hematoma *or* a large temporal/parietal hematoma increased the odds of having sustained a CHI by 28.7 times and 22.3 times, respectively. Overall, the variables which demonstrated statistically significant impacts in Model 4 were age in months (AOR=.92, 95% CI=[.90, .94], p<.001); an occipital medium hematoma as compared to no hematoma (AOR=5.47, 95% CI=[3.54, 8.46], p<.001); an occipital large hematoma as compared to no hematoma (AOR=28.7, 95% CI=[13.7, 59.9], p<.001); a temporal/parietal small hematoma as compared to no hematoma (AOR=4.74, 95% CI=[2.86, 7.86], p<.001); a temporal/parietal medium hematoma as compared to no hematoma (AOR=7.70, 95% CI=[5.66, 10.46], p<.001); and a temporal/parietal large hematoma as compared to no hematoma (AOR=23.3, 95% CI=[16.6, 32.7], p<.001).

Model 5 added one additional variable to Model 4: the severity of injury mechanism. After adjusting for the additional impact of injury severity in Model 5, age in months demonstrated a similar independent effect in Model 5 as it did in Model 4, with every additional month of age decreasing the odds of having sustained a CHI by 7.5% (AOR=.93, 95% CI=[.91, .94], p<.001). Overall, the variables which demonstrated statistically significant impacts in Model 5 were age in months; an occipital medium hematoma as compared to no hematoma (AOR=5.43, 95% CI=[3.46, 8.52], p<.001); an occipital large hematoma as compared to no hematoma (AOR=28.6, 95% CI=[13.9, 63.0], p<.001); a temporal/parietal small hematoma as compared to no hematoma (AOR=5.02, 95% CI=[2.98, 8.43], p<.001); a temporal/parietal medium hematoma as compared to no hematoma (AOR=8.02, 95% CI=[5.85, 10.98], p<.001); a temporal/parietal large hematoma as compared to no hematoma (AOR=24.5, 95% CI=[17.1, 35.0], *p*<.001); and a high severity injury mechanism as compared to a low severity injury mechanism (AOR=4.31, 95% CI= [1.94, 5.66], *p*<.001).

Model 6 built upon the previous two models and added four additional variables based on what are commonly considered "classic assumptions" regarding the symptoms of CHI in the general population. These variables include any reported vomiting, any reported or suspected LOC, any altered mental status on exam, and parental concern of child not acting normally, and were the same variables added to Model 3. The adjusted odds ratios in Model 6 remained fairly consistent with those of Models 4 and 5, increasing slightly for every variable except for frontal small or medium hematoma, where they decreased slightly. Overall, statistically significant effects in Model 6 were: age in months (AOR=.91, 95% CI=[.89, .93], *p*<.001); an occipital medium hematoma as compared to no hematoma (AOR=7.03, 95% CI=[4.30, 11.5], *p*<.001); an occipital large hematoma as compared to no hematoma (AOR=32.0, 95% CI=[14.1, 71.1], *p*<.001); a temporal/parietal small hematoma as compared to no hematoma (AOR=5.72, 95% CI=[3.20, 10.2], *p*<.001); a temporal/parietal medium hematoma as compared to no hematoma (AOR=9.52, 95% CI=[6.73, 13.5], *p*<.001); a temporal/parietal large hematoma as compared to no hematoma (AOR=25.0, 95% CI= [16.8, 37.1], *p*<.001); and a high severity injury mechanism as compared to a low severity injury mechanism (AOR=3.17, 95% CI= [1.77, 5.67], *p*<.001).

Regression Assumptions

In Models 4, 5, and 6, multicollinearity of the three independent variables related to hematoma size and location was addressed by creating a composite variable of "Hematoma Location and Size" which combined all three previous independent variables into one. The Hosmer-Lemeshow test was used to assess the goodness of fit of the data for the variables in each model. In Models 1 and 2, the Hosmer-Lemeshow test indicated that the model was *not* a good fit for the data (χ^2=41.33, p <.001 for Model 1, and (χ^2=39.601, p < .001 for Model 2); in Model 3, the Hosmer-Lemeshow test indicated that the model *was* a good fit for the data ((χ^2=18.719, p=.016). In Models 4, 5, and 6, the Hosmer-Lemeshow test also indicated that the model *was* a good fit for the data in all three models (χ^2=21.46, p = .006 for Model 4, χ^2=12.782, p=.120 for Model 5, and χ^2=12.363, p=.136 for Model 6).

Summary of Findings from the Six Regression Models

In the multivariable analysis, the following variables demonstrated statistically significant associations (all p<.001) with CHI in Models 1, 2, and 3: The Scalp Score's Composite Score (representing a risk score based on the child's age in months, location and size of hematoma) and a high severity mechanism of injury. The following variables demonstrated statistically significant associations with CHI in Models 4, 5, and 6: age in months, occipital hematomas that were medium or large (as compared to no hematoma), temporal/parietal hematomas that were small, medium or large (as compared to no hematoma), and high severity injury mechanism (as compared to low severity injury mechanism).

Research Question 2

The second research question was: What is the age "cut point" in months which represents the most accurate dichotomy to predict CHI in children under age 2 with suspected minor head injuries in this sample? The 23 indicator variables for age demonstrated sensitivities that ranged from 7.8% (for <1 month) to 98.6% (for < 23 months), and specificities ranging from 3.1% (for < 23 months) to 95.1% (for < 1 month) (Table 12).

Table 12

Sensitivity and Specificity of 23 Cut-points in Age with CHI

Age in Months	**Total Overall (*n*=3,329)**	**Positive for CHI (*n*=552)**	**Negative for CHI (*n*=2,777)**	**Sensitivity for detecting CHI**	**Specificity for detecting CHI**	**Youden Index**
<1 month	180 (5%)	43 (24%)	137 (76%)	7.8%	95.1%	.029
<2 months	451 (14%)	119 (26%)	332 (74%)	21.6%	88.0%	.096
<3 months	669 (20%)	179 (27%)	490 (73%)	32.4%	82.4%	.148
<4 months	844 (25%)	228 (27%)	616 (73%)	41.3%	77.8%	.191
<5 months	1,037 (31%)	272 (26%)	765 (74%)	49.3%	72.5%	.217
<6 months	1,227 (37%)	316 (26%)	911 (74%)	57.2%	67.2%	.244
<7 months	1,403 (42%)	345 (25%)	1,058 (75%)	62.5%	61.9%	.244
<8 months	1,560 (47%)	377 (24%)	1,183 (76%)	68.3%	57.4%	.257
<9 months	1,712 (51%)	406 (24%)	1,306 (76%)	73.6%	53.0%	.265
<10 months	1,844 (55%)	424 (23%)	1,420 (73%)	76.8%	48.9%	.257
<11 months	1,996 (60%)	437 (22%)	1,559 (78%)	79.2%	43.9%	.230
<12 months	2,118 (64%)	444 (21%)	1,674 (79%)	80.4%	39.7%	.202
<13 months	2,242 (67%)	454 (20%)	1,788 (80%)	82.2%	35.6%	.179
<14 months	2,341 (70%)	464 (20%)	1,877 (80%)	84.1%	32.4%	.165
<15 months	2,447 (74%)	473 (19%)	1,974 (81%)	85.7%	28.9%	.146
<16 months	2,565 (77%)	480 (19%)	2,085 (81%)	87.0%	24.9%	.119
<17 months	2,671 (80%)	487 18%)	2,184 (82%)	88.2%	21.4%	.096

Table 12

Cont.

Age in Months	**Total Overall (*n*=3,329)**	**Positive for CHI (*n*=552)**	**Negative for CHI (*n*=2,777)**	**Sensitivity for detecting CHI**	**Specificity for detecting CHI**	**Youden Index**
<18 months	2,774 (83%)	496 (18%)	2,278 (82%)	89.9%	18.0%	.078
<19 months	2,887 (86%)	510 (18%)	2,367 (82%)	92.4%	14.8%	.072
<20 months	2,980 (90%)	521 (17%)	2,459 (83%)	94.4%	11.5%	.058
<21 months	3,075 (92%)	529 (17%)	2,546 (83%)	95.8%	8.3%	.042
<22 months	3,162 (95%)	539 (17%)	2,623 (83%)	97.6%	5.5%	.032
<23 months	3,236 (97%)	544 (17%)	2,692 (83%)	98.6%	3.1%	.016

Since a goal of the current study was to identify variables which would help identify children at moderate to high risk of CHI, for Research Question Two the key priority was to identify the age cut-point with the highest sensitivity for the outcome of CHI while retaining moderate specificity. Youden's index was used to identify the cut-point of maximum overall accuracy in identifying CHI within the range of 0-23 months (Table 12). A regression model was computed using only one independent variable: age as a continuous variable ranging from 0-23 months. Predicted probabilities were computed, and a receiver operating curve was constructed so that the point of maximum overall accuracy (based on age alone) could be identified. The coordinates for the receiver operating curve were used to calculate the age that corresponded to each predicted probability. The age of 8.46 months was the age cut-point that maximized Youden's index for this sample with a value of 0.265.

While maximizing the specificity was also a goal, it was not as high a priority as maximizing sensitivity because in the context of the current study it does not involve missed injuries. Therefore, a secondary goal of the analysis of the age cut-points was to identify the age (or ages) at which marked increases or decreases in sensitivity for CHI occurred. A marked increase in sensitivity for CHI occurred at the age cut point of "less than two months" (22% sensitivity versus 8% sensitivity for the prior age cut point of "less than one month"). Between the ages of "less than one month" and "less than six months," sensitivity increased by an average of 10% (range of 8% – 14%) with each additional month of age. In contrast, between the ages of "less than seven months" and "less than 23 months," sensitivity increased by an average of 2% (range of 1% - 5%) with each additional month of age.

Research Question 3

The third research question was: Could the *Clinical Scoring System to Assess the Risk of Skull Fracture* by Greenes and Schutzman (2001) (the Scalp Score) be utilized by the ED triage nurse to accurately identify the risk of underlying CHI in children under age two presenting for evaluation of a suspected minor head injury?

The AUC for each regression model in the current study was estimated to determine where the receiver operating curve substantially improved, thereby indicating stronger model predictive ability for CHI (Figures 6-11). A two-sided p-value <0.05 was considered statistically significant. The goal of the receiver operating curve analysis in the current study was to identify the model with an AUC closest to 1.0 that contained a set of independent variables which maximized predictive value for CHI without containing additional variables deemed minimally impactful to that predictive value.

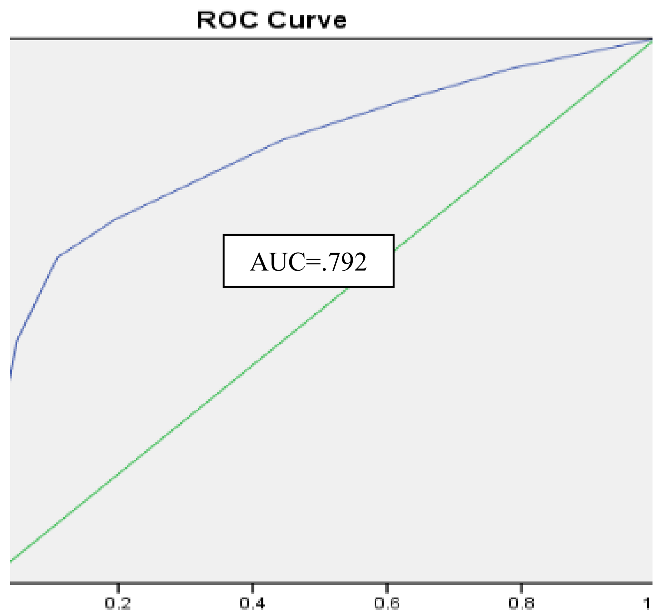


Figure 6. ROC Curve for Regression Model 1.

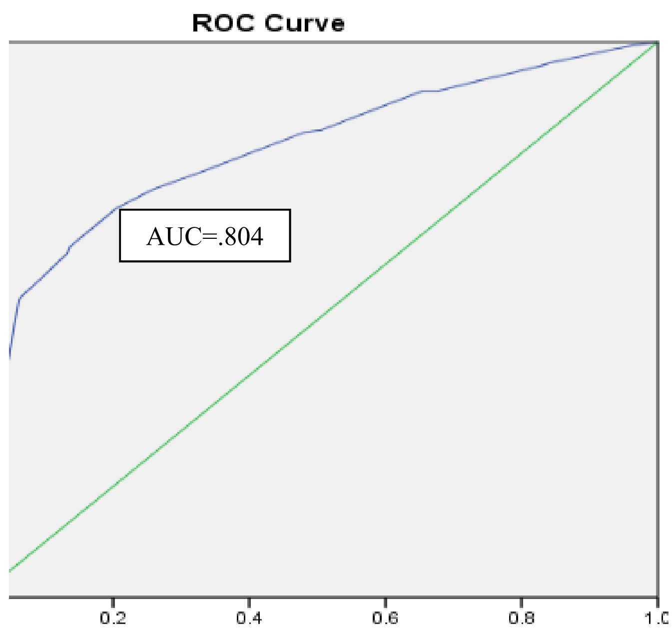


Figure 7. ROC Curve for Regression Model 2.

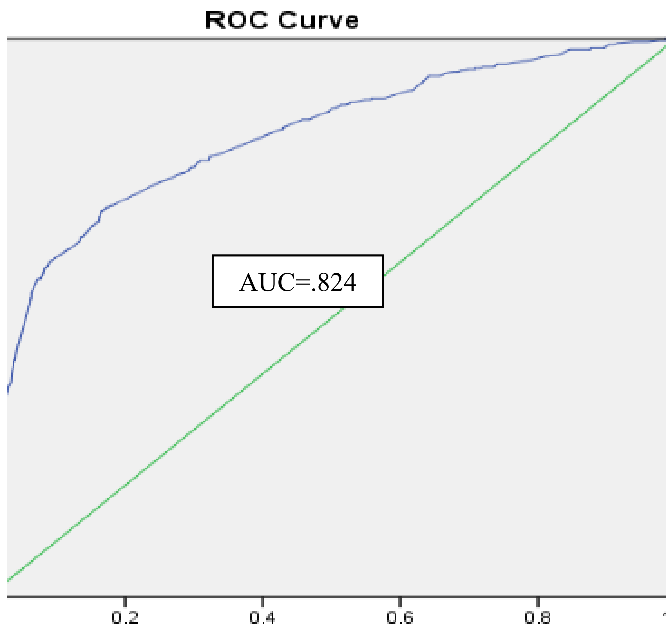


Figure 8. ROC Curve for Regression Model 3.

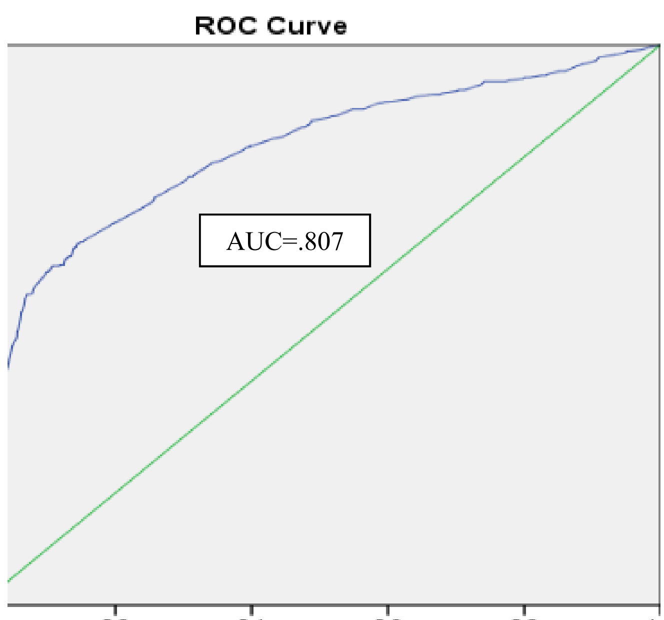


Figure 9. ROC Curve for Regression Model 4.

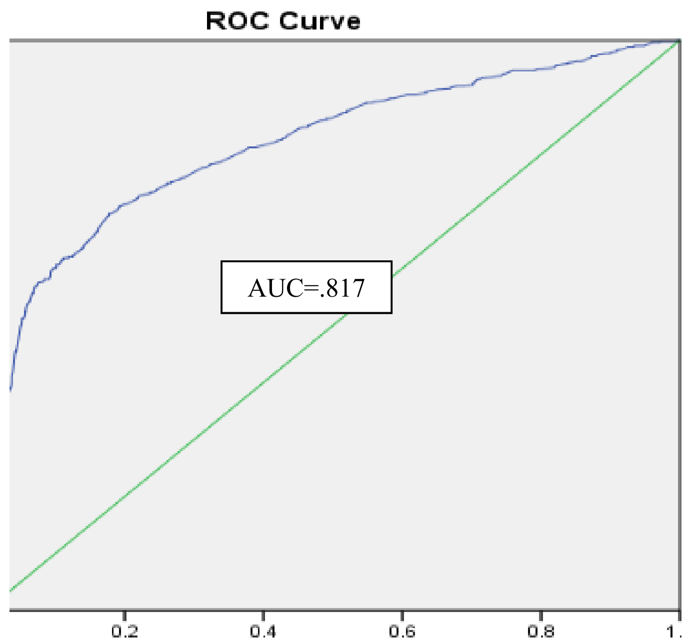


Figure 10. ROC Curve for Regression Model 5.

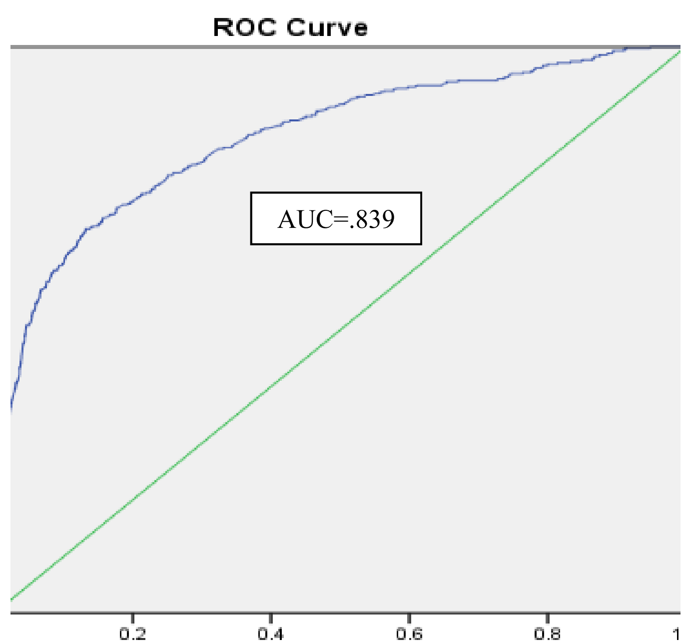


Figure 11. ROC Curve for Regression Model 6.

The AUC for Model 1 (Figure 2) was .792 (95% CI=[.77, .82], p<.001), indicating a good test or combination of variables as compared to chance. The AUC for Model 2 (Figure 3) was .804 (95% C.I.=[.78, .83], p<.001), indicating a slightly higher degree of predictive accuracy for CHI than Model 1 (Figure 2). The AUC for Model 3 (Figure 4) was .824 (95% CI=[.80, .85], p<.001), a slightly higher overall predictive ability for CHI as compared to Models 1 and 2. The AUC for Model 4 (Figure 5) was .807 (95% CI=[78, .83]), p<.001, indicating a good combination of variables as compared to chance. The AUC for regression Model 5 (Figure 6) was .817 (95% CI=[.79, .84]), p<.001, slightly higher than the .807 of Model 4. The AUC for regression Model 6 (Figure 7) was .839, (95% CI=[.82, .86], p<.001, slightly higher than Models 4 and 5 and the highest of all six models.

Summary of the Findings

The predictive ability of all six regression models to identify CHI was similar using AUC, ranging from a low of .792 for Model 1, to a high of .839 for Model 6. Considering the subject's age in months as a continuous variable (Models 3, 4, and 5) improved the overall performance of the model as compared to considering the age as a categorical variable (Models 1, 2, and 3). The variable representing severity of injury mechanism added a small amount of predictive ability to Models 1 and 4 and demonstrated statistical significance in all models for which it was included. Several of the independent variables included in Models 3 and 6 demonstrated no statistical significance, so while the AUC increased slightly for both models, the variable combinations are not ideal in identifying CHI. Of the six regression models, Models 4 and 5 demonstrated the best overall predictive ability for CHI while also demonstrating goodness of fit and retaining a parsimonious combination of variables. In answer to Research Question 3, the Scalp Score does not contain the optimal combination of variables, in the optimal format, to accurately predict the risk of underlying CHI in children under age two.

CHAPTER V

DISCUSSION

The purpose of the current study was to identify the variables associated with the risk of CHI in children under age two with suspected minor head injuries based on a Glascow Coma Score (GCS) that indicates they are neurologically-appropriate (GCS=15), or close to neurologically appropriate (GCS=14), on exam. This is the population of children that is the most difficult to assess for nurses and medical providers alike, because they are often considered clinically asymptomatic even when they have sustained a CHI. The goal of the current study was to propose a set of variables that, when considered together, have a high degree of predictive accuracy in identifying CHI in this population. This set of variables could be used to inform a clinical decision rule for the emergency department (ED) triage nurse assessment, designed as a risk scoring system to optimize evidence-based acuity decisions.

The current study was a secondary data analysis of the public-use dataset from the largest prospective, multi-center pediatric head injury study found in the current literature. The study examined the relationship of age in months, injury characteristics, reported signs and symptoms and presenting signs and symptoms with the risk of a closed head injury (CHI) in children under age two who are assessed for a suspected minor head injury. As part of the secondary analysis, an existing clinical decision rule by Greenes and Schutzman (2001) (the "Scalp Score") was tested using a sample of 3,329 children under age two, to determine whether it, or the individual variables within it, could be used alone or in conjunction with other variables to accurately predict the risk of underlying CHI in this population. This chapter includes a discussion of the study's findings.

The number of children under age two used as the sample in the current study was larger than the samples of children under age two found in prior studies that focused on head injuries. Due in part to its large size and prospective, multicenter design, the parent study has been the source for many secondary analyses which are still being published to date. Comparisons to prior research discussed in this chapter avoided the secondary analyses that shared the same parent dataset. An exception included if the outcome used was different than the outcome used in the current study. For example, the Dayan et al. (2014) secondary analysis of the same parent dataset excluded isolated linear skull fractures in its outcome. Isolated linear skull fractures were included in the current study, because ED triage nurses seek to identify children at moderate to high risk of *any* skull fracture, not just those who may have depressed or complex skull fractures.

The work of Schutzman et al. (2001), Greenes and Schutzman (2001), and Bin et al. (2010) most closely mirrored the current study in regard to patient age, outcome of interest and variables examined, so these studies served as a major basis for comparison with the current study. However, their sample sizes were much smaller than the current study (172 and 203, respectively). Their clinical decision rule, the Scalp Score, was initially derived in 2001 and validated in 2010. It was one of the first clinical decision rules created to help predict skull fracture and associated intracranial injury specifically in children under age two, and was designed to aid in the medical provider's assessment and decision regarding neuroimaging. This clinical decision rule's outcomes match the outcomes of the current study. However, the Scalp Score's derivation and validation studies examined the two outcomes of skull fracture and intracranial injury studied separately, whereas the current study used a composite variable (CHI) that combined them. The Scalp Score was tested in the current study's regression analysis to examine its accuracy at predicting CHI in a sample of 3,329 children under age two.

Sample Characteristics

Nationwide, about half of the children under age two who present to EDs for evaluation of their head injury receive neuroimaging (usually a CT scan), of which approximately 10% have some degree of documented underlying CHI (Mahajan, 2014). The current study included all children under age two from the parent study who *had* a CT scan (3,329 of 10,721; 31%). The percentage of children who had a CT scan in the parent study was lower than many nationwide estimates of CT scanning rates, most likely because the medical providers in the parent study worked in pediatric referral EDs. Providers who work in pediatric referral EDs generally have more experience with and exposure to pediatric patients, so it is reasonable to assume that they have more confidence assessing pediatric head injuries and may be less likely to order diagnostic imaging (such as CT scans) since CT scans are known to have the potential for harm.

In the current study of children whom had a CT scan, 1,780/3,329 (54%) were male. Of the children who had a CHI visible on CT scan, 321 (58%) were male, consistent with literature and prior research that indicates that male children have higher rates of head injury as compared to female children (Bin et al., 2010; Burns et al., 2016; Settle, Lawrence, & Kummerow, 2005). Bin et al. (2010), one of the few prior pediatric head injury studies that focused on exactly the same age group as the current study, reported that the mean age of their 203 imaged children under age two was 8.24 months (*SD*, 6.5). Whereas, the mean age of the 3,329 children in the current study was lower at 6.5 months (*SD*, 6.1), a difference which may be due to the much larger sample size and higher number of young infants included in the current study.

Injury Characteristics

In comparison to the literature and to the results of other studies, it is important to note that the number of CHIs in any given study will vary according to the inclusion criteria, imaging protocols and outcome used. For example, Mahajan (2014) states that approximately 3%-10% of children under age two with suspected minor head injuries and seemingly normal neurological exam will have an intracranial injury, with less than 1% having an injury requiring neurosurgical intervention. However, such broad estimates generally refer to *all* children under age two with suspected minor head injuries (both imaged and non-imaged). In contrast, since CT scanning is the diagnostic standard for skull fracture and intracranial injury, studies of CHIs can only report *definitive* CHIs for their patients who *had* CT scans. In contrast, the parent study by Kuppermann et al. (2009) that used the outcome of *clinically important traumatic brain injury* (ciTBI) was able to report on ciTBIs in both their imaged *and* non-imaged patients because they sought to identify only the most *severe* injuries which necessitated medical or surgical intervention. Kuppermann et al. (2009) conducted close follow-up of their non-imaged patients and concluded that any “missed” ciTBIs that resulted from a lack of imaging were eventually captured during telephone follow up, or when the patient returned to the original healthcare institution, another local healthcare institution, or died, due to clinical deterioration. The research team had methods in place to track all of the above scenarios. Because their outcome of ciTBI referred to only the most serious and life-threatening types of injuries, this assumption was reasonable.

The outcome of the parent study was different from the outcome of the current study because the question being asked in triage is *different* than the question being asked by the medical provider who assesses the child the question the parent study addresses. The medical provider is typically concerned with, “should this child get a CT scan?,” and the triage nurse is typically concerned with, “of those children who *appear* well after a head injury, which ones are at *high enough* risk of CHI that they should be assigned an ESI-2 (or urgent) acuity level so that they are expedited to an exam by a medical provider?” The outcome of the parent study matched their question. For instance, the outcome of the parent study did *not* include simple or linear skull fractures; it only included depressed skull fractures which are known to represent a high risk of secondary brain injury. This may be because when a non-displaced, linear skull fracture is suspected, the medical provider may choose to avoid CT scanning and use x-ray instead, which is known to involve considerably less risk to the patient in terms of radiation exposure. In contrast, the outcome of the current study *did* include linear skull fractures and smaller traumatic brain injuries that may not require urgent intervention, because the ED triage nurse is concerned about the possible presence of *any* CHI. In essence, the ED triage nurse must cast a "wider net" than that of the medical provider in order to identify the children at moderate to high risk for any CHI, because triage occurs *first*, before the medical provider's assessment. The triage nurse's acuity decision is the major factor that determines who sees a medical provider, and in what order.

In the current study, 3,329 (31%) of the children under age two received a CT scan. Of the sample of 3,329 children who received a CT scan in the current study, 552 (17%) sustained an underlying CHI, a number that is higher than the 10% estimate given by Mahajan (2014). However, the estimate by Mahajan (2014) was based on a 50% rate of CT scanning, whereas the rate in the current study was lower, at 31%. If 50% of the children under age two from the parent study had actually received a CT scan, the percentage with underlying CHI might have been closer to 10%. Therefore, the percentage of children found to have CHI, as a proportion of the total number of children under age two from the parent study, was consistent with Mahajan's estimate.

The results of the current study supported the findings of prior studies that found the presence of a skull fracture to be an independent predictor of intracranial injury (Bin et al., 2010; Dayan et al., 2014), but also highlighted the fact that one cannot *rule out* intracranial injury simply because there is no sign of overlying skull fracture. Of the 552 children who sustained a CHI in the current study, 82% of the injuries (n=450) included a skull fracture, but 18% (102/552) sustained an intracranial injury *in the absence of* a skull fracture. Sixty percent (268/450) of the skull fractures in the current study were linear, non-displaced fractures and the remaining 40% (182/450) were complex or depressed skull fractures, some of which also included intracranial injuries. Of the 552 children who sustained a CHI, almost 18% (*n*=98) of the children with CHIs had injuries considered ciTBIs.

First Research Question

The first research question was concerned with the variables that are significantly associated with the risk of underlying CHI in children under age two with suspected minor head injuries. The variables examined were identified *a priori* based on the literature and the PIs prior experience. Some variables, such as hematoma location and size, were examined because they have shown strong associations with CHI in smaller studies. Other variables, such any vomiting since the injury and any suspected or actual loss of consciousness, were examined because they are considered "classic" signs and symptoms of head injury across the lifespan. The variable of severity of injury mechanism was examined because it has been found to be an independent predictor of traumatic brain injury (a slightly different outcome than the current study). This variable was also included because the PIs prior experience, as well as one past study by Griffin et al. (2014), have shown that there is a gap in nursing knowledge, fueled largely by a gap in nursing and ED triage resources, regarding how to properly differentiate mechanism of injury severity for children under age two.

Relationship of Patient Age to Likelihood of CHI

A total of 32.4% (179/552) of the children who had sustained CHIs were under the age of 3 months (p<.001) in the current study. That is higher than the 24% (42/172) reported in the previous study by Greenes and Schutzman (2001) that examined almost an identical age group of 0-24 months but contained a much smaller sample. As a continuous variable ranging from 0-23, age in months also demonstrated a statistically significant association with CHI (p<.001). This is consistent with the parent study and other prior research that has found that there is a higher incidence of skull fracture in the first year of life (Powell et al., 2015; Shiomi et al., 2016). The younger the child, the weaker their neck muscles, the softer and more pliable their skull, and the more limited their ability to brace falls; therefore, the higher their risk of sustaining an underlying CHI from blunt head trauma (Bin et al., 2010; Griffin et al., 2014; Kuppermann et al., 2009; Powell et al., 2015).

Relationship of Presence of Scalp Hematoma to CHI

In the parent study, most, (74%, [3,329/4,476]) of the children who had a scalp hematoma had a CT scan. In the current study, scalp hematoma size and location demonstrated the highest degree of association with CHI among all the variables examined. Of the 3,329 children under age two who had a CT scan, most (76.1%) of those who sustained CHIs had a scalp hematoma, while only 23.6% of those who were negative for CHI had a scalp hematoma (p<.001). Since the presence of a scalp hematoma is a known risk factor for underlying skull fracture, that was likely the reason that most of the children with scalp hematomas had a CT scan. The results of the current study regarding the associations of hematoma location and size with CHI were consistent with the findings of Burns et al. (2016) who studied a different parent dataset of 2,043 patients under age two who had a CT scan, but excluded isolated linear skull fractures in their outcome.

In the regression analyses, the presence of a scalp hematoma was analyzed as part of a composite variable combining the presence/absence of any scalp hematoma, the location of any scalp hematoma, and the size of any scalp hematoma. When a hematoma was present, the hematoma size for those who had sustained a CHI was usually considered medium or large by a subjective measurement detailed by the parent study (Kuppermann et al., 2009). This is consistent with prior literature that has identified both hematoma presence and size as independent predictors of underlying skull fracture or intracranial injury (Bin et al., 2010; Dayan et al., 2015; Greenes & Schutzman, 2001).

Relationship of Region of Scalp Hematoma to CHI

Slightly more than half (51.4%, *n*=284) of the 552 CHIs in the current study resulted from injuries to the temporal/parietal region of the skull. Injuries to the occipital and frontal regions represented considerably fewer CHIs, at 11.8% (*n*=65) and 9.2% (*n*=51), respectively. This finding supports the literature that states that the occipital and frontal bones are stronger and more durable than the parietal and temporal bones, so are less vulnerable to fracture (Bethel, 2012). The high degree of association between temporal/parietal hematomas with CHI was consistent with the results of prior studies such as those by Greenes and Schutzman (2001) and Bin et al. (2010). However, the findings of the current study indicate that while occipital hematomas occur much *less frequently* than temporal/parietal hematomas, when they *do* occur, they can be at least equally concerning for underlying CHI. Findings from Greenes and Schutzman (2001) revealed no statistically significant association between skull fractures or intracranial injuries with *occipital* hematomas in children age 0-24 months. However, the authors noted that children with occipital hematomas seemed to have a "somewhat increased risk for skull fracture" (p. 91). The much smaller sample size of imaged children (172) in the Greenes and Schutzman study versus 3,329 in the current study was likely the reason for this variance in findings regarding occipital hematomas.

The reason why occipital hematomas occur much less frequently than those to other areas of the skull is likely multifactorial, related to fall characteristics as well as characteristics of the various skull regions. For example, the occiput is a relatively small region of the skull at the lower posterior area of the head and is not likely to be the first part of the head to hit the floor during a fall from a caregiver's arms or a fall from furniture. The occiput does not protrude as much as the larger, rounded temporal/parietal region or the frontal region, which further protects it from being the first point of impact. As discussed already, the temporal region of the skull is the thinnest of the skull regions and also overlies a major cerebral artery. While the temporal/parietal regions are often combined for assessment and research purposes due to their close proximity, it is important to note that the temporal region is at the highest risk of underlying skull fracture or other intercranial injury when subject to blunt trauma due to anatomical and physiological differences alone. However, this distinction is not commonly acknowledged in present nursing and triage resources.

In the current study, the odds ratios for medium *or* large occipital or temporal/parietal hematomas were the highest of all independent variables studied. Odds ratios for the current study were compared to the odds ratios from the Greenes and Schutzman (2001) study because the authors examined some of the same variables in an almost identical age group. However, a direct interpretation should be cautioned against because Greenes and Schutzman (2001) reported odds ratios for hematoma size separately from hematoma location. Whereas, the current study used a composite variable that differentiated three hematoma sizes in the three regions of the skull. This composite variable was created to avoid multicollinearity in the regression analysis between the three variables that related to scalp hematoma. Greenes and Schutzman (2001) reported an odds ratio of 38.2 for a parietal hematoma, 16.0 for a temporal hematoma, 2.8 for an occipital hematoma, and 0.6 for a frontal hematoma. The range of odds ratios for a large occipital hematoma (28.7-32.0) in the current study were similar to the range of odds ratios for a large temporal/parietal hematoma in the current study (23.3-25.0), indicating that a large occipital hematoma can be at least *as* concerning for underlying CHI as a large temporal/parietal hematoma. In comparison to the Greenes and Schutzman (2001) study, the current study included *many* more children who had occipital hematomas (219/552 [40%] in current study, versus 17/172 [10%] in the Greenes and Schutzman study).

Relationship of Specific Injury Mechanisms to CHI

Seventy-eight percent (433/552) of those who sustained a CHI had been injured from a fall, a finding consistent with the prior research (Crowe et al. 2012; Greenes & Schutzman, 1999; Hawley et al., 2013; Powell et al., 2015; Settle, Lawrence, & Kummerow, 2005). The observed differences between the children with and without CHI who were injured by the mechanism "fall from stairs" did not reach statistical significance in the current study at p=.161. One reason for this result may be the large variation in fall lengths and heights for falls from stairs, details which were not captured for this mechanism of injury. Recent literature has highlighted the fact that many children under age two who sustain CHIs have been injured by being dropped from a caregiver's arms (Burrows et al., 2015; Griffin et al., 2014; Hughes et al., 2016), currently considered high severity mechanism for this age when the height of the fall is over three feet. The results of this study strengthen the argument that falls (including being dropped from a caregiver's arms) is the most frequent severe injury mechanism in children under age two. Other severe mechanisms at this age include falls from shopping carts and changing tables, because both typically represent falls from an elevation of 3 – 3.5 feet. Because most children under age two with head injuries have been injured as the result of a fall or being dropped, it is also imperative that the triage nurse know the fall heights associated with low, moderate and high severity falls for children under age two. This information is not commonly found in existing nursing and triage resources.

It is important to remember that the parent study collected data on children who had suspected *minor* head injuries based on their clinical presentation; this did not include children who met national "trauma criteria" (Sasser et al., 2012) and received expedited medical assessment such as those injured in some motor vehicle crashes or pedestrian versus vehicle crashes. However, it is also worth noting that some children injured by such mechanisms initially appear well and neurologically appropriate despite having sustained CHI, and some of these children are brought to the ED by private auto or ambulance and therefore subject to ED triage. It is therefore imperative that the triage nurse be familiar with their institution's "trauma criteria" so they can properly identify and escalate these children.

Relationship of Neurological Status and Loss of Consciousness to CHI

The variables of *any suspected or reported loss of consciousness following the injury*, *GCS < 15 or other signs of altered mental status,* and *parental concern of child not acting normally,* all four demonstrated *negative independent* associations with CHI, so they probably would *not* be included in a clinical decision rule designed as a risk scoring system for CHI that added incremental points for each individual variable. However, these variables added a small degree of predictive accuracy to identifying CHI when they were present together in a regression model. This makes sense, because when assessing head injuries, the presence of multiple concerning signs or symptoms, even if some of them are not *independently* associated with CHI, causes higher concern for possible CHI. In a clinical decision rule for identifying CHI in children under age two, it would make sense to include "qualifying information" for the clinical decision rule, and to disqualify those with multiple signs and symptoms. For example, a child who presented to ED triage with a reported LOC, a history of vomiting, a parent who was concerned that the child wasn't acting normally, *and* had an altered mental status on triage exam, would be considered "urgent"; the triage nurse would not need a clinical decision rule to aid in that assessment or acuity decision.

With the exception of *suspected or reported loss of consciousness following the injury*, all four of the above variables were statistically significant at $p<.001$ in the bivariate analysis. However, it is important to note that none of these associations were considered *clinically* significant. Possible reasons for these unexpected results include issues with missing data for some variables, and global challenges with consistent neurologic assessment of infants. Most children under age two who present for a suspected minor head injury appear neurologically appropriate on exam (Bin et al., 2010; Kuppermann et al., 2009) making neurological assessment difficult and often inconclusive for caregivers and medical providers alike. Children under age two with head injuries do not typically present with true altered mental status unless significant brain injury has occurred with mass effect (Mahajan, 2014).

The parent study used the Glascow Coma Scale (GCS) to evaluate neurological status. Since 1974, the GCS has been a key tool used by both pre-hospital and in-hospital healthcare professionals to assess mental status and the severity of traumatic brain injury (Savitsky, Givon, Rozenfeld, Radomislensky, & Peleg, 2016). However, interrater reliability has been generally weak across studies (Savitsky et al., 2016) especially when the patient is a child (Simpson et al., 1991). Mental status assessment in children, and especially in those under age two, is a challenge that has been well documented in the literature. The suggested method by which to assess neurological status in young children varies in the current literature, primarily because the original GCS scale was developed for the assessment of people who were verbal (and many children under age two are not yet verbal). Some authors suggest using a modified pediatric GCS; others suggest using a simpler scale that is easy to interpret such as the “AVPU” scale that involves a quick assessment of whether the child is “alert,” responds to “verbal” stimulation, responds to “painful” stimulation, or is “unresponsive” (Gaichas et al., 2006).

While an extended loss of consciousness (LOC) of more than five minutes is always concerning for CHI following a head injury and is not being disputed, most of the time, reports of loss of consciousness in the parent study referred to isolated, short (less than five minutes), or questionable “suspected” LOC. Loss of consciousness following a head injury has classically been considered a concerning sign for underlying CHI across the lifespan. However, in the current literature, there is a lack of consensus regarding the significance of a transient or isolated LOC following a head injury. The significance of an isolated LOC has been previously studied by Lee et al. (2014) in their secondary analysis of the same parent study using the more severe outcome variable of ciTBI, the outcome of the parent study. The results of the secondary analysis by Lee et al. (2014) showed that an isolated LOC, in the absence of any other PECARN predictors for ciTBI, had a risk ratio of only 0.10 (95% CI, .06-.19) for ciTBI. The current study examined “any suspected or reported LOC following the injury” as an independent variable and found *no* association with CHI in this sample. A transient or isolated, brief LOC following a head injury can actually be a normal response to the trauma (Bethel, 2012). The take-away point is that in children under age two with suspected minor head injuries, results suggested that a suspected or actual LOC of less than five minutes is not necessarily a cause for concern in regard to risk of CHI.

Relationship of Vomiting to CHI

Vomiting is often considered concerning following a head injury due to the fact that vomiting can be a symptom of increased intracranial pressure, which occurs when there is bleeding or swelling within the brain. However, vomiting in children can also be a normal response or reaction to injuries (Bethel, 2012). For example, some young children with age-appropriate anxiety may vomit from crying very hard; others may have a pre-existing illness that includes vomiting, and infants may spit up after every feeding as a baseline behavior. All of these considerations make the presence of vomiting in a head-injured child difficult to assess for its possible association with the injury. In the current study, the variable of *any vomiting since the injury* had a *negative* independent association with CHI that was statistically significant; however, this was not considered clinically significant due to the multiple factors discussed above. While the variable *any vomiting since the injury* was significant in the bivariate analysis, it did not demonstrate statistical significance in the regression modeling. Notably, studies are consistent in reporting that *continued* vomiting (vomiting three or more times) is a more concerning finding, even in this age group (Kuppermann et al., 2009). In contrast to vomiting, a bulging anterior fontanelle is *also* a symptom of increased intracranial pressure, but that finding is *always* concerning, because it is rarely if ever "normal." *Any* infant with a bulging anterior fontanelle should be considered at least urgent, or ESI-2, according to the Emergency Severity Index (Gilboy et al., 2012), regardless of whether there has been a reported head injury. A bulging anterior fontanelle would be considered another "disqualifier" for a clinical decision rule for identifying CHI in children under age two.

The investigators in the parent study only ordered a CT scan if they felt it was indicated (if they had a concern). Thus, it is reasonable to assume that the 3,329 children from the parent study who had a CT scan done were the most symptomatic or at highest risk for underlying CHI due to some combination of age-and injury-related factors. Descriptive data for the 7,392 (69%) of children under age two who did *not* receive a CT, as compared to the 3,329 (31%) of children under age two who *did* receive a CT, are presented in Table 13.

Table 13

Characteristics of Entire PECARN Sample of Children Under Age Two, Comparing Those Who Had a CT with Those Who Did Not

Independent Variable	***No* CT Done (*N*=7,392; 69%)**	**CT Done (*N*=3,329; 31%)**	**Positive for CHI (*n*=552; 17%)**	**Negative for CHI (*n*=2,777; 83%)**
Age in months (*n*=10,904)	12.6 ± 6.3 (0, 23)	9.4 ± 6.8 (0, 23)	6.5 ± 6.1 (0, 23)	9.9 ± 6.8 (0, 23)
Under 3 mos.	478 (7%)	669 (20%)	179 (32%)	490 (18%)
3 mos. – 23 months	6,914 (93%)	2,660 (80%)	373 (68%)	2,287 (82%)
Missing	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Hematoma Location and Size (*n*=10,483)				
None	4,310 (58%)	1,697 (50%)	132 (24%)	1,565 (56%)
Frontal Small	507 (7%)	131 (4%)	8 (1%)	123 (4%)
Frontal Medium	146 (2%)	427 (13%)	29 (5%)	398 (14%)
Frontal Large	157 (2%)	165 (5%)	14 (3%)	151 (5%)
Occipital Small	1,359 (18%)	52 (2%)	4 (<1%)	48 (2%)
Occipital Medium	231 (3%)	130 (4%)	36 (7%)	94 (3%)
Occipital Large	235 (3%)	37 (1%)	25 (5%)	12 (.4%)
Temporal/Parietal Small	263 (4%)	86 (3%)	26 (5%)	60 (2%)
Temporal/Parietal Medium	17 (<1%)	275 (8%)	109 (20%)	166 (6%)
Temporal/Parietal Large	33 (<1%)	225 (7%)	149 (27%)	76 (27%)
Missing	134 (2%)	104 (3%)	20 (4%)	84 (3%)

Table 13

Cont.

Independent Variable	***No* CT Done (*N*=7,392; 69%)**	**CT Done (*N*=3,329; 31%)**	**Positive for CHI (*n*=552; 17%)**	**Negative for CHI (*n*=2,777; 83%)**
Severity of injury mechanism* (*n*=10,613)				
Mild	1,244 (17%)	328 (10%)	20 (4%)	308 (11%)
Moderate	4,845 (66%)	1,856 (56%)	257 (47%)	1,599 (58%)
Severe	1,258 (17%)	1,082 (32%)	252 (46%)	830 (30%)
Missing	45 (<6%)	63 (2%)	23 (4%)	40 (1%)
Any vomiting since the injury (*n*=10,639)				
Yes	714 (10%)	851 (26%)	86 (16%)	765 (28%)
No	6,636 (90%)	2,438 (73%)	457 (82%)	1,981 (71%)
Missing	42 (<1%)	40 (1%)	9 (2%)	31 (1%)
Any reported or suspected LOC since the injury (*n*=10,301)				
Yes (Reported)	98 (1%)	248 (7%)	27 (5%)	221 (8%)
Suspected	65 (<1%)	130 (4%)	40 (7%)	117 (4%)
Suspected *or* Yes	163 (2%)	378 (11%)	13 (2%)	338 (12%)
No	7,084 (96%)	2,676 (81%)	457 (83%)	2,219 (80%)
Missing	145 (2%)	275 (8%)	55 (10%)	220 (8%)
GCS = 14 or other signs of altered mental status (agitated, sleepy, slow to respond) (*n*=10,652)				
Yes	289 (4%)	922 (28%)	186 (34%)	736 (26%)
No	7,054 (96%)	2,387 (72%)	361 (65%)	2,026 (73%)
Missing	49 (<7%)	20 (<1%)	5 (1%)	15 (<1%)
Parental concern of child not acting normally/like themselves (*n*=10,297)				
Yes	458 (6%)	982 (29%)	145 (26%)	837 (30%)
No	6731 (91%)	2,126 (64%)	353 (64%)	1,773 (64%)
Missing	203 (3%)	221 (7%)	54 (10%)	167 (6%)

Note. * Severity of injury mechanism defined as follows: **Mild**=fall from ground level (or fall to ground from standing, walking or running), **Moderate**=any mechanism that doesn't fall into "mild" or "severe" severity category, **Severe**=falls of > 3 feet for children < 2 years of age; head struck by high impact object; motor vehicle collision with patient ejection, death of another passenger, or rollover; pedestrian or bicyclist without helmet struck by motorized vehicle.

The children in the parent study who did *not* have a CT scan done were assumed to be negative for ciTBI if follow up revealed no further sequelae from their injury. However, some of these children may well have sustained a less *serious* CHI (such as a linear skull fracture) that went unidentified. While children with less serious CHIs may not require medical or surgical intervention, they are still of concern to the triage nurse who is trying to minimize the child's risk of secondary injury by expediting the medical assessment and clinical observation for these children.

Notably, many children in the parent study who *did not* have a CT done *did* have personal or injury- related characteristics that were found to be independently associated with the risk of CHI in children under age two, in the current study. For example, 7% (478/7,392) of the children who *did not* have a CT done were under three months of age, versus 20% (669/3,329) of the children who *did* have a CT done. A total of 10% (779/7,392) of the children who *did not* have a CT done had a hematoma that was independently associated with CHI at this age versus 23% (753/3,329) of the children who *did* have a CT done (either an occipital medium or large hematoma, or a temporal/parietal hematoma of any size). A total of 17% (1,258/7,392) of the children who *did not* have a CT done had been injured by a severe mechanism for this age group, versus 32% (1,002/3,329) of the children who *did* have a CT done. Furthermore, children under age two who *did* have CTs done in the parent study were more likely than the ones who *did not* have CTs done to have *any reported or suspected LOC*, *any history of vomiting since the injury*, a *GCS=14 or other signs and symptoms of altered mental status*, or *parental concern of the child not acting normally.*

Second Research Question

The second research question was concerned with the age "cut point" in months that represented the most accurate dichotomy to predict CHI in children under age two with suspected minor head injuries. The age of 8.46 months, which could be simplified as "< 9 months," was the cut point that maximized overall accuracy. Interestingly, this age was very close to the mean age (of 9.4 months) for the 3,329 children in the overall sample. As previously discussed, it has been established that infants (children < 12 months of age) are at higher risk of CHI as compared to older children. The cut point of 8.46 months supports this. A developmental characteristic that likely influences this cut point is the fact that most infants are not yet walking at the age of eight months but are beginning to pull up on furniture and other objects and "cruise," or attempt to walk, holding onto objects, thereby putting themselves at higher risk for falls. At eight to nine months of age these children also have little if any sense of danger, further increasing their risk of injury.

While 8.46 months represented the best cut-point of overall accuracy, it is important to remember that "overall accuracy" considers both sensitivity and specificity. When trying to predict which children are at risk for CHI, maximizing sensitivity is a higher priority than maximizing specificity. A marked increase in sensitivity occurred at the age cut point of "< two months" (22% sensitivity at this age versus 8% sensitivity for the prior cut point of "< one month"). Between the ages of "less than one month" and "less than "six months," sensitivity increased by an average of 10% (range of 8% - 14%) with each additional month of age. In contrast, between the ages of "< seven months" and "less than 23 months," sensitivity for identifying CHI increased by an average of 2%

(range of 1% - 5%) with each additional month of age. The considerably higher increases in sensitivity for the younger age cut points was reflective of the considerably higher incidence of CHIs sustained as a proportion of the total number of children within these ages who had a CT scan. Within the sample of 3,329 children age 0-23 months, a considerable 37% (1,227/3,329) were less than six months, and 57% (316/552) had sustained an underlying CHI. Within the same sample, 20% (669/3,329) were less than three months, and 32% (179/552) had sustained an underlying CHI. Most existing nursing and triage resources lack guidance regarding how to differentiate risk of CHI based on age in months for children under age two, but this information would be helpful for the ED triage nurse.

Third Research Question

The third research question was concerned with whether the Scalp Score contained the optimal combination of variables, in the optimal format, to accurately identify the risk of underlying CHI in children under age two presenting for evaluation of a suspected minor head injury. The Scalp Score clearly contains the three variables that are most highly associated with CHI according to prior research and according to the results of the current study: age in months, hematoma size, and hematoma location. Model 1, which included only the Scalp Score's composite risk score, showed that for every additional unit increase in the composite risk score, the odds of having a CHI increased by 82% (AOR=1.82, 95% CI=[1.73, 1.92], $p<.001$). The area under the curve for Regression Model 1 was .792 (95% CI=[.769, .816]). However, the subsequent regression models demonstrated increased predictive accuracy, so while the Scalp Score would be helpful in identifying CHI in children under age two, the Scalp Score as-is does not contain the optimal set of variables in the optimal format to accurately predict CHI in children under age two.

The Scalp Score does not include variables such as vomiting, altered mental status according to caregiver or provider, or history of loss of consciousness. This makes sense because these variables, which are known to be "classic" signs and symptoms of head injury, are difficult to assess in children under age two due to age-related limitations and developmental differences. Of note, children with obvious signs of altered mental status were excluded in its derivation study (Greenes & Schutzman, 2001). The above variables, especially those related to mental status assessment, can also be very subjective and tend to have lower interrater reliability in children under age two as compared to variables such as hematoma location and size which are more objective. These variables were included in the regression modeling for the current study, largely to challenge "classic head injury assumptions" and to demonstrate that such assumptions cannot always be applied to children under age two. Models 3 and 6 both included the variables of *any vomiting since the injury, altered mental status on exam, parental concern of not acting normally, and any history of loss of consciousness*. These two models had slightly increased predictive accuracy for detecting CHI in the regression modeling, which indicates that when these variables are present *together*, they represent an increased risk of CHI. However, based on the individual results of the regression analyses and on the results of the bivariate analyses it is reasonable to conclude that these variables would not contribute substantial overall value to a risk scoring system designed to predict CHI in children under age two with suspected minor head injuries.

Regression Models 4, 5, and 6 that included the *component* parts of the Scalp Score rather than its composite risk score demonstrated increased predictive accuracy for CHI. For example, when considering the composite risk score of the Scalp Score, any size occipital hematoma represents a lower level of risk for CHI than any size temporal/parietal hematoma. However, based on the results of the current study, medium and large *occipital* hematomas can represent *at least equal* risk for underlying CHI than medium and large *temporal/parietal* hematomas. This is an important point and suggests that further differentiation of hematoma size and location would be warranted in a future clinical decision rule. This was one factor that led to the conclusion that the Scalp Score as-is would not be ideal for use in predicting CHI in the sample studied.

While age as a continuous variable also increased the predictive accuracy for predicting CHI in Regression Models 4, 5, and 6, it was a small increase. Therefore, no further differentiation of age would be suggested in a future clinical decision rule. Finer granularity for age could result in a risk assessment tool that is tedious and therefore unrealistic for use in ED triage. The existing Scalp Score includes risk-related cut-points for age that are supported by prior research and the findings of the current study: 0-2 months, 3-5 months, 6-11 months, and 12 months – 23 months. The fact that an age < 3 months represents a higher risk of CHI was well supported by the results of the current study and marked increases in sensitivity for CHI occurred up to the age of 6 months. While the most accurate cut point overall for identifying CHI could be simplified as being < 9 months, this considered the maximum combination of sensitivity and specificity together, while a clinical decision rule for identifying CHI would be more concerned with maximizing *sensitivity* so injuries were not missed. Having several risk-stratified categories for age in months, with larger points values for the younger ages, would be one way to address this in a clinical decision rule designed as a risk scoring system.

A severe injury mechanism (most common is a fall from over three feet in children under age two) added predictive accuracy in every model for which it was included. For example, in Model 5, a severe injury mechanism as opposed to a mild severity injury mechanism increased the child's odds of having sustained an underlying CHI by 331% (AOR=4.31, 95% CI=[1.94, 5.66], $p<.001$). The parent study by Kuppermann et al. (2009) published severity categories which differentiate by age and have been widely adopted by the medical and research communities. Thus, these categories of severity, which specify that a fall from over 3 feet is considered a *severe* injury mechanism for a child under age two, are well supported by other studies and by the parent study's results.

The importance of accurately assessing the severity of injury mechanism based on the child's age, cannot be understated. Thus, the severity of injury mechanism is a variable that should be included in any risk scoring system for children under age two. The rationale for this recommendation is threefold: 1) Severity of injury mechanism is an *independent* predictor of CHI in children under age two, and this can be easy to forget when the child appears "well," or neurologically appropriate and medically stable; 2)

Many children under age two with suspected minor head injuries are clinically asymptomatic or appear "well"; and 3) Information regarding what constitutes a "severe" versus "mild" or "moderate" injury severity mechanism for children under age two versus older children is not commonly found in existing triage resources.

Strengths and Limitations of the Study

This study was a secondary analysis of existing data, which is a limitation of the study for several reasons. The data in the study were collected from June, 2004 to September, 2006, so it was over 12 years old at the time of the current study. This represents a limitation to the degree that assessment of head injuries, treatment of head injuries, or CT scanning technology might have changed since that time. The sensitivity of CT scanners is the issue of most concern within these three possible factors. However, if CT scanners have become more sensitive in detecting CHI, that means that there would likely be more positive CHIs representing very small, clinically insignificant, findings on a CT scan done more recently. Therefore, this limitation is not a great concern and could even be considered a strength.

Another limitation of the current study is that due to the secondary nature of the data, the children could not be directly assessed. The sample available had already been subject to the inclusion and exclusion criteria of the parent study. Specifically, the greatest limitation is that the children who did *not* have a CT scan could not be assessed, because it is reasonable to assume that some of these children had a CHI such as a linear skull fracture, that was missed. To allow for a comparison of the two groups, Table One presents a summary of the characteristics for the children who *had* a CT done versus the children who *did not* have a CT done. The current study had no way to identify "missed cases" of CHI from the parent study so only those children who had a CT scan were included in the current study.

The fact that the data for the current study were from the largest multicenter prospective study of pediatric head injuries found in the current literature, conducted according to best practices for clinical decision rule development, was a major strength of the current study. Since its initial validation, the PECARN (parent) study has been externally validated and been found to be reliable in practice for identifying children at a very low risk of ciTBI (Schonfeld et al., 2014). It has also been subject to multiple secondary analyses which continue to be published to date.

Studies of head injuries vary widely in their inclusion and exclusion criteria. For example, some studies such as the parent study exclude subjects injured by "trivial" mechanisms or include only subjects with symptoms following their injury (Pickering et al., 2011). While this may make sense, it also introduces selection bias for a diagnostic test (or clinical decision rule) being developed as a result of the study and represents a limitation of the current study. The current study's exclusion criteria mirrored those of the parent study, that excluded children injured by trivial mechanisms such as falling from ground level or walking into a stationary object with no signs or symptoms of head trauma other than abrasions or lacerations (Kuppermann et al., 2009).

The exclusion criteria were likely chosen by the parent study because children injured by such trivial mechanisms are typically at very low risk for *ciTBI* and very unlikely to be deemed in need of a CT scan to evaluate their injury. However, since CT scan is the diagnostic standard for CHI, this was an unavoidable limitation, and is a limitation that exists in most other pediatric head injury studies for the same reason. The "perfect" study of CHIs in children under age two would be one in which 100% of the children presenting for evaluation of a head injury were subject to a CT scan. However, because of the risks associated with CT scans, especially in young children who are much more vulnerable to the effects of radiation, it would be unethical and a waste of resources to subject children to CT scanning simply for research purposes without a valid medical reason. Therefore, the current study represented the most reasonable and ethical "best case scenario" for a secondary analysis of CHI; a large sample obtained from a prospective multicenter study implemented by trained researchers and team members according to best practices for clinical decision rule development.

The parent study by Kuppermann et al. (2009) had broader inclusion criteria than the current study because it utilized a reference standard as opposed to a gold standard to identify its outcome of ciTBI (Kuppermann et al., 2009; Pickering et al., 2011). The parent study was concerned with identifying children with the most severe injuries, those requiring urgent surgical or medical intervention, so the assumption was that by using a reference standard that included close follow-up, any missed ciTBIs would be eventually captured. However, because the current study was concerned with identifying not just ciTBIs but also the less life-threatening CHIs, and because a CT scan is the diagnostic standard for CHIs (skull fractures and intracranial injuries), the children under age two who did *not* receive a CT scan were not included in the current study.

Finally, the subjective measurement of hematoma size in the parent study could also be considered a limitation of the current study. However, interrater reliability was considered moderate for this variable in the parent study κ=.74) (Kuppermann et al., 2009; Dayan et al., 2014) and similar subjective measurements have been used in other studies of pediatric head injury by Greenes and Schutzman (2001) and Burns et al. (2016). In addition, subjective measurement using concise descriptors such as "barely palpable," or "large and boggy" is more realistic to the ED triage setting, where brief assessments are done under time pressure, as opposed to obtaining precise measurements using a measuring tape.

Implications of the Study

Implications for Theory

The results of the current study have multiple theoretical implications based on the conceptual model used as a basis for the study. Examining the ED triage process through Donabedian's Structure, Process Outcome model (1988), the current study could strengthen the structure of ED triage in several ways so that the process would be more accurate and consistent. For example, the results of the current study could improve the structure of ED triage by adding to the evidence-base utilized in both academic and healthcare institution-based nursing education. The results could be disseminated immediately in emergency nursing education, and also in nursing education in any healthcare setting where injured children present for evaluation. Institution policies that require pediatric-specific education could help strengthen the structure of ED triage by affecting nurse characteristics/preparation, ensuring that all nurses who assess pediatric patients *have* this education as part of their required, professional competencies. A nurse-driven clinical decision rule for identifying CHI in children under age two could improve the structure of ED triage by serving as a resource for the triage nurse. Separate and specific injury severity criteria added to triage acuity rating systems such as ESI, and to national trauma criteria, could improve the structure of ED triage by providing age-specific guidance for assessing injury severity in children under age two. Utilizing the results of the current study for any or all of these structural improvements could help make the process of triage (triage assessments and acuity decisions) more evidence-based and consistent. While studying outcomes of triage was beyond the scope of the current study, one would assume that a more accurate ED triage process would lead to improved ED triage outcomes. This represents one of the opportunities for future research.

Implications for Future Research

Additional retrospective studies or chart reviews that examine the triage acuity assignment for all children under age two with a chief complaint of head injury, with and without a final diagnosis of CHI, would yield baseline triage accuracy rates that could be used as a foundation for future quality improvement initiatives targeted to increasing the accuracy and consistency of pediatric head injury triage. Studies that examine the performance of a validated clinical decision rule, either prospectively or retrospectively, to determine the risk of CHI in children under age two could yield valuable data regarding the value of such clinical decision rules. Lastly, additional prospective studies are needed that collect data regarding fall surfaces and fall heights and examine the influence of both of these factors with the resulting injury and outcome in children under age two.

Implications for Policy

Children under age two are among the age group with the highest rate of head-injury related ED visits in the U.S. (CDC, 2016) and globally (Crow et al., 2012). Since most pediatric studies of head injury focus on children of all ages, age-specific information is limited (Crowe et al., 2012). For instance, the current "Guidelines for Field Triage of Injured Patients" (Sasser et al., 2012), referred to and utilized as "trauma criteria" by many U.S. emergency medical services providers, do not differentiate falls-related criteria for children under age two versus children age two through 14, despite the fact that children under age two are known to be more vulnerable to CHIs from lower level falls than children over age two. All children age 0-14 are currently subject to the same trauma criteria of "falls of > 10 feet or two to three times the height of the child" as a qualifier for expedited "trauma" care (Sasser et al., 2012). Trauma criteria seek to identify those who have injuries that pose threat to life or limb, which is a different outcome than the outcome of the current study, which also included less severe injuries. However, in children under age two, mechanism of injury severity is an independent predictor of *any* CHI (Dayan et al., 2014), and falls from less than three feet are considered *severe* mechanisms of injury based on the PECARN study, which has become a gold-standard reference for medical providers. Fall heights, as well as child heights, are often estimated by caregivers who may or may not have even witnessed the actual falls.

The results of this study and of its parent study could be used to inform more age-specific recommendations for children under age two in national trauma criteria.

Implications for Emergency Department Triage

The data from the largest study of pediatric head injuries in the current literature shows that ED triage nurses need to change the way they assess head injuries in children under age two. Traditional assumptions based on what is known about head injuries in older children and adults do *not* apply to children under age two. Many children under age two who sustain CHIs only have a scalp hematoma as an outward sign or symptom, and this is especially common in the youngest infants.

Determining the child under age two's risk of CHI requires that the triage nurse be able to accurately assess the severity of the injury mechanism, as well as be familiar with the scalp hematoma characteristics that place children of this age group at greater risk of CHI. Since falls and being dropped are the most common mechanisms of injury for children under age two, information at the point of triage regarding common fall heights for this age group such as from a caregiver's arms, bed, couch, counter or shopping cart could be helpful in accurately assessing the severity of the injury mechanism. Having information at the point of care regarding the risks associated with the child's age in months; hematoma presence, size and location; and severity of injury would be very helpful to the ED triage nurse. This information could be presented in a risk scoring system for identifying CHI in children under age two and help the ED triage nurse determine which children should be made ESI-2, or urgent according to the Emergency Severity Index.

ED triage nurses could use the results of the current study to change the way they assess children under age two with head injuries. Due to age-related differences in CHI risk, any child under age two who presents to the ED for evaluation of a head injury should be triaged earlier rather than later; the younger they are, the more urgent is the need for a swift triage assessment to determine their risk of CHI and their acuity level. The children under age two who are at very low risk of CHI can be assigned ESI-4, or "nonurgent" status, according to the Emergency Severity Index. Those at moderate to high risk for CHI should be assigned "ESI-2" or "urgent" status, according to the Emergency Severity Index, and be prioritized appropriately to a medical provider.

A major take away point based on the results of the current study is that any child under age two who appears well, but has fallen or been dropped from a height of over three feet, has been injured by a high severity mechanism for their age and should be assigned an acuity level of ESI-2, or a level that reflects an urgent status, based on the injury mechanism alone, regardless of whether they have a scalp hematoma present. The younger the child, the higher their risk of CHI, even if they appear "well" or neurologically appropriate.

Implications for Education

The results of the current study have numerous implications for education of nurses, parents/caregivers, and others who care for children under age two such as day care workers. In addition to the implications already discussed for ED triage, nurses in outpatient pediatric clinics and urgent care centers could also benefit from having more information regarding common fall heights for children under age two. For example, a poster could be placed in pediatric offices to help educate parents/caregivers regarding the common ways children under age two fall, the common heights of those falls, and when to seek medical assessment for the fall. Similar information could be a valuable resource for daycare centers that care for children under age two, to help educate them regarding age-specific risk factors for CHI, and when to seek a medical assessment after a child under age two has a head injury.

Conclusion

Determining the risk of CHI in a child under age two who has a suspected minor head injury may be less difficult as one might think when accurate, evidence-based information is available at the point of care. According to the results of this study, the key to an accurate triage assessment includes familiarity with the main regions of the skull, being able to assess for the presence and size of any scalp hematoma and having access to accurate information regarding the child's age and the details of the injury mechanism. Regression Model 5 from the current study was the model that was assessed as containing the optimal mix of variables that could be used in a clinical decision rule for predicting CHI in children under age two. This model included 24 categories for the child's age in months, 10 categories for hematoma presence/size, and location, and three categories for severity of injury mechanism. However, in consideration of best practices for clinical decision rule development, the optimal structure of the variables would probably include *four* categories of age, such as in the Scalp Score, instead of 24 categories of age, as in Model 5. Those four categories appear to be appropriate risk-associated cut-points for age based on the results of the current study.

Future Research

The variables that should be considered by the triage nurse in identifying the risk of CHI in children under age two have been identified by the results of this study. The next step could involve further analysis of the variables from Model 5 regarding their predictive accuracy in identifying CHI in children under age two, and then determining how to appropriately scale each variable within a clinical decision rule designed as a risk scoring system. The variable of age in months could be analyzed as both a continuous variable and as a categorical variable with four categories of risk in determining how to best include it in a clinical decision rule. The resulting clinical decision rule could be designed in a similar structure to the Scalp Score but could include additional differentiation of risk based on hematoma presence, size and location, and will include an additional variable representing severity of injury mechanism. Since clinical decision rules and any calculations necessary with them can now be easily embedded into the electronic health record, the number of variables and categories within them suggested by the results of the current study could still be considered realistic within a clinical decision rule for ED triage.

The same parent study could be used for the testing of variables from Model 5 as was used in the current study. The results of this testing and analysis could inform a proposed, nurse-driven clinical decision rule that is designed specifically for ED triage. Future plans could include testing the new clinical decision rule in a prospective, multi-center study to determine whether it helps improve triage accuracy and consistency for children under age two.

A nurse-driven clinical decision rule, designed as a risk scoring system, could be embedded electronically in the triage assessment, with the final risk score linked to suggested acuity levels, and used as an adjunct in acuity decisions for children under age two presenting with head injuries, regardless of the acuity rating system used. Such a clinical decision rule could significantly change nursing practice by changing the way head injuries in children under age two are assessed in ED triage, and help optimize evidence-based triage decisions which may ultimately improve the outcomes of ED triage.

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