

ORIGINAL RESEARCH

Trauma

# Emergency department observation of mild traumatic brain injury with minor radiographic findings: shorter stays, less expensive, and no increased risk compared to hospital admission

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[Correction added on 30 June 2020, after first online publication: the name of the author is updated from John K. Kanter to John H. Kanter and his initials is updated from JKK to JHK under author contributions.]

## Abstract

**Objective:** The management of mild traumatic brain injury (mTBI) with minor radiographic findings traditionally involves hospital admission for monitoring, although this practice is expensive with unclear benefit. We implemented a protocol to manage these patients in our emergency department observation unit (EDOU), hypothesizing that this pathway was cost effective and not associated with any difference in clinical outcome.

**Methods:** mTBI patients with minor radiographic findings were managed under the EDOU protocol over a 3-year period from May 1, 2015 to April 30, 2018 (inclusions:  $\geq 19$  years old, isolated acute head trauma, normal neurological exam [except transient alteration in consciousness], and a computed tomography [CT] scan of the head with at least 1 of the following: cerebral contusions  $< 1$  cm in maximum extent, convexity subarachnoid hemorrhage, or closed, non-displaced skull fractures). These patients were retrospectively analyzed; clinical outcomes and charges were compared to a control cohort of matched mTBI hospital admissions over the preceding 3 years.

**Results:** Sixty patients were observed in the EDOU over the 3-year period, and 85 patients were identified for the control cohort. There were no differences in rate of radiographic progression, neurological exam change, or surgical intervention, and the overall incidence of hemorrhagic expansion was low in both groups. The EDOU group had a significantly faster time to interval CT scan (Mean Difference (MD) 3.92 hours, [95%CI 1.65, 6.19]),  $P = 0.001$ , shorter length of stay (MD 0.59 days [95% CI 0.29, 0.89],  $P = 0.001$ ), and lower encounter charges (MD \$3428.51 [95%CI 925.60,

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5931.42],  $P = 0.008$ ). There were no differences in 30-day re-admission, 30-day mortality, or delayed chronic subdural formation, although there was a high rate of loss to follow-up in both groups.

**Conclusions:** Compared to hospital admission, observing mTBI patients with minor radiographic findings in the EDOU was associated with significantly shorter time to interval scanning, shorter length of stay, and lower encounter charges, but no difference in observed clinical outcome. The overall risk of hemorrhagic progression in this subset of mTBI was very low. Using this approach can reduce unnecessary admissions while potentially yielding patient care and economic benefits. When designing a protocol, close attention should be given to clear inclusion criteria and a formal mechanism for patient follow-up.

#### KEYWORDS

ED observation, EDOU, mild TBI

## 1 | INTRODUCTION

### 1.1 | Background and Importance

Mild traumatic brain injury (mTBI) with acute but minor radiographic findings represents a common presentation to the emergency department (ED).<sup>1</sup> Given a perceived risk of deterioration, these patients are frequently admitted for close monitoring, often in an intensive care unit.<sup>2</sup> This widespread practice carries significant expense with an uncertain clinical necessity in the absence of risk factors.<sup>3,4</sup> Regardless, foregoing monitoring altogether can be difficult to achieve given expectations from patients and referring providers, even with a presumably low risk injury.

One alternative strategy is a period of monitoring in the ED, thereby minimizing unnecessary hospital admissions. This could be achieved in the primary ED ward or, when available, a dedicated ED observation unit (EDOU). Although mTBI observation protocols in such units appear effective,<sup>5</sup> there are sparse data in the literature, and to our knowledge, no studies have compared outcomes or cost with patients who undergo traditional management via hospital monitoring.

To reduce unnecessary admissions and relieve inpatient capacity, our center developed a management pathway to facilitate monitoring of mTBI with minor radiographic findings in the EDOU. Patients who met pre-specified criteria were observed in this unit, without an accompanying hospital admission, and were discharged from the ED if there were no clinical changes along with stable repeat imaging.

### 1.2 | Goals of this Investigation

In this retrospective observational case series, we analyzed outcomes of all patients monitored under this protocol over a 3-year period and compared this group to a matched cohort of hospital admissions over the 3 years preceding the protocol's implementation. We aimed to determine if observation in the EDOU was associated with any differ-

ences in clinical outcome compared to hospital admission, to identify any risk factors for radiographic expansion of intracranial hemorrhage in this population, and to examine potential economic impact.

## 2 | METHODS

This study was approved by our Institutional Review Board and was exempted from continuing review after the board determined minimal risk to human subjects. Informed consent was waived. A written, detailed study protocol was developed a priori describing the study design, outcome measures, and methods for systematic data abstraction.

### 2.1 | Setting—EDOU protocol for mTBI

Our medical center is a level-1 designated trauma center serving a population of 1.7 million, with 31,000 annual ED visits. The EDOU is a separate unit adjacent to the ED that facilitates temporary monitoring and triage of various patients when hospital admission is not clearly indicated. It is managed by the emergency department and is not an inpatient hospital unit. Typically, the unit is staffed with associate providers such as physician assistants or nurse practitioners, with oversight from the emergency physicians on duty.

To develop an EDOU management pathway for mTBI with acute radiographic findings, the departments of neurosurgery and emergency medicine reached a consensus on inclusion criteria to be used in a pre-specified protocol (Figure 1). These criteria included all patients  $\geq 19$  years old with isolated acute head trauma, a normal neurological exam at presentation (except transient alteration in consciousness), and a non-contrasted computed tomography (CT) scan of the head with 1 or more of the following 3 injuries: (1) cerebral contusions  $< 1$  cm in maximum extent, (2) convexity subarachnoid hemorrhage, or (3) closed, non-displaced skull fractures. Patients with

contusions >1 cm, epidural or subdural hematomas, open or displaced skull fractures, acute neurological deficits, seizures at presentation, altered mental status, Glasgow Coma Scale (GCS) <15, age <19, thrombocytopenia (platelets <90,000), coagulopathy (INR >1.5), anticoagulant use, antiplatelet use (except aspirin), additional injuries/polytrauma, unstable vital signs, or other unstable medical conditions were considered at higher risk and excluded from consideration into the protocol. The emergency medicine attending made the final determination regarding the patient's eligibility for monitoring in the EDOU.

Once inclusion criteria were met, an initial neurosurgery consultation was obtained, and patients were moved to the EDOU for overnight observation. Standardized management included serial neurological checks every 2 hours by nursing staff (for 4 hours, then once every 4 hours thereafter), cardiac monitoring, and a scheduled interval CT scan after a minimum of 8 hours. A neurosurgery team member would round on the patient following the second CT head. If both the clinical exam and interval scan remained unchanged, the patient was discharged directly from the EDOU, with planned follow-up in neurosurgery clinic at 4–6 weeks. If, during observation, the exam or scan demonstrated interval change, or the patient developed a medical condition warranting further evaluation, the patient was admitted to the inpatient hospital for further management by the appropriate service. The protocol was commenced on May 1, 2015.

## 2.2 | Study design

We retrospectively analyzed all mTBI patients admitted to the EDOU under this protocol over a 3-year period between May 1, 2015 and April 30, 2018. Patient data including demographics, co-morbidities, mechanism of injury, presenting features, complications, antiplatelet usage, length of stay, follow-up, and outcomes, and encounter charges were extracted from the patient record by the DHMC Analytics Institute and author chart review (TL, MR). Standardized software, data sheets, and coding were used for data extraction and recording. The mechanism of injury was recorded as ground level fall (GLF), fall from height (FFH), motor vehicle collision (MVC), altercation (ALT), motor versus pedestrian (MP), or other (OTH). The time to interval CT was defined as the time in hours between the initial and second CT head. Radiographic changes among interval scans were identified by author review of images and by reports from the reading radiologist at the time of the study, and neurological exam changes identified by review of documentation in the medical record. Follow-up was defined as the patient's initial outpatient visit in neurosurgery clinic (usually scheduled approximately 4–6 weeks after injury). Thirty-day mortality and local readmission rate for any reason were recorded.

To serve as a control group for comparison, we identified a second cohort of patients admitted to the hospital with mTBI over the 3-year period between May 1, 2012 and April 30, 2015 (immediately preceding the implementation of the EDOU protocol). ICD-9 codes 800, 801, and 850–854 were used to identify an initial list of all patients admitted to DHMC with acute traumatic head injury over this times-

### The Bottom Line

The practice of admitting patients with mild traumatic brain injury (mTBI) with CT-confirmed injuries for monitoring and interval imaging is expensive and has unclear benefit. Use of the emergency department observation unit (EDOU) offers a potential alternative. In this study of 145 mTBI (60 EDOU, 85 admitted), use of the EDOU resulted in 4 hours faster time to CT, 0.6 days shorter length of stay, and saved \$3,400 in encounter charges, without any differences in clinical outcomes. The EDOU may offer a viable strategy for managing mTBI, although the high loss to follow-up in this study limits any conclusions on long term benefits.

pan. Inclusion and exclusion criteria identical to the EDOU group were applied to these patients by author chart review (BKR, DCC, JHK) for inclusion into the control cohort; presenting documentation and radiographic imaging were reviewed to determine if the patient met criteria at presentation to the ED (ie, would have met criteria for the protocol had it been in effect). Once identified for inclusion, equivalent information regarding outcomes, charges, and follow-up were recorded. Periodic meetings were held regarding data abstraction, and a consensus approach was implemented to resolve any disagreement.

## 2.3 | Outcome measures

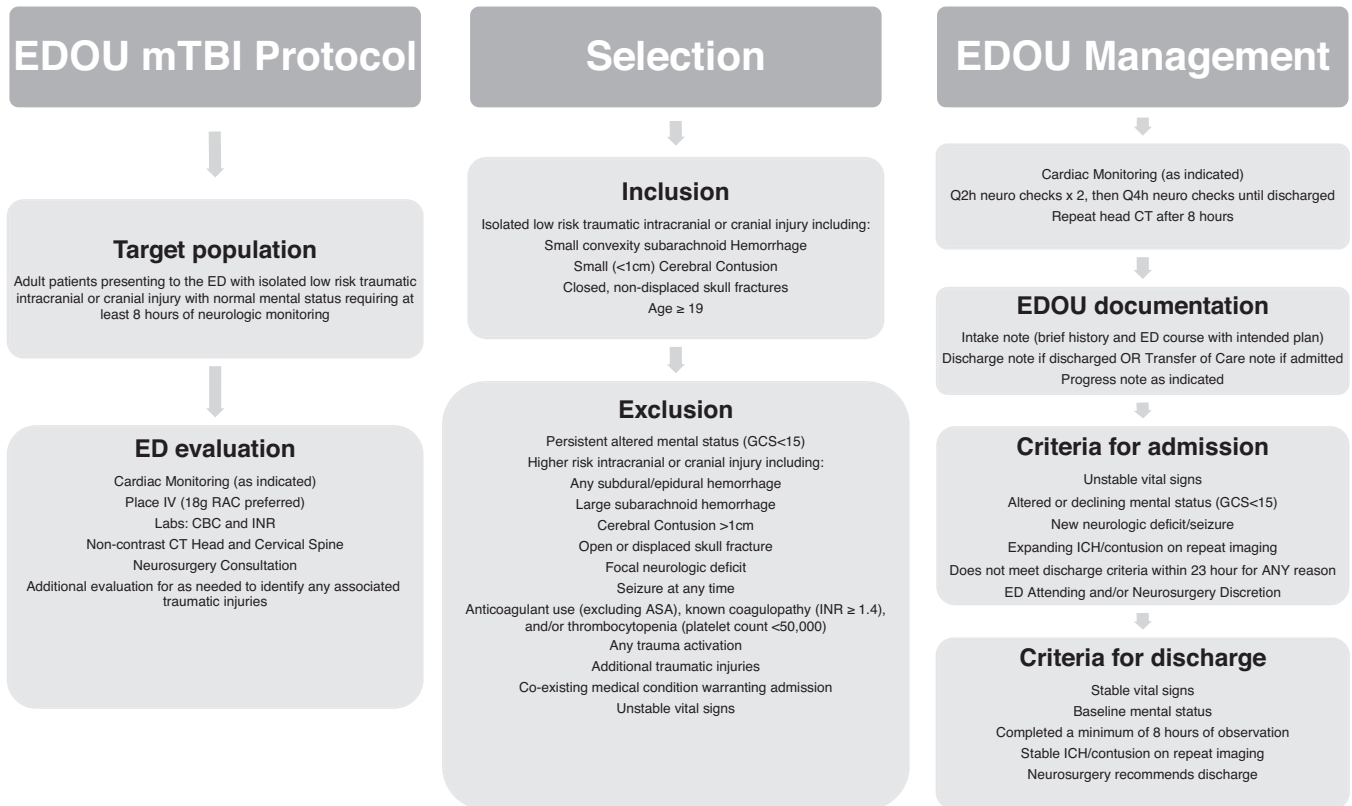
The primary outcomes were time to repeat head CT (hours), rate of hemorrhagic expansion on the interval CT head, length of stay (days), rate of surgical intervention, and encounter charges (USD). Secondary outcomes included rate of follow-up, length to follow-up (days), 30-day mortality, 30-day readmission, and incidence of any delayed complications at follow-up.

## 2.4 | Statistical analysis

Statistical significance for continuous variables was calculated using student's t-test assuming unequal variance. Contingency analysis between categorical variables was performed with Chi-square testing. Two-tailed *P* values <0.05 were considered statistically significant. All statistical calculations were performed in SPSS Statistics (Version 26.0, IBM, Armonk, NY).

## 3 | RESULTS

There were 60 patients with mTBI who met criteria for EDOU observation and were managed under the protocol between May 1, 2015 and April 30, 2018. The mean age was 64 (SD = 20.45, R = 19–93). Hypertension was the most common co-morbidity, present in 22 patients



**FIGURE 1** EDOU mTBI monitoring protocol. EDOU, Emergency Department Observation unit; ED, emergency department; CBC, complete blood count; INR, international normalized ratio; CT, computed tomography; GCS, Glasgow coma scale; ASA, aspirin; ICH, intracranial hemorrhage

(37%). Thirty-one (52%) suffered a transient loss of consciousness after the injury and 20 (33%) used a daily aspirin. The most common mechanism of injury was a ground-level fall (53%), followed by fall from height (22%), motor vehicle collision (7%), altercation (5%), vehicle versus pedestrian (2%), and other/unspecified (11%) (Table 1).

A total of 55 (92%) patients were discharged from the observation period after repeat CT and serial exam demonstrated no interval change; 5 (8%) were admitted to the hospital for continued monitoring and workup. Of these, 3 were admitted for medical reasons discovered during the observation but unrelated to the head injury (one each for medication management, desaturation secondary to a pleural effusion, and elevated troponins); these patients did not have any appreciable change on the interval CT scan of the head. The remaining 2 patients (3%) had a small but clear increase in the size of at least 1 contusion on the repeat CT head and were admitted to neurosurgery for additional monitoring. These 2 patients did not suffer any neurological sequelae and were subsequently discharged without further event. Overall, none of the 60 patients observed in the EDOU cohort demonstrated a neurological exam change during the encounter or required a surgical procedure (Table 2).

Thirty-three patients (55%) underwent scheduled follow-up in neurosurgery clinic; the mean length to follow-up was 32.18 days (SD 12.27). One patient developed a new chronic subdural hematoma; this individual underwent readmission for uncomplicated burr hole drainage that resulted in eventual resolution (notably, this was not 1

of the 2 patients who required admission for radiographic progression at the initial encounter). An additional patient had been previously readmitted within 30 days due to an unrelated problem. None of the remaining patients with available follow-up developed any new clinical or radiographic changes, and there was no known 30-day mortality (Table 2).

To serve as a control group, ICD-9 codes were used to identify mTBI patients admitted to the hospital between May 1, 2012 and April 30, 2015, the 3-year period prior to the implementation of the EDOU protocol. A total of 1351 patients were initially identified using this broad search. After reviewing admission documentation and initial imaging, 85 patients with isolated mTBI met criteria for inclusion. The remaining 1266 patients were excluded due to at least 1 of the following: (1) severe intracranial injury, (2) polytrauma, (3) negative intracranial imaging at presentation, (4) unstable vital signs, (5) anticoagulant usage, (6) epidural or subdural hematomas, (7) age <19, or (8) neurological deficits at presentation (excepting transient loss of consciousness). The mean age of the control cohort was 59 (SD = 10, R = 20–94). The control group was matched to the EDOU cohort with regards to age, sex, mechanism of injury, characteristics of presentation, and co-morbidities. The control group, however, had a significantly higher proportion of fracture injury type compared to the EDOU cohort (3% EDOU versus 15% Ctrl,  $P = 0.02$ ) (Table 1).

Two patients in the control cohort (2%) demonstrated radiographic progression of a contusion on the interval head CT, however, neither

**TABLE 1** Baseline demographics, comorbidities, and injury characteristics of EDOU and control groups

Variable	EDOU (n = 60)	Control (n = 85)	MD (95% CI) or Z score	P
Demographics				
Age, mean (SD), y	64.46 (20.45)	59.36 (10.10)	5.10 (−1.68, 11.88)	0.139
Male sex	23 (38)	42 (49)	−1.32	0.187
Female sex	37 (62)	43 (51)	1.32	0.187
Mechanism of injury				
GLF	32 (53)	45 (53)	0.04	0.960
FFH	13 (22)	19 (22)	−0.09	0.920
MVC	4 (7)	11 (13)	−1.22	0.222
ALT	3 (5)	3 (4)	0.44	0.660
MP	1 (2)	1 (1)	0.25	0.803
OTH	7 (11)	6 (7)	0.95	0.337
Injury type				
Contusion <1 cm	24 (40)	26 (31)	1.17	0.242
Convexity subarachnoid hemorrhage	42 (70)	60 (71)	−0.07	0.936
Skull fracture	2 (3)	12 (15)	−2.32	0.020*
>1 foci of injury	8 (13)	12 (15)	−0.33	0.741
Clinical features				
+ LOC (%)	31 (52)	45 (53)	−0.15	0.881
Recent ASA usage	20 (33)	18 (21)	1.64	0.101
Acute EtOH intoxication	5 (8)	7 (8)	0.02	0.984
Comorbidities				
HTN	22 (37)	32 (38)	−0.12	0.905
HLD	9 (15)	6 (7)	−1.72	0.085
DM	8 (13)	12 (15)	−0.33	0.741
CAD	4 (7)	6 (7)	−0.09	0.928
CHF	3 (5)	3 (4)	0.44	0.660
COPD	4 (7)	1 (1)	1.78	0.075
Epilepsy	1 (2)	3 (4)	−0.67	0.503
Prior CVA	2 (3)	4 (5)	−0.40	0.682

Data are presented as no. (%) unless indicated otherwise.

ALT, altercation; ASA, aspirin; CAD, coronary artery disease; CHF, congestive heart failure; COPD, chronic obstructive pulmonary disease; CVA, cerebrovascular accident (stroke); DM, diabetes mellitus; EtOH, ethanol; FFH, fall from height; GLF, ground-level fall; HLD, hyperlipidemia; HTN, hypertension; LOC, loss of consciousness (at injury); MP, motor versus pedestrian; MVC, motor vehicle collision; OTH, other.

\*Indicates  $P < 0.05$ .

patient suffered any clinical sequelae and both were later discharged without event. None of the 85 patients suffered a neurological examination change during the course of their admission. Fifty-four (64%) underwent scheduled follow-up; 1 patient required readmission and drainage of a newly discovered chronic subdural hematoma (Table 2).

Between the 2 cohorts, there were no statistical differences in radiographic progression on repeat imaging, 30-day readmission rate, or rate of follow-up. There was no known incidence of neurological deterioration, surgical intervention (except delayed surgery for chronic subdural hematoma at follow-up) or 30-day mortality in either group. The EDOU cohort had a significantly shorter time interval between

the admission and initial interval head CT in hours (12.12 EDOU vs 17.03 Ctrl, MD 3.92 [95% CI 1.65, 6.19],  $P < 0.001$ ) and shorter length of stay in days (1.0 EDOU vs 1.59 Ctrl, MD 0.59 [95% CI 0.29, 0.89],  $P < 0.001$ ). Finally, the EDOU cohort had significantly lower encounter charges (\$11,430.25 EDOU vs \$14,858.76 Ctrl, MD 3428.51 [95% CI 925.60, 5931.42],  $P = 0.008$ ), 23% lower than the control group (Table 2).

Given the high loss to follow-up observed in both groups, we performed a post-hoc complete case analysis for delayed outcomes. There were no significant differences in time to follow-up, 30-day mortality, 30-day readmission, and rate of chronic subdural hematoma formation. (Table 3)

**TABLE 2** Clinical outcomes, encounter charges, and follow-up of EDOU and control groups

Variable	EDOU (n = 60)	Control (n = 85)	MD (95% CI) or Z score	P
Acute mTBI encounter				
Repeat CT interval, mean (SD), h	13.12 (4.6)	17.03 (7.44)	3.92 (1.65, 6.19)	0.001 <sup>*</sup>
Radiographic progression	2 (3)	2 (2)	1.08	0.280
Neurological exam change	0	0	NA	
Surgical intervention	0	0	NA	
Required hospital admission	5 (8)	NA		
LOS, mean (SD), d	1.00 (0.66)	1.59 (1.15)	0.59 (0.29, 0.89)	<0.001 <sup>*</sup>
Charges, mean (SD), USD	11,430.25 (6278.84)	14,858.76 (8536.01)	3428.51 (925.60, 5931.42)	0.008 <sup>*</sup>
Follow-up				
Number with follow-up	33 (55)	54 (64)	-1.57	0.116
cSDH at follow-up	1 (2)	1 (1)	0.06	0.803
30-day readmission	2 (3)	1 (1)	0.90	0.368
30-day mortality	0	0	NA	NA

Data are presented as no. (%) unless indicated otherwise.

cSDH, chronic subdural hematoma; CT, computed tomography; LOS, length of stay.

<sup>\*</sup>Indicates  $P < 0.05$ .

**TABLE 3** Complete case analysis of delayed follow-up data

Variable	EDOU (n = 33)	Control (n = 54)	MD (95% CI) or Z score	P
Time to follow-up, mean (SD), days	32.18 (12.27)	33.94 (14.29)	1.76 (-3.99, 7.52)	0.544
cSDH at follow-up	1 (3)	1 (2)	0.12	0.722
30 day readmission	2 (6)	1 (2)	1.09	0.297
30 day mortality	0	0	NA	NA

Data are presented as no. (%) unless indicated otherwise.

cSDH, chronic subdural hematoma.

<sup>\*</sup>Indicates  $P < 0.05$ .

## 4 | LIMITATIONS

All retrospective studies are subject to potential unmeasured confounders, and selection or reporting bias as the authors, as data abstractors, were not blinded to the study hypothesis. Comparisons between sequential cohorts can be affected by changes in practice, referral patterns, and coding, which are difficult to account for. These data are from a single rural academic center with an unusually large geographic catchment area, which may not represent referral patterns and conditions reflected nationwide. Neurocognitive outcomes, while relevant to this study population, were not available to us and could not be analyzed. The study population had a low rate of adverse events, which could affect the analysis; a prospective, controlled study with a larger sample size would be ideal for further investigation. Finally, both groups had a high loss to follow-up (many patients may have followed up with a primary care provider or at another center). As such, there is a possibility delayed outcomes were not detected.

## 5 | DISCUSSION

mTBI is a common presentation to the ED, with an incidence of 100–300 per 100,000 population.<sup>1</sup> There exists wide variability in the management of mTBI with acute radiographic findings, although most patients are admitted and monitored given the perceived risk of hemorrhagic expansion or clinical deterioration.<sup>2</sup> This is despite evidence casting uncertainty on the necessity of inpatient monitoring in the absence of specific risk factors.<sup>3,6</sup> Nonetheless, many referring providers may feel apprehensive discharging a patient with acute intracranial hemorrhage, especially at small, lower acuity hospitals without local neurosurgical coverage. Patients can also feel insecure about returning home absent a period of monitoring. Hence, in our experience, transfer to the principal trauma center with admission has remained the typical management pathway.

One way to potentially reduce hospital admissions in this context may be a defined monitoring period in the ED. As EDs frequently suffer

their own capacity constraints, many high volume centers have developed EDOUs (frequently called “clinical decision units”) as a dedicated space for patients who need continued monitoring or triage, but do not meet clear admission criteria.<sup>7</sup> These units, often staffed with a mid-level practitioner and supervised by ED attending staff, were originally developed to monitor patients presenting with chest pain but low clinical probability of myocardial infarction, with the goal of using fewer resources than the analogous admission to a cardiac ICU.<sup>8</sup> Subsequent data have shown that EDOUs can reduce inpatient admission rate, length of stay, and cost for a wide variety of acute medical problems<sup>9–14</sup> and the Institute of Medicine has concluded that EDOUs can reduce unwarranted hospitalizations and improve institutional patient flow.<sup>15</sup>

Despite this, few studies have evaluated EDOU protocols for acute neurological presentations. One found that EDOU monitoring of acute transient ischemic attacks can significantly reduce both length of stay and encounter costs, with comparable clinical outcomes.<sup>16</sup> EDOU protocols may also be feasible for sudden-onset headache with equivocal diagnostic workup.<sup>17</sup> Two prior studies have evaluated EDOU management pathways in the mTBI population and found supportive results similar to ours, although only 1 used a pre-specified protocol, and neither was compared to a group of patients admitted under a traditional pathway or examined financial aspects.<sup>5,18</sup>

Our protocol, developed by joint consensus between the departments of neurosurgery and emergency medicine, was intended to identify low risk patients unlikely to decline or require surgery. For example, small cerebral contusions and convexity subarachnoid hemorrhage have been shown to be at very low risk for surgical intervention,<sup>19,20</sup> whereas displaced skull fractures are more likely to require surgery.<sup>6</sup> Accordingly, our protocol included all patients presenting with isolated contusions, convexity subarachnoid hemorrhage, and non-displaced fractures. Other excluding factors, given evidence suggestive of higher risk, included GCS <15, epidural hemorrhage (EDH), anticoagulation or coagulopathy, hemodynamic instability, and additional systemic injuries.<sup>2,21,22</sup> Aspirin usage was not considered a high-risk feature.<sup>22</sup>

Although subdural hematomas were excluded from our initial protocol, subsequent studies have suggested that some subdural hematomas in the setting of mTBI are at low risk of progression.<sup>23,24</sup> In recognition of this, we recently implemented a second protocol to include minor subdural hematomas in our EDOU. Although we did not include subdural hematoma in this study, as these patients were explicitly excluded in the original protocol, further investigation into EDOU management of this injury is clearly warranted.

The findings of this study demonstrate that the subset of mTBI identified by the protocol herein represents a minimal risk of acute complication. Among the patients observed in the EDOU, there was only a 3.33% rate of radiographic progression, and none of these instances were associated with any form of clinical deterioration. There was also no overall incidence of neurological decline, surgical intervention, or 30-day mortality. Further supporting the low risk of the protocol is the similarly low complication rate seen in the control cohort, identified using identical presenting criteria. Although 1 patient from each cohort developed a delayed chronic subdural, both of these were only identified at follow-up, well after the acute period.

Given this decidedly small risk of deterioration, several refinements to the protocol could be considered to further reduce redundant or unnecessary care. For example, although acquiring a repeat CT head is common for acute mTBI, recent studies have questioned the necessity of this practice.<sup>25,26</sup> Our results lend support to these conclusions, given the extremely low incidence of radiographic worsening, combined with the lack of clinical sequelae even in the setting of interval progression. As such, scheduled repeat imaging could be reasonably eliminated from the protocol. A second adjustment could be the norm of routine neurosurgical consultation. Although this is often conventional in the setting of acute hemorrhage, some evidence reinforces safe management of mTBI without a formal consultation.<sup>27</sup>

Overall, the EDOU and control cohorts were well matched in regard to demographics, comorbidities, mechanism of injury, and presenting features. However, they differed in fracture injury type, with substantially fewer skull fractures in the EDOU cohort. The reason for this difference is uncertain, as skull fractures were included in the initial inclusion protocol, and this was not changed during the course of the examined time period. Because the ED attending ultimately had final determination as to which patients met eligibility criteria for the protocol, non-adherence for this subtype of injury is possible, especially if the perceived risk of the injury was so low that such patients were discharged from the ED without any extended monitoring at all (EDOU or inpatient). It is also conceivable that “closed, non-displaced skull fractures” was too vaguely defined, leading to an inconsistent application of the criteria. For example, compared to a convexity fracture, a fracture of the skull base could be interpreted as higher risk given the possibility of a CSF leak, which could lead to differences in management. As such, based on our experience, we feel it is important to define the size and location of minor skull fractures in mTBI protocols.

There were no statistical differences in clinical outcomes between the EDOU and control groups. Notably, there was no difference in either radiographic progression on the interval CT scan of the head or neurological exam changes during the monitoring period. None of the patients in either group required surgery (the only exception being 2 patients who required burr holes for chronic subdural hematoma evacuation, both of which were detected at later follow-up). This suggests that observation of well-selected mTBI in an ED setting can be achieved safely, and admission to the hospital confers no advantages regarding acute clinical outcome. Avoiding admission has putative benefits for both the patient and for busy medical centers. At our institution, which is frequently fully occupied and forced to reroute patients, liberating additional capacity is of intuitive value.

Although we assessed mortality and the need for surgical intervention, long-term neurocognitive outcomes are particularly relevant for mTBI patients. Unfortunately, we were unable to use a neurocognitive outcome measure in our study population, because this information was not reliably recorded. Although this represents a limitation to the study, our findings still suggest that monitoring mTBI in an EDOU is safe in the acute setting. It remains unclear if long-term neurocognitive effects could vary between an EDOU or inpatient management strategy. Based on our experience, future protocols should clearly define and record neurocognitive outcomes so that these can be assessed.

Despite the analogous clinical outcomes, there were 2 important differences in respect to management. First, there was a significantly shorter time to each patient's interval head CT. Our ED has a CT scanner located directly adjacent to the EDOU, and the scans were scheduled in advance, both of which likely contributed to this difference. On the contrary, admitted patients have to travel a much further distance across different floors to the nearest scanner, which is dependent on the schedules of busy transport staff, and scans are not routinely scheduled in advance given the lack of a standard protocol. Second, the overall LOS was significantly shorter in the EDOU cohort. This is likely attributable to the faster interval scanning, combined with clear, pre-determined criteria for discharge that is defined in advance. Although clinical judgement by experienced physicians cannot be supplanted, we believe that management protocols for uncomplicated, lower risk presentations such as this can foster improvements in efficiency.

Finally, the total encounter charges for the EDOU group were 23% lower than the control group. This is in agreement with economic benefits seen when using an EDOU for other conditions.<sup>11</sup> Hospital admissions represent an enormous social expense and have been identified as a principal driver of increasing health care spending in the United States, despite constituting only a small proportion of health care utilization.<sup>28</sup> Furthermore, admissions incur substantially higher costs than ED visits on a per-encounter basis.<sup>29,30</sup> Given the high frequency of mTBI presentations nationwide, and the frequency of subsequent hospital admissions, reducing admission rates with similar EDOU protocols could represent a substantial decrease in domestic health-care expenditures. To our knowledge, this is the only study to suggest that EDOU protocols for mTBI can have positive economic impacts.

An important consideration of this finding is that hospital charges are not always analogous to the cost of care, the latter typically being lower in the US system.<sup>31,32</sup> Cost figures representing resource consumption are generally less accessible and often only indirectly measured. Billable charges represent a more available source of financial data. Although hospital charges are normally higher than cost in actual amount, proportional differences are usually similar and often inferred as such.<sup>33,34</sup> Therefore, as charges associated with the EDOU mTBI protocol were significantly lower, it is likely that cost in terms of resource allocation is similarly reduced.

One form of expense not included in this study is hospital-to-hospital transfers. This can be a considerable cost and is not always medically necessary for mTBI.<sup>33</sup> At our center, a large proportion of ED presentations are transfers from another facility. We were unable to factor these charges into our results, given the lack of consistent access to financial data by outside hospitals and transport companies. As such, the global charges per patient encounter may be underestimated. Nevertheless, the results do lend support to regional management pathways that mitigate hospital transfers, because the findings reinforce safe monitoring of well-selected patients in an ED setting without the need for surgical intervention. Carefully selected patients, perhaps combined with usage of specialist tele-consults, could help avoid costly and unnecessary hospital transfers.

A major limitation to this study is the high loss to follow-up. Indeed, this is a very frequent problem in the TBI population.<sup>35</sup> Our

study demonstrates the importance of a thorough follow-up plan, as 2 patients developed a chronic subdural hematoma requiring delayed surgery. Although our protocol specified a 1-month follow-up in the neurosurgery clinic, it did not provide a formal mechanism for scheduling or confirming the visit, a notable weakness in its design. Given our experience, we suggest including a specific mechanism to facilitate follow-up when designing such a protocol in advance. This could be through a specialty office, concussion clinic, or primary care provider, with automatic outreach to the patient to confirm and encourage follow-up. Finally, we note that despite the limitation imposed by the high loss to follow-up, the outcomes derived from the acute encounter (length of stay, acute radiographic or neurological progression, and charges) remain unaffected.

In summary, compared with hospital admission for monitoring, management of mTBI patients in an EDOU using a pre-specified protocol was not associated with any difference in adverse clinical outcomes, but was associated with shorter time to interval scanning, shorter length of stay, and lower encounter charges. The overall risk of radiographic progression or clinical complications in this defined subset of mTBI was very low. Using an EDOU mTBI protocol to safely mitigate unnecessary admissions can therefore yield patient care, hospital capacity, and economic benefits. When developing a protocol, in addition to developing a standardized and evidence-based management plan, close attention should be given to clear inclusion criteria for each category of injury, along with a formal mechanism to facilitate follow-up.

## CONFLICT OF INTEREST

The authors declare no conflict of interest.

## AUTHOR CONTRIBUTIONS

BKR, HSG, and PLL conceived the study. BKR and PLL supervised the conduct of the study. BKR, JHK, DCC, and MR-Z provided data extraction. All authors contributed to interpretation of data and results. BKR provided statistical analysis and drafted the preliminary manuscript. HSG and BKR created figures. All authors contributed to manuscript revision. BKR takes responsibility for the paper as a whole.

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