Published in final edited form as:

J Trauma Acute Care Surg. 2014 April ; 76(4): 1089–1095. doi:10.1097/TA.000000000000155.

Management of Children with Mild Traumatic Brain Injury and Intracranial Hemorrhage

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Abstract

BACKGROUND—Traumatic brain injury (TBI) is a significant public health problem affecting tens of thousands of children each year, and an important subset of these patients sustains intracranial hemorrhage (ICH). The purpose of this study was to test the hypothesis that we could identify a subset of children with traumatic ICH who could be monitored on a general neurosurgery ward with a low risk of clinical deterioration.

METHODS—We performed a retrospective review of pediatric patients 18 years of age with mild TBI (Glasgow Coma Scale score 14–15) and traumatic ICH admitted to Saint Louis Children’s Hospital between 2006 and 2011. We excluded patients with injuries unrelated to the TBI that would require ICU admission and those with penetrating intracranial injuries.

RESULTS—We identified 118 patients meeting inclusion criteria. Repeat neuroimaging was obtained in 69/118 patients (58%). Radiologic progression was noted in 6/69 (8.7%) patients, with a trend toward more frequent progression in patients with epidural hematoma (EDH) versus other ICH (3/15 (20%) vs. 3/54 (5.6%); $p=0.11$). Eight of 118 patients (6.8%) experienced clinically important neurological decline (CIND), and 6/118 (5.1%) required neurosurgical intervention. Both CIND and need for neurosurgical intervention were significantly higher in patients with EDH (21% each) compared to those with other types of ICH (4% and 2% respectively) ($P=0.02$; $P<0.01$). Based on these results, we developed a preliminary management framework to assist in determining which patients can be safely observed on a neurosurgery ward without an intensive care unit (ICU) admission. Specifically, those patients without EDH, intraventricular hemorrhage,

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Authorship:

I.T.S., J.K.G., and D.D.L. designed the study. I.T.S. and J.K.G. contributed to data acquisition. I.T.S. and J.K.G. performed data analysis. I.T.S. and J.K.G. wrote the first draft of the manuscript. All authors participated in data interpretation and critical revision of the manuscript.

Conflicts of Interest and Source of Funding: no authors have any conflict of interest.

coagulopathy, or concern for a high-risk neurosurgical lesion (e.g. arteriovenous malformation) may be safely observed on the ward.

CONCLUSIONS—These results demonstrate that few children with mild TBI and ICH experience CIND, and the preliminary framework we developed assists in identifying which patients can safely avoid ICU admission. This framework should be validated prospectively and externally.

LEVEL OF EVIDENCE—Therapeutic/care management, level IV.

Keywords

mild traumatic brain injury; pediatrics; intracranial hemorrhage

Background

Traumatic brain injury (TBI) is a significant healthcare problem, leading to 37,000 to 50,000 pediatric hospitalizations each year (Langlois *et al.* 2005; Schneier *et al.* 2006).

Approximately 50–80% of patients sustain mild TBI, defined as a Glasgow Coma Scale (GCS) score of 14–15 (Balmer *et al.* 2006; Simon *et al.* 2001), and approximately 4–19% of children with mild TBI have associated intracranial hemorrhage (ICH) on CT scan (Simon *et al.* 2001; Boran *et al.* 2006). There have been significant efforts in both pediatric and adult populations to identify which patients with mild TBI require head CT evaluation (Simon *et al.* 2001; Kuppermann *et al.* 2009; Nigrovic *et al.* 2012; Stiell *et al.* 2001; Stiell *et al.* 2003). However, for those patients with ICH on CT and mild TBI, the appropriate care pathway (intensive care unit (ICU) vs. ward observation) varies among and even within institutions. In many institutions, the presence of ICH on CT dominates the clinical care paradigm, often committing the child to ICU observation. However, while a few studies have reported rates of neurosurgical intervention in this population (Simon *et al.* 2001; Boran *et al.* 2006; Wang *et al.* 2000), data on the frequency and magnitude of neurological deterioration are needed to inform patient management in those patients where upfront surgery is not planned. In the adult population, recent evidence has suggested that many patients with mild TBI and ICH do not require ICU admission (Washington *et al.* 2012). In order to triage patients appropriately and manage resources efficiently in the pediatric population, it is necessary to better understand the clinical complications experienced by this select group of patients. The primary objective of this study was to identify a subset of children with traumatic ICH who could be monitored on a general neurosurgery ward with a low risk of clinical deterioration.

Methods

The Institutional Review Board at Washington University (IRB # 201102013) approved all research procedures and waived the need for signed informed consent. Saint Louis Children's Hospital (SLCH) is a level one trauma center with 54,000 to 56,000 emergency room (ER) visits annually. A retrospective review was performed by searching the SLCH hospital database for all consecutive International Classification of Disease codes for ICH from January 2006 through July 2011. Inclusion criteria in the study were: 1) admission GCS score of 14–15 following TBI; 2) initial head CT or MRI positive for any type of ICH before determination of inpatient disposition status; 3) an initial plan for non-operative

management, regardless of whether the patient was admitted to the ICU or general ward; and 4) age ≥ 18 years at the time of admission. Exclusion criteria were: 1) mechanical ventilation on discharge from the ER or presence of injuries unrelated to the TBI that would require ICU admission (e.g. pneumothorax, severe liver injury); and 2) penetrating intracranial injuries. All types of intracranial hemorrhage patterns were included: contusions/intraparenchymal hemorrhage (IPH), subarachnoid hemorrhages (SAH), subdural hematomas (SDH), epidural hematomas (EDH), and intraventricular hemorrhage (IVH).

Retrospective electronic chart review was performed and the presenting GCS scores were recorded based on the exam at the time of presentation to the SLCH ER. GCS scores were assigned by the ER physicians and/or neurosurgeon upon admission to the emergency room. When no record of the GCS score was documented, a score was assigned retrospectively based on the initial recorded exam. Imaging data were classified according to type of hemorrhage pattern, Marshall CT classification (Marshall *et al.* 1991), and progression in hemorrhage size during admission. Estimates of hemorrhage volume were done using the AxBxC/2 method, as previously described (Zazulia *et al.* 1999).

Outcome measures in this study included radiologic progression of hemorrhage within 14 days of injury (increase in ICH volume $> 30\%$ (Washington *et al.* 2012) or new area of hemorrhage), medical decline (worsening cardiopulmonary status, new electrolyte disturbance, or other change that may have necessitated ICU monitoring), and clinically important neurological decline (CIND) noted within 14 days of injury. CIND was defined by modifying a previously published definition of clinically important TBI (Kuppermann *et al.* 2009) to delineate criteria that would necessitate ICU admission: death from TBI, neurosurgical intervention, intubation for more than 24 hours after TBI, or hospital admission for more than 2 nights resulting from neurological complications of TBI (persistently altered mental status or ongoing seizure management). Isolated, brief episodes of seizure or confusion were not considered CIND if they did not represent persistent problems. Persistent headache or emesis was not considered CIND, as these findings alone would not generally necessitate ICU admission. Neurosurgical interventions (craniotomy, craniectomy, shunt revision, or placement of an external ventricular drain (EVD) or intracranial pressure (ICP) monitor) were also recorded and reported, as were admission characteristics, neuroimaging indications, and readmissions within 14 days of injury for a related presentation. Given the absence of prospectively recorded data, neuroimaging indications were inferred from retrospective review of the medical record. Hospital costs were identified using data from year 2005 Healthcare Cost and Utilization Project (HCUP) State Inpatient Databases and were adjusted for inflation using the consumer price index inflation calculator from the US Department of Labor, Bureau of Labor Statistics (AHRQ, 2005; HCUP, 2005; Consumer Price Index, 2013). 95% confidence intervals (CI) for test statistics were calculated using a binomial profile likelihood interval using R version 3.0.2 (The R Foundation for Statistical Computing, Vienna, Austria). Statistical analysis of categorical data was done using Fisher's Exact Test and analysis of continuous data was done using Independent Samples T-test using SPSS version 21 (IBM, Armonk, NY). P values < 0.05 were considered significant.

Results

During the study time period, 1183 patients presented to the SLCH ER with mild TBI and 760 (64%) received CT imaging. 130 of these patients (17%) had ICH at the time of presentation. Nine patients were excluded because of planned operative management at the time of admission (six for symptomatic EDH, three for penetrating injuries), two were excluded because of severe non-neurological injuries that warranted ICU admission (hemopneumothorax, severe liver injury), and one was excluded because of uncontrolled recurrent seizures in the context of co-existent brain infarction, leaving 118 patients meeting inclusion criteria (Table 1). Most patients (89%) in our cohort had a GCS of 15. The mean age was 7.9 ± 6.1 years, with a range of nine days to 17 years. There were 75 (64%) males, and 43 (36%) females. The most common mechanism of injury was fall (40%). At the time of admission, 35 patients (30%) were noted to have nausea or vomiting, and 50 (42%) were found to have headache.

Imaging Results

Characteristics of initial head CT are described in Table 2. Contusion or IPH was the most common injury (seen in 44%), followed by SDH (37%). 29 patients (25%) had skull fractures. Imaging was available to assign Marshall scores in 103 cases (87%), and the most common Marshall score was II, seen in 94 (91%) patients. The most common indication for initial imaging was mechanism of injury (47%), and almost all patients had imaging indications consistent with those put forth by Kuppermann *et al.* (Kuppermann *et al.* 2009). Repeat neuroimaging was performed in 58% of patients, and the most common indication for repeat imaging was to monitor hemorrhage progression, in the absence of any significant change in relevant symptoms or clinical exam (Table 3). Of the 69 patients who received follow-up imaging, six (8.7%) showed evidence of radiographic progression of their ICH—3/15 (20%) with EDH versus 3/54 (5.6%) without EDH ($P=0.11$) (Table 4). There was no difference in rates of radiographic progression between younger (< 2 years) and older (> 2 years) children ($p=0.18$). One child developed new ICH following repeat trauma within 14 days of initial injury, but this development was not considered radiographic progression due to the novel intervening injury. Of the six patients with radiographic progression, three had associated changes in mental status. Importantly, one patient with an EDH underwent hematoma evacuation after repeat imaging showed an increase in EDH size, despite a stable clinical exam. Among those with repeat imaging, the negative predictive value (NPV) of an unchanged mental status in predicting radiographic stability was 61/64 (95%).

Clinical Outcomes

Descriptions of the hospital course for the 118 included patients are shown in Table 4. The average ICU stay for all patients was 1.0 ± 0.9 days (range 0 to 5 days) and the average hospital stay was 2.5 ± 1.9 days (range 1 to 12 days). 82 patients (70%) spent at least one night in the ICU. No patients died during hospital admission.

Among the included patients, 11 had a seizure prior to admission, including 2 in the SLCH ER. 10/11 (91%) of these patients received antiepileptic drugs (AED) at the time of admission and 8/11 initially were admitted to the ICU. One of these 11 patients seized again

after admission to the hospital, despite receiving AED's. Two other patients who did not seize prior to admission had seizures after admission; one of these patients had received AED's at admission.

In total, eight patients (6.8%) experienced clinically important neurological decline (CIND). CIND was more common among patients with EDH (4/19, 21%) than among those with other forms of ICH (4/99, 4.0%) ($P=0.02$). CIND was also more frequent among patients known to have or with concern for a significant comorbid neurosurgical lesion, such as shunted hydrocephalus or an arteriovenous malformation (AVM), (3/8, 38%; $P=0.01$). There was also a suggestion of higher rates of CIND among patients with IVH (1/2; $P=0.13$) or significant coagulopathy (1/1; $P=0.07$), though the number of patients in each group was small. There was no difference in rates of CIND between younger and older children ($p=0.43$). Risk factors associated with higher rates of CIND are shown in Figure 1A. Six subjects (5.1%) required neurosurgical intervention. Need for intervention was significantly higher among patients with EDH (4/19, 21%) compared to those without (2/99, 2.0%) ($P<0.01$). Cases of neurosurgical intervention involved 3 patients who received hematoma evacuation, one who received an ICP monitor, one who had an EVD placed, and one who underwent shunt revision. There was one medical complication: a patient with a history of poorly-controlled type 1 diabetes mellitus and non-EDH ICH developed diabetic ketoacidosis during her admission. All episodes of clinical decline during initial admission occurred in the ICU. In total, 11 patients (2 with EDH) were readmitted within 14 days of injury for related concerns, including three patients (2 with EDH) who underwent neurosurgical intervention. The most common reasons for readmission were headache and nausea/vomiting.

Management Recommendations

Based on the results presented herein, we have created a potential framework for managing children who present with mild TBI and traumatic ICH (Figure 1B). The current study suggests that the factors associated with increased risk of CIND include: EDH or IVH on CT; significant coagulopathy; and the known presence or concern for a high-risk comorbid lesion (e.g. shunted hydrocephalus, AVM) (Figure 1A). This framework proposed had a sensitivity of 8/8 (100%; 95% CI 68–100) for CIND. Of the 28 children with at least one predictor, eight experienced CIND (positive predictive value 29%; 95% CI 14–47). 90 patients met none of the predictor criteria, and none of these children experienced CIND (negative predictive value of 100%; 95% CI 96–100). ICU admission could have been safely avoided for these children.

Discussion

This study contributes critical data regarding the rate of clinical complications and neurological decline among pediatric patients with mild TBI and ICH. In this relatively large cohort of 118 subjects, overall rates of clinical complications and radiologic progression were low. Only 6.8% of patients experienced CIND, and 5.1% needed neurosurgical intervention. However, both CIND and need for intervention were significantly higher among patients with EDH compared to those with other ICH. 8.7% of

patients with follow-up CT scans experienced radiographic progression, with progression seen in 3/8 patients with CIND. Despite overall low rates of clinical complications, 70% of patients spent at least one night in the ICU.

It is common practice at various institutions to admit patients with ICH to the ICU, regardless of the type of hemorrhage or presenting GCS score. These patients typically spend at least one night in the ICU after which they are often transferred to a general neurology/neurosurgery ward, if no complications arise. The argument for ICU admission has been based in part on the notion that hemorrhagic lesions may progress or pose a high risk of complications during the first 24 hours after admission (Narayan *et al.* 2008; White *et al.* 2009). Within the pediatric population, there is insufficient data regarding rates of radiographic progression of ICH among patients with mild TBI. In limited reports of patients with mild TBI, many of whom had intracranial injury on initial imaging, 20–26% had radiographic worsening on repeat CT (Givner *et al.* 2002; Hollingworth *et al.* 2007). By comparison, studies of children with moderate to severe TBI and intracranial injury have found that 13–48% experience radiographic progression on repeat imaging (Hollingworth *et al.* 2007; da Silva *et al.* 2008; Tabori *et al.* 2000), consistent with a study by Durham *et al.* (Durham *et al.* 2006) in which injury severity was not specified. Within the adult population, one literature review found that injury progression was seen in 8–67% of patients with TBI undergoing repeat imaging (Wang *et al.* 2006), but recent studies have found that in low severity TBI, only 6–20% of patients show imaging progression (Washington *et al.* 2012; Almenawer *et al.* 2013).

In this study of low severity TBI, 58% of patients received repeat imaging and 8.7% of those select patients showed imaging worsening on subsequent exam, lower than most previous estimates. However, given that almost half of our patients did not receive repeat imaging, the true rate of imaging progression is unknown but may be lower than 8.7%. Imaging progression did not significantly differ based on type of ICH, though there was a trend toward increased rates of progression among patients with EDH. This finding is in contrast to recent results in the adult population where intraparenchymal contusion was the only lesion associated with increased progression (Washington *et al.* 2012), potentially reflecting differences in injury mechanisms, skull or brain structure, or the high rate of comorbid antiplatelet/anticoagulation therapy (38%) in older populations. A larger sample will be needed to determine if the trend toward radiographic progression that we observed in children with EDH is significant.

In this study, the most common indication for reimaging was to monitor lesion progression (68%), independent of any clinical change. However, determining whether or when to reimage patients depends heavily on the relationship between radiographic progression and clinical worsening. Specifically among children with mild TBI and intracranial injury, recent findings have suggested that repeat neuroimaging does not change clinical management (Dawson *et al.* 2012). Among children with moderate to severe TBI, the NPV of improved or unchanged mental status in predicting radiographic stability or improvement was 89% (da Silva *et al.* 2008). In our study restricted to children with ICH on initial imaging, only 3/8 patients with CIND experienced radiographic progression. While the Marshall score was not helpful for predicting clinical deterioration in our population — all patients with CIND had

Marshall score II — this metric has only been validated in patients with severe TBI (mostly adults), and the validation has focused on patient outcome (Martins *et al.* 2009; Servadei *et al.* 2000). Significantly, the NPV of an unchanged mental status in predicting radiographic stability was 95%. However, in one case radiographic progression alone led to surgical intervention without a change in clinical status. Given these results, reimaging appears to be unnecessary in most children with stable clinical exams; however, we acknowledge that there may be specific scenarios where repeat CT may be appropriate, but the design and sample size of the current study limited our ability to define which patients fall into this higher-risk group needing closer radiologic follow-up.

Although several studies have examined the relationship between presenting GCS and intracranial injury, there is relatively little evidence in the pediatric population about rates of clinical complications among patients with mild TBI and ICH. In our institution, many patients are initially admitted to the ICU for observation, but few studies have detailed whether observed complication rates justify this use of limited resources for all cases of ICH. Several studies of children with mild TBI and intracranial injury have found neurosurgical intervention was needed in 6–43% of cases, (Simon *et al.* 2001; Boran *et al.* 2006; Wang *et al.* 2000). By comparison, Holsti *et al.* (Holsti *et al.* 2005) found that among a cohort of 38 patients with primarily mild TBI and intracranial injury, none required unplanned hospital admission. However, these studies have significant limitations: they did not explain the indications for intervention, whether surgery was planned from the time of admission or occurred due to a delayed complication, did not describe medical and neurological complications not requiring intervention, and did not describe the relationship between imaging progression and clinical decline.

In this study, we attempt to address this void in the literature by providing meaningful estimates of the rates of clinical complications among patients with mild TBI + ICH as well as a potential framework for initial management. We found that overall rates of complications were lower than most previous reports, with only 6.8% experiencing CIND and 5.1% requiring neurosurgical intervention. Among 11 patients with seizure prior to admission, only one had repeat seizure after admission; however, this was a minor event and may have been managed safely on an experienced neurology/neurosurgery ward. Though overall complication rates were low, certain groups, such as those with EDH (and potentially IVH) or concern for significant comorbid conditions, were at increased risk for complications. Based on these observations, we developed the preliminary management framework in Figure 1B. This recommendation, which requires testing and validation in a larger, prospective study, extends the decision rules for imaging in children with mild TBI developed by Kuppermann *et al.* (Kuppermann *et al.* 2009) by focusing on the clinical management of those patients where ICH is identified on initial imaging. Though our limited sample size restricted our ability to test the statistical significance of each predictor, this algorithm was 100% sensitive for diagnosing CIND, and identified a majority of our population (76%) that had no risk predictors. While developing separate management rules for younger and older children—like the recommendation regarding which children with mild TBI require head CT (Kuppermann *et al.* 2009)—would require a substantially larger population, rates of CIND were not significantly different between younger and older

children. Significantly, even among patients requiring neurosurgical intervention during index admission, there were no episodes of acute deterioration or signs of brain herniation requiring emergent therapy, and most cases of decline likely would have been recognized during serial neurological exams on an experienced ward. Moreover, three of six patients requiring neurosurgical intervention did not show clinical decline until more than three days after presentation, well after they were discharged from the ICU. Therefore, beyond ICU observation, these higher-risk patients required deliberate monitoring over the ensuing days-weeks following discharge, emphasizing the need for close attention by families in the immediate post-discharge period.

Based on multi-state data, the cost for a 24-hour ICU stay, updated to 2013 dollars, is \$2,200, compared to \$1,514 for the general hospital ward (AHRQ, 2005; HCUP, 2005; Consumer Price Index, 2013). Thus, by more efficiently determining which patients would benefit from observation in the ICU, almost \$700 could be saved over 24 hours. Based on the results presented in this study, the current practice of admitting most children with mild TBI and ICH to the ICU is probably unnecessary.

This study has several limitations. Most significantly, the retrospective design necessitates reliance on radiologic data and medical records that may not have been collected using uniform practices, and may be deficient of important information. Additionally, the retrospective design inevitably involved variability in treatment decisions that may have impacted clinical care. Finally, since serious, potentially life-threatening complications of mild TBI and ICH are rare, the size of our cohort is also a limitation. These limitations emphasize the importance of prospective, multicenter studies of hospitalized patients with mild TBI and ICH.

Conclusion

Among children with mild TBI and ICH, few experience clinical decline or require neurosurgical intervention. As a result of financial demands on the healthcare system and limited beds in pediatric ICUs, clinicians should aim to maximize the efficient use of healthcare resources, while not compromising patient care. This study suggests that most children with mild TBI and ICH can be monitored safely on a general neurosurgery ward and explores which patients are at highest risk for clinical deterioration. The management framework presented here is now being tested prospectively at our institution and should be validated externally in a larger population.

Acknowledgments

This work was supported by the Clinical and Translational Science Award (CTSA) program of the National Center for Advancing Translational Sciences (NCATS) of the National Institutes of Health (NIH) under Award Numbers UL1 TR000448 and TL1 TR000449, and by the Intellectual and Developmental Disabilities Research Center at Washington University (NIH/NICHD P30 HD062171). The content is solely the responsibility of the authors and does not necessarily represent the official views of the NIH.

We thank Dr. Michael Wallendorf for assistance with statistical analyses, Dr. Mary Hartman for assistance with cost estimates, and Ms. Rebecca Munro for assistance with data acquisition.

References

1. Langlois JA, Rutland-Brown W, Thomas KE. The incidence of traumatic brain injury among children in the United States: differences by race. *J Head Trauma Rehabil.* 2005; 20:229–38. [PubMed: 15908823]
2. Schneier AJ, Shields BJ, Hostetler SG, Xiang H, Smith GA. Incidence of pediatric traumatic brain injury and associated hospital resource utilization in the United States. *Pediatrics.* 2006; 118:483–92. [PubMed: 16882799]
3. Balmer B, Boltshauser E, Altermatt S, Gobet R. Conservative management of significant epidural haematomas in children. *Childs Nerv Syst.* 2006; 22:363–7. [PubMed: 16273415]
4. Simon B, Letourneau P, Vitorino E, McCall J. Pediatric minor head trauma: indications for computed tomographic scanning revisited. *J Trauma.* 2001; 51:231–8. [PubMed: 11493779]
5. Boran BO, Boran P, Barut N, Akgun C, Celikoglu E, Bozbuga M. Evaluation of mild head injury in a pediatric population. *Pediatr Neurosurg.* 2006; 42:203–7. [PubMed: 16714859]
6. Kuppermann N, Holmes JF, Dayan PS, Hoyle JD Jr, Atabaki SM, Holubkov R, Nadel FM, Monroe D, Stanley RM, Borgialli DA, et al. Identification of children at very low risk of clinically-important brain injuries after head trauma: a prospective cohort study. *Lancet.* 2009; 374:1160–70. [PubMed: 19758692]
7. Nigrovic LE, Lee LK, Hoyle J, Stanley RM, Gorelick MH, Miskin M, Atabaki SM, Dayan PS, Holmes JF, Kuppermann N. Prevalence of clinically important traumatic brain injuries in children with minor blunt head trauma and isolated severe injury mechanisms. *Arch Pediatr Adolesc Med.* 2012; 166:356–61. [PubMed: 22147762]
8. Stiell IG, Wells GA, Vandemheen K, Clement C, Lesiuk H, Laupacis A, McKnight RD, Verbeek R, Brison R, Cass D, et al. The Canadian CT Head Rule for patients with minor head injury. *Lancet.* 2001; 357:1391–6. [PubMed: 11356436]
9. Stiell IG, Clement C, Wells GA, Brison R, McKnight RD, Schull M, Rowe BH, Dreyer JA, Bandiera GLJ, MacPhail I, et al. Multicenter Prospective Validation of the Canadian CT Head Rule. *Acad Emerg Med.* 2003; 10:539.
10. Wang MY, Griffith P, Sterling J, McComb JG, Levy ML. A prospective population-based study of pediatric trauma patients with mild alterations in consciousness (Glasgow Coma Scale score of 13–14). *Neurosurgery.* 2000; 46:1093–9. [PubMed: 10807241]
11. Washington CW, Grubb RL Jr. Are routine repeat imaging and intensive care unit admission necessary in mild traumatic brain injury? *J Neurosurg.* 2012; 116:549–57. [PubMed: 22196096]
12. Marshall LF, Marshall SB, Klauber MR, Clark MvB, Eisenberg HM, Jane JA, Luerksen TG, Marmarou A, Foulkes MA. A new classification of head injury based on computerized tomography. *Special Supplements.* 1991; 75:S14–S20.
13. Zazulia AR, Diringner MN, Derdeyn CP, Powers WJ. Progression of mass effect after intracerebral hemorrhage. *Stroke.* 1999; 30:1167–73. [PubMed: 10356094]
14. Agency for Healthcare Research and Quality (AHRQ): HCUP State Inpatient Databases (SID). Rockville, MD: AHRQ; 2005. Available at: <http://www.hcup-us.ahrq.gov/sidoverview.jsp>
15. Healthcare Cost and Utilization Project (HCUP). Cost-to-Charge-Ratio Files. Rockville, MD: HCUP; 2005.
16. Consumer Price Index Inflation Calculator. United States Department of Labor, Bureau of Labor Statistics; Available at: http://www.bls.gov/data/inflation_calculator.htm [Accessed in June, 2013]
17. Narayan RK, Maas AI, Marshall LF, Servadei F, Skolnick BE, Tillinger MN. Recombinant factor VIIA in traumatic intracerebral hemorrhage: results of a dose-escalation clinical trial. *Neurosurgery.* 2008; 62:776–88. [PubMed: 18496183]
18. White CL, Griffith S, Caron JL. Early progression of traumatic cerebral contusions: characterization and risk factors. *J Trauma.* 2009; 67:508–15. [PubMed: 19741392]
19. Givner A, Gurney J, O'Connor D, Kassarian A, Lamorte WW, Moulton S. Reimaging in pediatric neurotrauma: factors associated with progression of intracranial injury. *J Pediatr Surg.* 2002; 37:381–5. [PubMed: 11877652]
20. Hollingworth W, Vavilala MS, Jarvik JG, Chaudhry S, Johnston BD, Layman S, Tontisirin N, Muangman SL, Wang MC. The use of repeated head computed tomography in pediatric blunt head

- trauma: factors predicting new and worsening brain injury. *Pediatr Crit Care Med*. 2007; 8:348–56. [PubMed: 17545925]
21. da Silva PS, Reis ME, Aguiar VE. Value of repeat cranial computed tomography in pediatric patients sustaining moderate to severe traumatic brain injury. *J Trauma*. 2008; 65:1293–7. [PubMed: 19077616]
 22. Tabori U, Kornecki A, Sofer S, Constantini S, Paret G, Beck R, Sivan Y. Repeat computed tomographic scan within 24–48 hours of admission in children with moderate and severe head trauma. *Crit Care Med*. 2000; 28:840–4. [PubMed: 10752839]
 23. Durham SR, Liu KC, Selden NR. Utility of serial computed tomography imaging in pediatric patients with head trauma. *J Neurosurg*. 2006; 105:365–9. [PubMed: 17328259]
 24. Wang MC, Linnau KF, Tirschwell DL, Hollingworth W. Utility of repeat head computed tomography after blunt head trauma: a systematic review. *J Trauma*. 2006; 61:226–33. [PubMed: 16832279]
 25. Almenawer SA, Bogza I, Yarascavitch B, Sne N, Farrokhyar F, Murty N, Reddy K. The value of scheduled repeat cranial computed tomography after mild head injury: single-center series and meta-analysis. *Neurosurgery*. 2013; 72:56–64. [PubMed: 23254767]
 26. Dawson EC, Montgomery CP, Frim D, Koogler T. Is repeat head computed tomography necessary in children admitted with mild head injury and normal neurological exam? *Pediatr Neurosurg*. 2012; 48:221–4. [PubMed: 23548857]
 27. Martins ET, Linhares MN, Sousa DS, Schroeder HK, Meinerz J, Rigo LA, Bertotti MM, Gullo J, Hohl A, Dal-Pizzol F, et al. Mortality in severe traumatic brain injury: a multivariate analysis of 748 Brazilian patients from Florianopolis City. *J Trauma*. 2009; 67:85–90. [PubMed: 19590314]
 28. Servadei F, Murray GD, Penny K, Teasdale GM, Dearden M, Iannotti F, Lapierre F, Maas AJ, Karimi A, Ohman J, et al. The value of the “worst” computed tomographic scan in clinical studies of moderate and severe head injury. European Brain Injury Consortium. *Neurosurgery*. 2000; 46:70–7. [PubMed: 10626937]
 29. Holsti M, Kadish HA, Sill BL, Firth SD, Nelson DS. Pediatric closed head injuries treated in an observation unit. *Pediatr Emerg Care*. 2005; 21:639–44. [PubMed: 16215464]

A

Risk Factor	No. with Risk Factor	No. with CIND (%)
Epidural hematoma	19	4 (21)
Intraventricular hemorrhage	2	1 (50)
Concern for comorbid lesion	8	3 (38)
Coagulopathy	1	1 (100)

B **Figure 1.**

Management considerations for patients with mild TBI and ICH. **A.** Risk factors for clinically important neurological decline (CIND), the number of patients affected, and the proportion developing CIND. **B.** Framework for the clinical management of patients with mild TBI and ICH and an initial plan for non-operative neurosurgical management. The proportion of patients with each risk factor that developed CIND is shown.

Table 1

Summary admission characteristics of the 118 patients included in the study MVC=motor vehicle crash;
NAT=non-accidental trauma

Characteristic	n (%)
Mean age in years (range)	7.9 ± 6.1 (9 days–17 years)
Sex F	43 (36)
Arrival GCS score	
15	105 (89)
14	13 (11)
Mechanism of injury	
Fall	50 (40)
MVC	28 (24)
Bike, skateboard, or scooter accident	10 (8.5)
Assault (non-NAT)	9 (7.6)
Suspected NAT	6 (5.1)
Pedestrian accident	3 (2.5)
Other	12 (10.2)
Headache present at admission	50 (42)
Nausea/vomiting present at admission	35 (30)

Table 2

Characteristics of initial neuroimaging for the 118 patients included in the study

Characteristic	n (%)
Type of hemorrhage	
Contusion or IPH	52 (44)
SDH	44 (37)
SAH	28 (24)
EDH	19 (16)
IVH	2 (1.7)
Skull Fracture	29 (25)
Marshall Score	
I	0 (0)
II	94 (91)
III	6 (5.8)
IV	1 (1.0)
V	0 (0)
VI	2 (1.9)

Table 3

Indications for initial head CT and repeat neuroimaging

Characteristic	n (%)
Indication for imaging*	
Mechanism	55 (47)
Loss of consciousness	37 (31)
Altered mental status	31 (26)
Severe headache	28 (24)
Emesis	25 (21)
Suspected seizure	11 (9.3)
Other	15 (13)
Repeat neuroimaging performed	69 (58)
Indication for repeat imaging**	
Monitor progression	47 (68)
Headache	8 (12)
Emesis	6 (8.7)
Altered mental status or acting abnormal	5 (7.2)
Concern for vascular lesion	7 (10)
Evaluate for NAT	6 (8.7)
Other	10 (15)

* Indications were inferred from retrospective chart review. Numbers do not equal 100%, since patients had more than one indication for imaging in some instances.

** Indications were inferred from retrospective chart review. Numbers do not equal 100% since patients were reimaged more than once in some cases.

Table 4

Hospital course of the included patients

Measure	All Subjects (n=118)	Subjects with EDH (n=19)	Subjects with other ICH types (n=99)	P-value *
Mean hospital stay in days (range)	2.5 ± 1.9 (1–12)	2.8 ± 1.9	2.4 ± 1.9	0.37
Mean ICU stay in days (range)	1.0 ± 0.9 (0–5)	1.4 ± 1.0	0.9 ± 0.9	0.03
Number of patients spending ≥ 1 day in the ICU (%)	82 (70)	18 (95)	64 (65)	<0.01
Radiographic worsening (%)	6 (8.7)	3 (20)	3 (5.6)	0.11
Increased hemorrhage	5 (7.2)	2 (13)	3 (5.6)	0.30
New hemorrhage	1 (1.4)	1 (6.7)	0 (0)	0.22
Clinical complications (%)				
CIND	8 (6.8)	4 (21)	4 (4.0)	0.02
Need for neurosurgical intervention	6 (5.1)	4 (21)	2 (2.0)	<0.01
Seizures prior to admission	11 (9.3)	0 (0)	11 (11)	0.21
Seizures after admission	3 (2.5)	1 (5.3)	2 (2.0)	0.41
Hospital Readmissions within 14 days (%)	11 (9.3)	2 (11)	9 (9.1)	1.0

* P-values for patients with EDH compared to those with other types of ICH.