Epidemiology of Mild Traumatic Brain Injury with Intracranial Hemorrhage: Focusing Predictive Models for Neurosurgical Intervention

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■ OBJECTIVE: **To outline differences in neurosurgical intervention (NI) rates between intracranial hemorrhage (ICH) types in mild traumatic brain injuries and help identify which ICH types are most likely to benefit from creation of predictive models for NI.**

■ METHODS: **A multicenter retrospective study of adult patients spanning 3 years at 4 U.S. trauma centers was performed. Patients were included if they presented with mild traumatic brain injury (Glasgow Coma Scale score 13–15) with head CT scan positive for ICH. Patients were excluded for skull fractures, "unspecified hemorrhage," or coagulopathy. Primary outcome was NI. Stepwise multivariable logistic regression models were built to analyze the independent association between ICH variables and outcome measures.**

■ RESULTS: **The study comprised 1876 patients. NI rate was 6.7%. There was a significant difference in rate of NI by ICH type. Subdural hematomas had the highest rate of NI (15.5%) and accounted for 78% of all NIs. Isolated subarachnoid hemorrhages had the lowest, nonzero, NI rate (0.19%). Logistic regression models identified ICH type as the most influential independent variable when examining NI. A model predicting NI for isolated subarachnoid hemorrhages would require 26,928 patients, but a model predicting NI for isolated subdural hematomas would require only 328 patients.**

■ CONCLUSIONS: **This study highlighted disparate NI rates among ICH types in patients with mild traumatic brain injury and identified mild, isolated subdural hematomas as most appropriate for construction of predictive NI models. Increased health care efficiency will be driven by accurate understanding of risk, which can come only from accurate predictive models.**

INTRODUCTION

In the United States, an estimated 1.7 million people experience a traumatic brain injury (TBI) each year,[1] with 75% being considered a mild traumatic brain injury (mTBI) based on a Glasgow Coma Scale (GCS) score between 13 and 15.[2] Of these mTBIs, approximately 127,500 (10%) will have an intracranial hemorrhage (ICH) discovered on initial imaging.[3] This equates to roughly 1 mTBI with an ICH every 4 minutes. Owing to a concern for deterioration and potential requirement of a neurosurgical intervention (NI)—including surgical and monitoring interventions—most patients with mTBI and ICH who are first evaluated at a facility lacking neurosurgical capability will subsequently be transferred to

Key words
- Adult
- Intracranial hemorrhage
- Mild
- Neurosurgical intervention
- Traumatic brain injury

Abbreviations and Acronyms
AIS: Abbreviated Injury Scale
CCHR: Canadian CT Head Rule
CT: Computed tomography
ED: Emergency department
EDH: Epidural hematoma
GCS: Glasgow Coma Scale
ICD-9: International Classification of Diseases, Ninth Revision
ICH: Intracranial hemorrhage
ISS: Injury Severity Score
mTBI: Mild traumatic brain injury
NI: Neurosurgical intervention
NOC: New Orleans Criteria
SAH: Subarachnoid hemorrhage
SDH: Subdural hematoma
TBI: Traumatic brain injury

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the closest center providing neurosurgical coverage. Although requiring neurosurgical involvement for all patients with mTBI and ICH might seem as the most practical and safe solution, it may not be the most efficient interhospital transfer criterion.

As the resolution of computed tomography (CT) imaging has increased over time, our ability to detect smaller hemorrhages has increased, but our ability to understand the risk differences between hemorrhages of different sizes is not reflected in changing triaging practices. This situation leads to patients with small hemorrhages—which may not have not been identified in the past—being treated similarly to patients with large hemorrhages. For example, patients with mTBI and small subarachnoid hemorrhages (SAHs) are often transferred to higher level trauma centers but have NI rates near zero and are ultimately treated similarly to patients with concussions and no ICH.[4]

These inefficiencies and potential overutilization of resources have led some authors to suggest revisions are required in transfer guidelines for patients with mTBI and ICH.[5-8] A more recent study examined the effects of a nontransfer protocol for patients with mTBI and small ICH at a Level III Trauma Center without neurosurgical coverage.[9] This 6-year study demonstrated that a subset of patients with mTBI and small ICH could safely forgo direct neurosurgical care; no patient kept at the facility required a NI, and all patients were discharged home in good neurologic condition. However, the limitation of this nontransfer protocol was that it lacked the detail and power necessary for widespread implementation.

The medical community has reacted quickly in the past to blatant inefficiencies but has failed to react properly to others. When presented with the fact that only 10% of patients with a mTBI have a concomitant ICH, the medical community understood that 90% of patients were receiving unnecessary radiation exposure by way of CT scans. The reaction was to develop predictive models and scoring systems to determine which patients should receive head CT scans and which should not, thus significantly reducing the amount of unnecessary radiation exposure and expense.[10-12] Similarly, the same medical community now knows that only a small subset of patients (0%–9%) with mTBI and ICH will require NI, yet we have not developed accurate clinical decision tools to properly identify and triage this patient group.[5,11-19]

Notwithstanding the efforts by some researchers to investigate models and clinical decision tools predicting a patient's future neurosurgical risk, it has been difficult to create a decision tool with the ability to accurately identify which patients will or will not require a NI.[11,20] We believe the reason for this difficulty is due to the pervasive trend to evaluate all ICHs equally, instead of approaching each ICH type individually. There is a paucity of data on the risk of NI in patients with mTBI according to the type of ICH, which would better inform the development of clinical decision tools. The purpose of this study was to describe the in-hospital outcomes of patients with mTBI and ICH in terms of the specific ICH type and its accompanying NI and mortality rates.

MATERIALS AND METHODS

Study Site and Patient Population

This was a multicenter retrospective observational cohort study of consecutively admitted adult trauma patients over 3 years at 2 Level I Trauma Centers and 2 Level II Trauma Centers in the United States. All data were collected through the trauma registries at each hospital. Patients were included if they presented with a mTBI (emergency department [ED] Glasgow Coma Scale [GCS] score 13–15) and had a head CT scan positive for ICH that included at least 1 of the following diagnoses: cerebral contusion (excluding cerebral lacerations), traumatic SAH, subdural hematoma (SDH), or epidural hematoma (EDH) (International Classification of Diseases, Ninth Revision [ICD-9] codes 851.0–852.59). Patients were excluded from the study if they presented with skull fractures because the ICH type cannot be determined from skull fracture–related ICD-9 codes. Patients were also excluded if their only ICH-related ICD-9 code was "unspecified hemorrhage" (853.0–854.19) or if they presented with coagulopathy. An ICH type was considered isolated if the patient presented with a single ICH. This study was reviewed and approved by the institutional review board at each institution and was granted a waiver of consent.

Outcomes and Covariates

The primary outcome of this study was a neurosurgical procedure (craniotomy, craniectomy, or craniostomy; burr hole; placement of intracranial pressure monitor; or ventriculostomy). The secondary outcome was in-hospital mortality. Covariates were as follows: facility, age, sex, mechanism of injury (fall, motor vehicle accident, and other), ED GCS score, GCS components (eye, motor, verbal), severe head injury (maximum head Abbreviated Injury Scale [AIS] score $\geq$4), Injury Severity Score (ISS) (0–8, 9–15, 16–25, $\geq$26), normal ED systolic blood pressure (<120 mm Hg), normal ED respiratory rate (12–16 breaths/minute), normal ED pulse (60–100 beats/minute), normal ED body temperature (36.6°C–37.2°C), ED disposition, hospital length of stay (days), and hospital disposition.

Statistical Analysis

Univariate analyses used χ^2 test or Fisher exact test. One-way analysis of variance test was used to examine the association between all covariates and outcome measures. The χ^2 or Fisher exact test was used to examine the associations between ICH types and NI and in-hospital mortality. Stepwise multivariable logistic regression models were built to analyze the independent association between ICH variables and outcome measures; entry and exit criteria were 0.20 and 0.10, respectively. The presence of effect modification was examined for all variables included in the final logistic regression models. Area under the receiver operator curves, c-statistics, and Hosmer-Lemeshow goodness-of-fit statistics are reported for all adjusted logistic regression models. All statistical analyses were 2-tailed and had an α value of 0.05. SAS 9.3 (SAS Institute Inc., Cary, North Carolina), was used for all analyses.