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Original Article

The Correlation Between CT Findings and Neurosurgical Intervention in Mild Traumatic Brain Injury Patients with Isolated Subdural Hematomas

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Abstract

Objective In patients with mild traumatic brain injuries (mTBIs), with Glasgow Coma Scale (GCS) scores of 13 to 15, isolated subdural hematomas (iSDHs) are identified as a prevalent category of intracranial hemorrhage. The primary objective of our research was to investigate the relationship between the characteristics of iSDHs, as revealed through computed tomography (CT) scans on patient admission, and the consequent necessity for neurosurgical intervention.

Materials and Methods This was a 1-year study, employing a prospective observational design at our institution. We enrolled adult trauma patients diagnosed with mTBIs and concurrent iSDHs, intent on documenting the hemorrhages' quantitative parameters such as maximum length and thickness, among other related variables. The eventual execution of neurosurgical procedures constituted our primary outcome, aiming to establish a decisive correlation between CT scan metrics of iSDHs upon admission and the imperative for subsequent surgical intervention.

Results A total of 50 patients were included in our study: 14 patients received a neurosurgical intervention and 36 patients did not. The neurosurgical intervention group had a mean maximum SDH length and thickness that were 38 mm longer and 9.6 mm thicker than those of the non-neurosurgical intervention group ($p < 0.001$ for both).

Conclusion In this study, we evaluated the odds of a neurosurgical intervention based on hemorrhage characteristics on CT, in patients with an iSDH and mTBI. Once validated in a second population, these data can be used to evaluate the necessity of interhospital transfers and to better inform patients and families of the risk of future neurosurgical intervention and prognosis.

Keywords
- ► isolated subdural hematomas
- ► mild traumatic brain injuries
- ► neurosurgical intervention

Introduction

The spectrum of traumatic brain injuries (TBIs) spans a wide range of severity, with mild traumatic brain injuries (mTBIs), characterized by Glasgow Coma Scale (GCS) scores between 13 and 15, emerging as the most commonly encountered form.[1,2] Within this subset, isolated subdural hematomas (iSDHs) stand out as a prevalent category of intracranial hemorrhage (ICH).[3–5] Despite the recognition of their frequency, the management strategy for patients

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presenting with TBIs and concurrent ICH, as detected on head computed tomography (CT) scans, often follows a one-size-fits-all approach, necessitating uniform neurosurgical readiness irrespective of injury severity.

This uniform approach to management has implications. A notable investigation spanning two states revealed that iSDHs were implicated in approximately 80% of all neurosurgical interventions for the mTBI cohort, boasting the highest rate of surgical intervention (16%) among ICH varieties.[4] Interestingly, it is estimated that a vast majority (around 84%) of these cases might not benefit from surgical intervention. Yet, they are managed as potential candidates for such procedures, leading to potential inefficiencies in the use of hospital resources and possibly prompting unwarranted interhospital transfers.

Further insights come from a multicenter analysis by Orlando et al, focusing on mTBI patients with ICH but excluding those with coagulopathies. They reported a general neurosurgical intervention rate of 6.7%, with specific rates varying widely by ICH type—from as low as 0.95% for isolated subarachnoid hemorrhages (SAHs) to as high as 15.5% for SDHs.[4] Such disparities underscore the variability in neurosurgical needs across different ICH types within the mTBI demographic, challenging the rationale behind the blanket approach in current management guidelines that do not differentiate between ICH types, often leading to unnecessary neurosurgical consultations and patient transfers to specialized facilities. Thus, a question repeatedly posed in the TBI literature is whether a neurosurgical consultation, or a requirement for neurosurgical coverage, is necessary for all patients with an mTBI and ICH.[6–12]

Given the varied rates of neurosurgical intervention across different ICH types, there is a clear necessity for a more nuanced understanding and approach to managing these conditions in mTBI patients.[13] Particularly, iSDHs, which account for a significant proportion of neurosurgical procedures in this patient group, warrant a closer examination to develop predictive models for surgical intervention.[3–5] This study aims to bridge this knowledge gap by meticulously analyzing the relationship between the quantitative characteristics of iSDHs identified on admission CT scans and the subsequent need for neurosurgical intervention, paving the way for more tailored and efficient management strategies in mTBI care.

Methods

This was a prospective observational cohort study of adult trauma patients admitted over 1 year at our trauma center. Patients were selected on a first come first served basis. We had fixed the GCS criteria for inclusion into our study. Patients were included in the study if they presented with an mTBI (GCS score 13–15) at our emergency department (ED) and had an SDH on admission head CT.

Patients were excluded from the study if they presented with (1) skull fractures; (2) coagulopathy; (3) no acute hemorrhage; (4) a hemorrhage other than an SDH, not including intraventricular hemorrhages (IVHs); (5) no radiological imaging done on admission; or (6) radiological imaging obtained only after a neurosurgical procedure.

This study was reviewed and approved by the institutional review board and was approved by ethics committee.

Outcomes and Covariates

The primary outcome of our study was execution of a neurosurgical procedure such as craniotomy, craniectomy, burr hole, intracranial pressure monitor or shunt placement or catheter drainage of SDH, or any neurosurgeon-recommended neurosurgical procedure. If an operation was not done because of refusal by the family or the patient after recommendation by a neurosurgeon, the patient was put on nonsurgical care, or if there were other circumstances due to which a neurosurgical operation could not be done, the patient was still included in the group that has received a neurosurgical intervention for this study. The objective of this study was to evaluate how iSDHs are associated with the necessity or recommendation of a neurosurgeon to operate, and did not introduce patient or family bias. The secondary outcomes were in-hospital mortality, hospital length of stay (LOS), and hospital disposition. Covariates were as follows: age, sex, mechanism of injury (assault, fall, road traffic accident, and other), interhospital transfer status, admission GCS score, severe head injury (maximum head Abbreviated Injury Scale [AIS] score $\geq$4), Injury Severity Score (ISS 0–15, $\geq$16), admission blood pressure (systolic and diastolic in mm Hg), admission respiratory rate (breaths/min), admission pulse (beats/min), admission body temperature (°F), admission blood oxygen levels (% saturation), ED disposition, associated comorbid conditions (obesity, diabetes mellitus, and hypertension), hospital LOS (days), and hospital disposition.

Radiological Data Abstraction

The following data were collected from each patient: presentation clinical signs and symptoms (nausea, vomiting, headache, dizziness, poor concentration, fatigue, seizures, irritability, rhinorrhea, otorrhea, hemotympanum, raccoon eyes, pupil response, hypothermia, hypoxia, and postinjury loss of consciousness [LOC]); hemorrhage lobe involvement (falx and tentorial hemorrhages were not assigned a lobe of involvement); and hemorrhage status on follow-up CT (completely resolved, resolving, stable, increased, and no follow-up CT). The presence of acute-on-chronic (AOC) hemorrhage, IVH, mass effect, and midline shift was obtained. Hemorrhage measurements were done using admission CT head scans. Maximum hemorrhage length was measured from the most anterior to the most posterior location, using transverse/axial CT or magnetic resonance (MR) images, with at least three measurements used to obtain the length. Maximum hemorrhage thickness was measured perpendicularly from the cortex to the skull, also using transverse/axial CT or MR images. Measurements of maximum thickness and maximum length were obtained from different slices of the head CT or MR image. Measurements were taken using the ruler tool.

Statistical Analysis

The presentation of the categorical variables was done in the form of number and percentage (%). On the other hand, the quantitative data with normal distribution were presented as the means ± standard deviation (SD) and the data with non-normal distribution as median with the 25th and 75th percentiles (interquartile range). The data normality was checked by using the Shapiro–Wilk test. In the cases in which the data were not normal, we used nonparametric tests. The following statistical tests were applied for the results:

- The comparison of the variables that were quantitative and not normally distributed in nature were analyzed using the Mann–Whitney *U* test and variables that were quantitative and normally distributed in nature were analyzed using the independent *t*-test.
- The comparison of the variables that were qualitative in nature were analyzed using the chi-squared test. If any cell had an expected value of less than 5, then Fisher's exact test was used.

The data entry was done in the Microsoft EXCEL spreadsheet and the final analysis was done with the use of Statistical Package for Social Sciences (SPSS) software version 25.0 (IBM, Chicago, Illinois, United States).

For statistical significance, a *p* value of less than 0.05 was considered statistically significant.

Results

Fifty patients were included in this study. Overall, the majority of patients were 20 to 40 years or older, and male (►**Table 1**). Gender distribution between the two groups was similar, with approximately 19.44% females in the conservative treatment cohort and 21.43% in the surgical intervention group. Likewise, male representation was

Table 1 Comparison of demographic characteristics between conservative treatment and surgical intervention

Demographic characteristics	Conservative treatment ($n=36$)	Surgical intervention ($n=14$)	Total	*p*-Value
Gender				
Female	7 (19.44%)	3 (21.43%)	10 (20%)	1[a]
Male	29 (80.56%)	11 (78.57%)	40 (80%)	
Mechanism of injury				
Assault	3 (8.33%)	0 (0%)	3 (6%)	0.498[a]
Fall	8 (22.22%)	5 (35.71%)	13 (26%)	
RTA	25 (69.44%)	9 (64.29%)	34 (68%)	
Head AIS				
2	1 (2.78%)	0 (0%)	1 (2%)	0.337[a]
3	24 (66.67%)	10 (71.43%)	34 (68%)	
4	10 (27.78%)	2 (14.29%)	12 (24%)	
5	1 (2.78%)	2 (14.29%)	3 (6%)	
Mean ± SD	3.31 ± 0.58	3.43 ± 0.76	3.34 ± 0.63	0.538[b]
ISS				
1–15	19 (52.78%)	10 (71.43%)	29 (58%)	0.341[a]
> 15	17 (47.22%)	4 (28.57%)	21 (42%)	
Symptoms				
No symptoms	3 (8.33%)	1 (7.14%)	4 (8%)	1[a]
LOC	19 (52.78%)	11 (78.57%)	30 (60%)	0.118[a]
Seizure	3 (8.33%)	1 (7.14%)	4 (8%)	1[a]
Headache	1 (2.78%)	0 (0%)	1 (2%)	1[a]
Ear bleed	8 (22.22%)	1 (7.14%)	9 (18%)	0.414[a]
Nasal bleed	2 (5.56%)	0 (0%)	2 (4%)	1[a]
Dizziness	1 (2.78%)	1 (7.14%)	2 (4%)	0.486[a]
ENT bleed	0 (0%)	2 (14.29%)	2 (4%)	0.074[a]
Vomiting	17 (47.22%)	7 (50%)	24 (48%)	0.86[c]

(*Continued*)

Table 1 (*Continued*)

Demographic characteristics	Conservative treatment ($n = 36$)	Surgical intervention ($n = 14$)	Total	p-Value
Comorbidity				
No comorbidity	30 (83.33%)	9 (64.29%)	39 (78%)	0.144[c]
CVA	1 (2.78%)	1 (7.14%)	2 (4%)	0.486[a]
DM	2 (5.56%)	1 (7.14%)	3 (6%)	1[a]
Hypertension	4 (11.11%)	4 (28.57%)	8 (16%)	0.197[a]
Lobe				
Frontal and temporal	3 (8.33%)	5 (35.71%)	8 (16%)	0.036[a]
Frontal, temporal, and parietal	11 (30.56%)	6 (42.86%)	17 (34%)	
Parietal	1 (2.78%)	0 (0%)	1 (2%)	
Temporal	9 (25%)	0 (0%)	9 (18%)	
Temporal and parietal	12 (33.33%)	3 (21.43%)	15 (30%)	
Age (y)	38.25 ± 18.73	55.71 ± 21.24	43.14 ± 20.81	0.006[b]
GCS score on admission	13.5 ± 1.08	13.57 ± 0.85	13.52 ± 1.01	0.826[b]
Systolic blood pressure (mm Hg)	134.72 ± 11.39	137.57 ± 17.94	135.52 ± 13.4	0.588[b]
Diastolic blood pressure (mm Hg)	73.44 ± 7.97	70.14 ± 6.49	72.52 ± 7.66	0.174[b]
Pulse rate (per min)	69.33 ± 8.05	72.43 ± 10.74	70.2 ± 8.88	0.273[b]
Temperature (°F)	98.49 ± 0.16	98.49 ± 0.15	98.49 ± 0.15	0.981[b]
Respiratory rate (per min)	17.97 ± 4.23	18.21 ± 4.61	18.04 ± 4.3	0.86[b]
Oxygen level (%)	98.42 ± 0.97	98.43 ± 0.94	98.42 ± 0.95	0.969[b]
Midline shift	3.55 (2.625–4.725)	7.4 (3.6–11)	3.65 (3.05–4.975)	0.001[d]

Abbreviations: AIS, Abbreviated Injury Scale; GCS, Glasgow Coma Scale; CVA, cardiovascular disease; DM, diabetes mellitus; ENT, ear, nose, and throat; ISS, Injury Severity Score; LOC, loss of consciousness; RTA, road traffic accident; SD, standard deviation.
[a]Fisher's exact test.
[b]Independent *t*-test.
[c]Chi-squared test.
[d]Mann–Whitney *U* test.

comparable, constituting approximately 80.56 and 78.57% of the respective groups ($p = 1$; ►**Table 1**).

Ninety-eight percent of non–GCS-15 scores were attributable to decreased verbal functioning. Hypertension was the most prevalent comorbidity (16%; ►**Table 1**).

Mechanisms of injury showed no significant variation between the treatment groups ($p = 0.498$). Assault, falls, and road traffic accidents were the predominant causes across both cohorts (►**Table 1**).

In terms of injury severity and symptomatology, no notable discrepancies were found. Head AIS, ISS, and demographic characteristics including symptoms and comorbidities exhibited similar distributions between the conservative and surgical groups ($p = 1$ for demographic characteristics).

Regarding lobe involvement, a distinct pattern emerged. A higher proportion of conservative treatment patients showed involvement of the parietal, temporal, and temporoparietal lobes, while frontal and temporal lobe involvement was more prevalent in the surgical intervention group ($p = 0.036$). The neurosurgical intervention group had significantly more patients with hemorrhages involving multiple lobes; there was a significant, positive trend between number of lobes involved and the proportion of patients in the neurosurgical intervention group ($p < 0.001$). There was also a positive correlation between the number of lobes involved and the maximum SDH length ($p < 0.001$; ►**Table 1**).

Clinical parameters such as GCS score on admission, blood pressure, pulse rate, temperature, respiratory rate, and oxygen levels did not significantly differ between the two treatment arms.

Notably, patients undergoing surgical intervention were significantly older, with a mean age of 55.71 years compared with 38.25 years in the conservative treatment group ($p = 0.006$). Additionally, the median midline shift was significantly higher in the surgical intervention group (7.4 vs. 3.55, $p = 0.001$).

Overall, while many clinical parameters aligned between conservative and surgical treatments, distinctions in lobe involvement, age demographics, and midline shift underscored the differing characteristics and considerations of each treatment modality (►**Table 1**).

A notable distinction was observed in SDH characteristics between patients undergoing conservative treatment and those receiving surgical intervention ($p < 0.05$).

The neurosurgical intervention rate in our iSDH population with mTBI was 28%. The neurosurgical

Table 2 Comparison of SDH thickness and length (mm) between conservative treatment and surgical intervention

SDH thickness and length (mm)	Conservative treatment ($n = 36$)	Surgical intervention ($n = 14$)	Total	p-Value
SDH thickness (mm)	6.15 ± 2.24	15.61 ± 2.68	8.8 ± 4.89	< 0.0001[a]
SDH length (mm)	102.34 ± 29.49	140.22 ± 15.07	112.95 ± 31.25	< 0.0001[a]

Abbreviation: SDH, subdural hematoma.
[a]Independent *t*-test.

intervention group had an average maximum SDH length that was 38.0 mm longer than that of the non-neurosurgical intervention group. Additionally, the neurosurgical intervention group had an average maximum SDH thickness that was 9.6 mm thicker than that of the non-neurosurgical intervention group. The smallest SDH in the intervention group, on initial presenting CT was 12.2 mm in thickness. In the surgical intervention group, the mean ± SD of SDH thickness and length measured 15.61 ± 2.68 and 140.22 ± 15.07 mm, respectively. These values were notably higher compared with the conservative treatment group, where the mean ± SD of SDH thickness and length were 6.15 ± 2.24 mm ($p < 0.0001$) and 102.34 ± 29.49 mm ($p < 0.0001$), respectively (►**Table 2**).

This suggests that patients receiving surgical intervention tended to present with thicker and longer SDH, warranting surgical management (►**Table 2**, ►**Fig. 1**).

The distribution of hospital disposition, whether patients were discharged or expired, showed no significant variation between conservative treatment and surgical intervention groups ($p = 1$). Specifically, approximately 86.11 and 85.71% of patients were discharged in the conservative and surgical groups, respectively, while 13.89 and 14.29% expired, respectively (►**Table 3**).

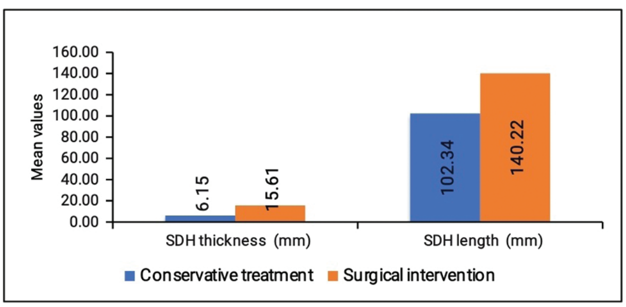

Fig. 1 Comparison of subdural hematoma (SDH) thickness and length (mm) between conservative treatment and surgical intervention.

Regarding the outcome GCS score on discharge, there was no significant difference between the two treatment approaches ($p = 0.23$). The mean ± SD of outcome GCS on discharge was 14.1 ± 0.98 for conservative treatment and 14.42 ± 0.67 for surgical intervention, indicating comparable neurological outcomes.

However, a significant difference was observed in the outcome LOS between the two groups ($p < 0.05$). The mean ± SD of LOS in the surgical intervention group was 11.5 ± 2.93 days, significantly higher than that in the conservative treatment group, which had a mean ± SD LOS of 6.19 ± 1.83 days ($p < 0.0001$). This suggests that patients undergoing surgical intervention tended to have longer hospital stays compared with those receiving conservative treatment (►**Table 3**).

Furthermore, neither maximum hemorrhage thickness nor length was significantly associated with increased odds of in-hospital mortality. The only radiographic characteristic that was significantly associated with in-hospital mortality was the presence of mass effect.

Discussion

The goal of our investigation was to scrutinize the correlation between the quantitative characteristics of iSDHs observed in initial CT scans of patients presenting with mTBIs and their subsequent requirement for neurosurgical operations. Our research has successfully pinpointed a multitude of radiological and clinical indicators predictive of the need for such interventions. Specifically, factors such as the hemorrhage's location, the engagement of multiple cerebral lobes, the detection of AOC hemorrhages,

Table 3 Comparison of outcome between conservative treatment and surgical intervention

Outcome	Conservative treatment	Surgical intervention	Total	p-Value
Hospital disposition				
Discharged	31 (86.11%)	12 (85.71%)	43 (86%)	1[a]
Expired	5 (13.89%)	2 (14.29%)	7 (14%)	
Length of stay (d)	6.19 ± 1.83	11.5 ± 2.93	7.68 ± 3.24	< 0.0001[b]
GCS on discharge	14.1 ± 0.98	14.42 ± 0.67	14.19 ± 0.91	0.23[b]

Abbreviations: GCS, Glasgow Coma Scale.
[a]Fisher's exact test.
[b]Independent *t*-test.

evidence of mass effect, and midline shift were all found to significantly predicate the necessity for surgical intervention. Crucially, the maximum dimensions of the hemorrhage, in terms of both thickness and length, were determined to be substantial predictors for the engagement of neurosurgical procedures.

A pivotal revelation from our study was that the most critical determinant influencing the decision for neurosurgical intervention among our patient cohort was the maximum thickness of the iSDH. This finding is particularly noteworthy in light of a recent examination by Shih et al, who analyzed neurosurgical interventions across a sample of 347 mTBI patients with various types of ICHs, gathering data on hemorrhage volumes.[14] They calculated the total volume for each EDH, SDH, and intraparenchymal contusion, and found that only the volume of EDH was significantly different between neurosurgical intervention groups in univariate analysis. The study was limited to the inclusion of only one independent predictor in the final logistic regression model due to limited outcome observations ($n = 13$). EDH volume was identified as the only independent variable predicting subsequent neurosurgical intervention (area under the receiver operating characteristic curve [AUROC]: 0.92; 95% confidence interval [CI]: 0.80–1.00). Although it achieved a high AUROC value, the study only included six patients with an EDH, and had an unusually low neurosurgical intervention rate for SDHs (3.6%), limiting the generalizability of the results and the neurosurgical practices.

The literature on TBI highlights a discernible gap in studies focused on neurosurgical interventions specifically within the mTBI demographic, a gap our study aims to fill.[15,16] Historically, the size of hemorrhages has been subjectively classified as “mild” or “clinically unimportant” based more on anecdotal evidence and surveys than robust, quantitative analysis. The Brain Injury Guidelines study categorizes SDHs as “minor head injury” if they are $\leq$4 mm thick.[17] Huynh et al defined SDHs less than 3 mm thick as “clinically unimportant” and based the definition on the presentation and outcomes of no more than 10 patients with SDHs, for which there was no detailed reporting of hemorrhage characteristics.[8] Additionally, the Canadian CT Head Rule defines SDHs as “clinically unimportant” if the patient is neurologically intact and has a hemorrhage less than 4 mm thick.[18] This determination was not made based on an analysis of quantitative hemorrhage data; instead, it was based on a survey of 129 academic physicians. Although experienced practicing neurosurgeons have believed this opinion to be accurate for many years, our quantitative analysis has further proven this assumption. In general, we should shy away from categorizing hemorrhages as “minor” or “unimportant,” because these definitions probably underestimate the variance in risk of poor patient outcomes. Our findings challenge these conventions by demonstrating that no patients with SDHs under 5 mm in maximal thickness, or those confined to the falx or tentorium, necessitated neurosurgical intervention. This underscores the necessity of incorporating quantitative risk assessments into clinical decision-making processes, moving beyond the reliance on generalized guidelines that may not accurately reflect individual patient risks.

Furthermore, while the GCS score is frequently used as a barometer for neurological deterioration and a potential indicator for surgical intervention, our findings corroborate the narrative that admission GCS scores are not reliable predictors of the need for neurosurgical intervention.[7,12,14] This observation supports the premise that while GCS scores can indicate mortality risk, they are not effective stand-alone predictors of surgical necessity. Our analysis revealed that the likelihood of requiring neurosurgical intervention was more closely associated with the quantitative characteristics of the hemorrhage, specifically its thickness, rather than the initial GCS score.

Limitations

Despite the insightful findings of our study, it is crucial to acknowledge its limitations, particularly its sample size and the consequent inability to adjust for a broader range of confounding variables. With only a small number of in-hospital deaths recorded, our capacity to explore the relationship between hemorrhage characteristics and mortality was constrained. Therefore, while our study contributes valuable insights into the predictive value of quantitative hemorrhage characteristics for neurosurgical intervention in mTBI patients with iSDHs, further research with larger sample sizes and more diverse populations is essential for validating and expanding upon our conclusions.

Conclusion

In summary, our research illuminates the critical role of specific quantitative CT scan characteristics of iSDHs in guiding neurosurgical intervention decisions for mTBI patients. By using a fixed criteria of GCS for inclusion into our study, we had eliminated the role of GCS as the primary determining factor for neurosurgical intervention. Our study advocates for a more nuanced and evidence-based approach to managing mTBI patients with iSDHs. Future investigations are encouraged to replicate and build upon our findings, exploring the predictive value of hemorrhage metrics across a wider spectrum of ICHs and patient demographics.

Patients' Consent
Informed consent was obtained from all individual participants or their parents who were included in this study.

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Conflict of Interest
None declared.

References

1 Faul MD, Xu L, Wald MM, Coronado VG Traumatic Brain Injury in the United States. Emergency Department Visits, Hospitalizations, and

Deaths, 2002–2006. Atlanta, GA: Centers for Disease Control and Prevention, National Center for Injury Prevention and Control; 2010
2 National Center for Injury Prevention and Control. Report to Congress on Mild Traumatic Brain Injury in the United States: Steps to Prevent a Serious Public Health Problem. Atlanta, GA: Centers for Disease Control and Prevention; 2003. Accessed February 15, 2018 at: https://www.cdc.gov/traumaticbraininjury/pdf/mtbireport-a.pdf
3 Nishijima DK, Sena MJ, Holmes JF. Identification of low-risk patients with traumatic brain injury and intracranial hemorrhage who do not need intensive care unit admission. J Trauma 2011;70(06):E101–E107
4 Orlando A, Levy AS, Carrick MM, Tanner A, Mains CW, Bar-Or D. Epidemiology of mild traumatic brain injury with intracranial hemorrhage: where should we focus predictive models for neurosurgical intervention? World Neurosurg 2017; 107:94–102
5 Sweeney TE, Salles A, Harris OA, Spain DA, Staudenmayer KL. Prediction of neurosurgical intervention after mild traumatic brain injury using the national trauma data bank. World J Emerg Surg 2015;10:23
6 Carlson AP, Ramirez P, Kennedy G, McLean AR, Murray-Krezan C, Stippler M. Low rate of delayed deterioration requiring surgical treatment in patients transferred to a tertiary care center for mild traumatic brain injury. Neurosurg Focus 2010;29(05):E3
7 Ditty BJ, Omar NB, Foreman PM, Patel DM, Pritchard PR, Okor MO. The nonsurgical nature of patients with subarachnoid or intraparenchymal hemorrhage associated with mild traumatic brain injury. J Neurosurg 2015;123(03):649–653
8 Huynh T, Jacobs DG, Dix S, Sing RF, Miles WS, Thomason MH. Utility of neurosurgical consultation for mild traumatic brain injury. Am Surg 2006;72(12):1162–1165, discussion1166-7
9 Joseph B, Aziz H, Sadoun M, et al. The acute care surgery model: managing traumatic brain injury without an inpatient neurosurgical consultation. J Trauma Acute Care Surg 2013;75 (01):102–105, discussion 105
10 Levy AS, Orlando A, Salottolo K, Mains CW, Bar-Or D. Outcomes of a nontransfer protocol for mild traumatic brain injury with abnormal head computed tomography in a rural hospital setting. World Neurosurg 2014;82(1-2):e319–e323
11 Miller EC, Holmes JF, Derlet RW. Utilizing clinical factors to reduce head CT scan ordering for minor head trauma patients. J Emerg Med 1997;15(04):453–457
12 Wu C, Orringer DA, Lau D, Fletcher JJ. Cumulative incidence and predictors of neurosurgical interventions following nonsevere traumatic brain injury with mildly abnormal head imaging findings. J Trauma Acute Care Surg 2012;73(05):1247–1253
13 Jagoda AS, Bazarian JJ, Bruns JJ Jr, et al; American College of Emergency Physicians Centers for Disease Control and Prevention. Clinical policy: neuroimaging and decisionmaking in adult mild traumatic brain injury in the acute setting. Ann Emerg Med 2008;52(06):714–748
14 Shih FY, Chang HH, Wang HC, et al. Risk factors for delayed neurosurgical intervention in patients with acute mild traumatic brain injury and intracranial hemorrhage. World J Emerg Surg 2016;11:13
15 Maas AI, Lingsma HF, Roozenbeek B. Predicting outcome after traumatic brain injury. Handb Clin Neurol 2015;128:455–474
16 Perel P, Edwards P, Wentz R, Roberts I. Systematic review of prognostic models in traumatic brain injury. BMC Med Inform Decis Mak 2006;6:38
17 Joseph B, Friese RS, Sadoun M, et al. The BIG (brain injury guidelines) project: defining the management of traumatic brain injury by acute care surgeons. J Trauma Acute Care Surg 2014;76(04):965–969
18 Stiell IG, Wells GA, Vandemheen K, et al. The Canadian CT head rule for patients with minor head injury. Lancet 2001;357 (9266):1391–1396

