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Beyond Glasgow Coma Scale: Prehospital prediction of traumatic brain injury

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ABSTRACT

Introduction: Early identification of traumatic brain injury followed by timely, targeted treatment is essential. We aimed to establish the ability of prehospital Glasgow Coma Scale score alone and combined with vital signs to predict hospital-diagnosed traumatic brain injury.

Methods: This study included adults from the 2017–2020 Trauma Quality Improvement Program data set with blunt mechanism. We calculated test characteristics of prehospital Glasgow Coma Scale score ≤12 alone and Glasgow Coma Scale score combined with heart rate and systolic blood pressure for predicting (1) any traumatic brain injury and (2) moderate to severe traumatic brain injury. Diagnostic performances were calculated in all patients and older adults (≥55 years). We used decision curve analysis to determine the net diagnostic benefit of prehospital Glasgow Coma Scale score combined with heart rate + systolic blood pressure over Glasgow Coma Scale score alone.

Results: Of 1,687,336 patients, 39.1% had any traumatic brain injury, 3.7% had moderate to severe traumatic brain injury, and 9.1% had a prehospital Glasgow Coma Scale score ≤12. Prehospital Glasgow Coma Scale score ≤12 alone had a sensitivity 83.1%, specificity 93.7%, negative predictive value 99.3%, and positive predictive value 33.7% for predicting moderate to severe traumatic brain injury. Adding prehospital heart rate <65/min and systolic blood pressure >150 mm Hg to Glasgow Coma Scale score ≤12 improved the positive predictive value for moderate to severe traumatic brain injury (55.3%), with a preserved negative predictive value of 96.4%. Decision curve analysis showed the traumatic brain injury prediction model including prehospital heart rate and systolic blood pressure had the greatest net benefit across most threshold probabilities.

Conclusion: Less than a third of adult blunt trauma patients with a prehospital Glasgow Coma Scale score ≤12 have moderate to severe traumatic brain injury. Supplementing Glasgow Coma Scale score with prehospital vital signs improves diagnostic accuracy, potentially by filtering out patients with altered consciousness due to shock. Future work should better identify patients for traumatic brain injury–specific treatments in prehospital settings, including triage destination.

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Introduction

Traumatic brain injury (TBI) is a common cause of morbidity and mortality in the United States and worldwide.[1,2] TBI encompasses a wide range of pathologies, ranging from concussion to coma and death.[3] Moderate to severe TBI carries the most significant morbidity and mortality, but even after mild TBI, more than half of patients have impairments at 12 months postinjury.[4] Current methods of early TBI detection, critical for immediate and appropriate intervention, are inadequate. Today, the prehospital measurement of the Glasgow Coma Scale (GCS), a summative scale ranging from 3 to 15 that assesses the motor, verbal, and eye response of the acutely injured patient,[5–7] serves as the primary tool to identify patients with suspected TBI in the field. This scale, however, does not differentiate between TBI itself and other causes of altered mental status (ie, not specific for TBI) and also does not capture patients with TBI who have yet to decompensate neurologically (ie, not sufficiently sensitive).[8,9]

To improve prehospital diagnosis, there have been attempts to incorporate prehospital vital signs and/or physical examination findings in addition to GCS score alone.[10–13] Older adults are at particular risk of undertriage and missed prehospital diagnosis of TBI for a variety of reasons, including age-related physiological responses to injuries, and cerebral atrophy permitting accumulation of (initially) asymptomatic traumatic hemorrhage.[14–17] A recent consensus panel proposed a new decision scheme for detecting older adult TBI patients who require transport to a trauma center.[18]

Despite the widespread use of GCS to triage and diagnose TBI in the prehospital setting, there are no published test characteristics for using prehospital GCS score to diagnose TBI. We aimed to establish the accuracy of prehospital GCS alone and GCS combined with vital signs to predict hospital-diagnosed TBI. We hypothesized that prehospital GCS alone would not adequately predict a confirmed, hospital-diagnosed TBI and that the addition of vital sign thresholds would improve the positive predictive value (PPV) for the prehospital GCS score. Our objective was to analyze a comprehensive, nationwide data set to better understand the current limitations of prehospital TBI diagnosis, rather than to develop a new prediction model for individual patient management.

Methods

Study population

We conducted a retrospective cohort study using patient data from the Trauma Quality Improvement Program (TQIP), a national quality monitoring and improvement program for the care of the injured patients established by the American College of Surgeons Committee on Trauma.[19] Criteria for inclusion into TQIP are established by the National Trauma Data Standard, but in brief, they include presentation to participating trauma centers with any injury from a traumatic mechanism.[20] This study was reviewed by the Vanderbilt Institutional Review Board and determined to be exempt.

We included all patients from the 2017–2020 TQIP database who were aged ≥18 years and had a documented blunt mechanism of injury. Penetrating injuries were excluded given the lack of diagnostic uncertainty we are interested in evaluating. We also excluded patients missing prehospital GCS documentation or other prehospital vital signs, specifically systolic blood pressure (SBP) and/or heart rate (HR). We planned a subset analysis of older adults, using an age cutoff of ≥55 years based on prior work, because of the known undertriage and missed prehospital diagnosis of TBI in older adults.[18]

Definition of traumatic brain injury

We defined a hospital-confirmed diagnosis of TBI as an Abbreviated Injury Scale–Head (AIS-Head) score of 1 to 6. The AIS-Head scale is an anatomic injury classification, but broadly, a score of 1–2 corresponds to mild TBI, a score of 3–6 to moderate to severe TBI, and a score of 6 represents fatal TBI. We defined a hospital-confirmed diagnosis of moderate to severe TBI as requiring both an AIS-Head score of 3–6 and a postresuscitation GCS score between 3 and 12, the GCS being administered on the calendar day after hospital arrival.[7,21]

Tests of interest

We primarily assessed prehospital GCS score ≤12 for its accuracy in predicting a hospital-confirmed diagnosis of any TBI and moderate to severe TBI. We used this cutoff of GCS score ≤12 because traditional classification of TBI assigns severe TBI to a GCS score of 3 to 8 and moderate TBI to a GCS score of 9 to 12.[22] We next assessed the combination of prehospital GCS score ≤12 in combination with prehospital HR (<65/min) and SBP (>150 mm Hg). The SBP and HR cutoffs were chosen based on their highest predictive power for diagnosing TBI. We elected to use these 2 vital signs separately rather than combined into a single shock index to maximize the predictive power of commonly available prehospital data. In older adults (≥55 years), we also evaluated the test characteristics of the recent panel-proposed decision scheme for triaging older adult patients with suspected TBI for triage to a trauma center, namely, inability to follow commands (GCS motor score less than 6) and/or not alert (approximated with GCS verbal score less than 5).[18] For simplicity, we refer to this as the “older adult triage tool” going forward.

Temporal changes in GCS score

Use of the prehospital GCS score alone as a diagnostic criterion for TBI assumes it as a stable predictor. In order to demonstrate clinically relevant temporal fluctuations in the GCS score in the initial hours after injury, we further used the TQIP database to visually depict this variation. For all patients with GCS scores recorded across the prehospital, emergency department (ED), and post-resuscitation time points, we generated a Sankey plot to visually depict changes in GCS scoring in the initial hours after injury. Postresuscitation GCS score is defined in the TQIP database as the highest GCS score on hospital day 2; and this variable is reported for patients with an AIS-Head score of 1–6. For patients with an AIS-Head score of 0, postresuscitation GCS score was assumed to be in the 13–15 range. Additional GCS scores over time, including at hospital discharge, are not available in the TQIP database.

Analysis

We used descriptive statistics to summarize the demographics, prehospital vitals, injury severity, and hospital mortality of our study populations. We calculated the test characteristics of prehospital GCS score ≤12 alone and combined with HR and SBP for predicting any TBI and moderate to severe TBI. Test characteristics included the sensitivity, specificity, negative predictive value (NPV), and PPV. We calculated and used the HR and SBP cutoffs that were most predictive of TBI in combination with the GCS score based on the PPV. In older adults (≥55 years), we also evaluated the test characteristics of the older adult triage tool described in the previous section.[18]

In accordance with standard methods, we used decision curve analysis to display and determine the net diagnostic benefit of prehospital GCS score combined with HR and SBP over prehospital GCS score alone for diagnosing TBI.[23,24] The net benefit is the difference between expected benefit (true positives, patients correctly diagnosed) and expected harm (false positives, patients without TBI incorrectly diagnosed with TBI). This approach compares the net benefit of accurate TBI diagnosis among potential diagnostic options across the probability of TBI warranting intervention.

Statistical analyses were performed using R Statistical Software (version 4.2.2; R Foundation for Statistical Computing, Vienna, Austria) and R Studio (version 2023.03.0+386).

Results

After applying the inclusion and exclusion criteria, our study population comprised 1,687,336 patients (Figure 1).

Table I demonstrates the study population demographics and prehospital vital signs. Overall, 39.1% had any TBI, 3.7% had moderate to severe TBI, and 9.1% had a prehospital GCS score ≤12. Among the 954,715 patients aged 55 years or older, 36.3% had any TBI, 2.9% had moderate to severe TBI, and 6.8% had a prehospital GCS score ≤12. Moderate to severe TBI patients had a median prehospital GCS score of 5 with an interquartile range (IQR) of 3–10, whereas older adults had a median prehospital GCS score of 7 with an IQR ranging from 3 to 12. For patients aged ≥65 years with moderate to severe TBI (not shown), the median prehospital GCS score was 8 (IQR 3, 13).

Test characteristics of prehospital GCS score with and without vitals

Table II displays the sensitivity, specificity, PPV, and NPV of prehospital GCS score ≤12 for predicting any head injury and moderate to severe TBI. The NPV of prehospital GCS score ≤12 for ruling out moderate to severe TBI was >99% in all ages and in older adults. Adding prehospital HR <65/min and SBP >150 mm Hg to GCS score ≤12 improved the PPV for moderate to severe TBI from 33.7% to 55.3%, with a modest decrease in the NPV to 96.4% (from 99.3%). Figure 2 shows that a TBI Prediction Model including prehospital HR and SBP had the greatest net benefit across most threshold probabilities relative to the use of prehospital GCS score alone. Threshold probability represents the predicted probability of moderate to severe TBI that would warrant intervention, measuring clinician preference of missing the diagnosis versus treatment for a false positive (assuming that diagnosis leads to

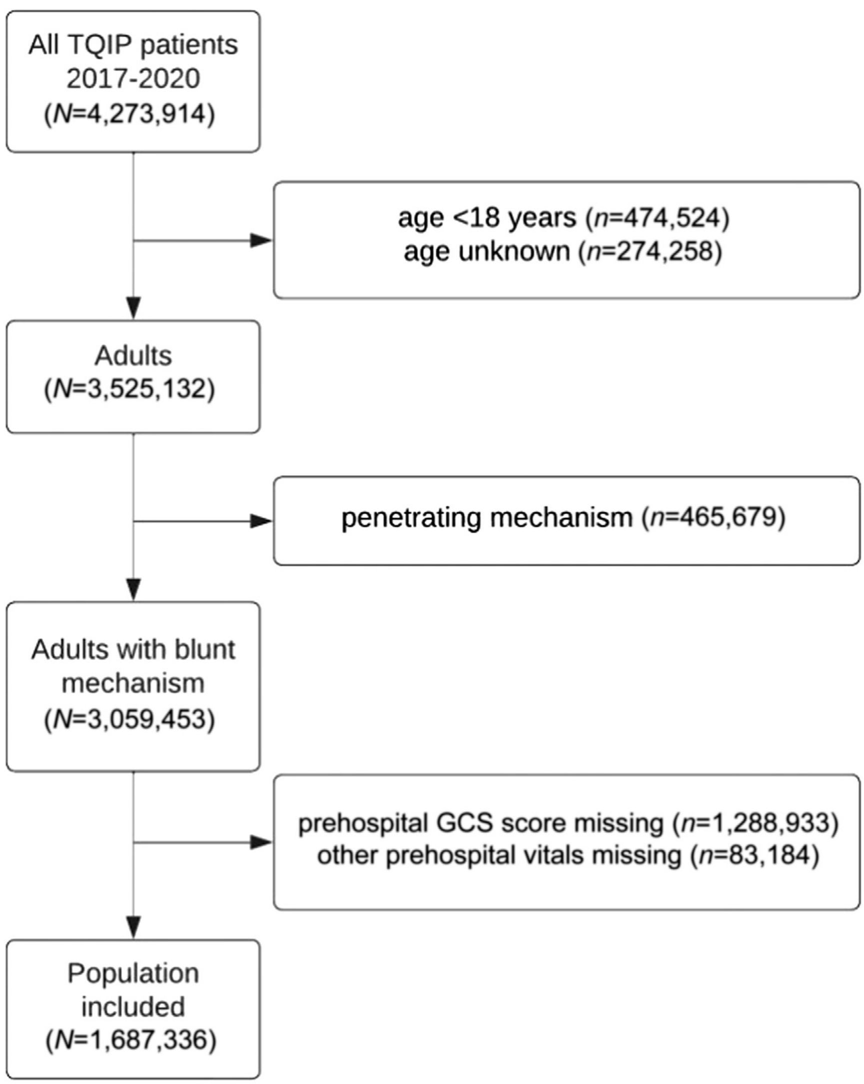

Figure 1. Study flowchart. *GCS*, Glasgow Coma Scale; *TQIP*, Trauma Quality Improvement Program.

Table I
Study population demographics and prehospital vitals

All ages			
	All patients (n = 1,687,336)	Any head injury (n = 660,420)	Moderate to severe TBI (n = 62,508)
Age	59 [38, 75]	56 [35, 73]	51 [31, 68]
Male, n (%)	959,850 (57)	423,190 (64)	45,445 (73)
Prehospital GCS score	15 [15, 15]	15 [14, 15]	5 [3, 10]
Prehospital SBP, mm Hg	140 [123, 158]	140 [122, 159]	137 [110, 160]
Prehospital HR, min^{-1}	88 [76, 100]	89 [76, 103]	90 [72, 110]
Injury severity score	9 [4, 12]	10 [5, 17]	26 [21, 34]
Inpatient mortality, n (%)	48,487 (3)	34,754 (5)	22,024 (35)
		Patients ≥55 y	
	All patients (n = 954,715)	Any head injury (n = 346,104)	Moderate to severe TBI (n = 27,885)
Age	73 [64, 81]	72 [63, 81]	70 [62, 79]
Male, n (%)	456,919 (48)	197,443 (57)	18,481 (66)
Prehospital GCS score	15 [15, 15]	15 [14, 15]	7 [3, 12]
Prehospital SBP, mm Hg	146 [127, 165]	147 [128, 168]	149 [122, 176]
Prehospital HR, min^{-1}	84 [72, 96]	84 [73, 97]	87 [72, 103]
Injury severity score	9 [5, 10]	10 [5, 17]	26 [19, 30]
Inpatient mortality, n (%)	34,496 (4)	22,955 (7)	12,508 (45)

All values are median [interquartile range] unless otherwise specified.
GCS, Glasgow Coma Scale; *HR*, heart rate; *SBP*, systolic blood pressure.

Table II
Test characteristics for using prehospital GCS score ≤12 to diagnose TBI

	Predicting any head injury*		Predicting moderate to severe TBI†	
	All ages, %	Age ≥55 y, %	All ages, %	Age ≥55 y, %
Sensitivity	17.9	14.2	83.1	76.9
Specificity	96.5	97.4	93.7	95.3
PPV	76.8	75.5	33.7	33.0
NPV	64.6	66.6	99.3	99.3

GCS, Glasgow Coma Scale; *NPV*, negative predictive value; *PPV*, positive predictive value; *TBI*, traumatic brain injury.
* Abbreviated Injury Scale-Head (AIS) 1–6.
† Both AIS-Head scores 3–6 and post-resuscitation GCS scores ≤12.

treatment). For example, a threshold probability of 20% (corresponding to 1:4 odds) is the preference that missing the diagnosis of moderate to severe TBI (and not treating) is 4 times worse than falsely diagnosing without TBI (and then treating for TBI).

Older Adults

The sensitivity of prehospital GCS score ≤12 for identifying moderate to severe TBI was lower in patients aged ≥55 years than in the overall adult population ($P < .01$), as seen in Table II. The use of prehospital GCS score ≤12 alone failed to capture 6,433 older adults with a hospital-confirmed diagnosis of moderate to severe TBI. The older adult triage tool (GCS motor score <6 and/or not alert) had a PPV and NPV of 73.0% and 67.4% for any head injury and 26.0% and 99.4% for moderate to severe TBI, respectively. Use of this older adult triage tool alone would have failed to capture 5,191 older adults with a hospital-confirmed diagnosis of moderate to severe TBI.

Changes in GCS score over time

After excluding 63,999 patients with missing GCS scores in the ED and 14,056 patients with deaths in the ED, we included 1,609,646 patients in the visual comparison of changes in GCS scores across the prehospital, ED, and postresuscitation time points in a Sankey plot (Figure 3). Overall, 6.0% of patients had a change in their GCS score category (3–8, 9–12, or 13–15) from the prehospital to ED setting. Among patients with a prehospital GCS score >12, 1.8% changed to an ED GCS score ≤12, and 26.7% of those maintained a postresuscitation GCS score ≤12 corresponding to moderate to severe TBI. Among older adults with a prehospital GCS score >12, 1.7% changed to an ED GCS score ≤12, and 30.8% of those maintained a postresuscitation GCS score ≤12.

Discussion

Prehospital identification of TBI is essential for appropriate triage and transport to specialized trauma centers and targeted therapy to minimize secondary brain injury. We found that supplementing GCS score with prehospital vital signs improves diagnostic accuracy, potentially by filtering out patients with altered consciousness as a result of shock, but it remains inadequately sensitive because not all confirmed TBI patients are captured using GCS score and vital signs alone. Less than a third of adult blunt trauma patients with a prehospital GCS score ≤12 actually have moderate to severe TBI, consistent with previous studies showing low GCS score to be less predictive of TBI in polytrauma patients.[25] Prehospital GCS score was largely sufficient to rule out moderate to severe TBI except in older adults; for example, in adults aged ≥65 years later diagnosed with moderate to severe TBI, the interquartile range for prehospital GCS score included a GCS score of 13. To our knowledge, this is the largest study to systematically examine the utility of prehospital GCS score alone and in combination with vital signs to diagnose TBI of varying severities.

The Glasgow Coma Scale, celebrating its 50th anniversary this year, was originally developed as an objective tool to be used only after hemodynamic resuscitation and expressly in the absence of pharmacologic sedation, paralysis, or other forms of intoxication.[7,26] Use of the GCS score is now an integral part of our trauma protocols spanning the prehospital, ED, and inpatient environments as a repetitive, reproducible scale that allows for ongoing neurologic assessments performed by a variety of health care professionals. It was never intended to screen for suspected TBI patients in the prehospital setting for triage and treatment, and although it does so adequately for most patients, we must move beyond GCS score by adding other diagnostic tools.

Our finding that adding an HR ≤ 65/min and SBP ≥ 150 mm Hg improved the PPV for moderate to severe TBI echoes prior work, including a decision tool to predict the need for emergency neurosurgery (higher SBP and lower HR),[10] a machine learning

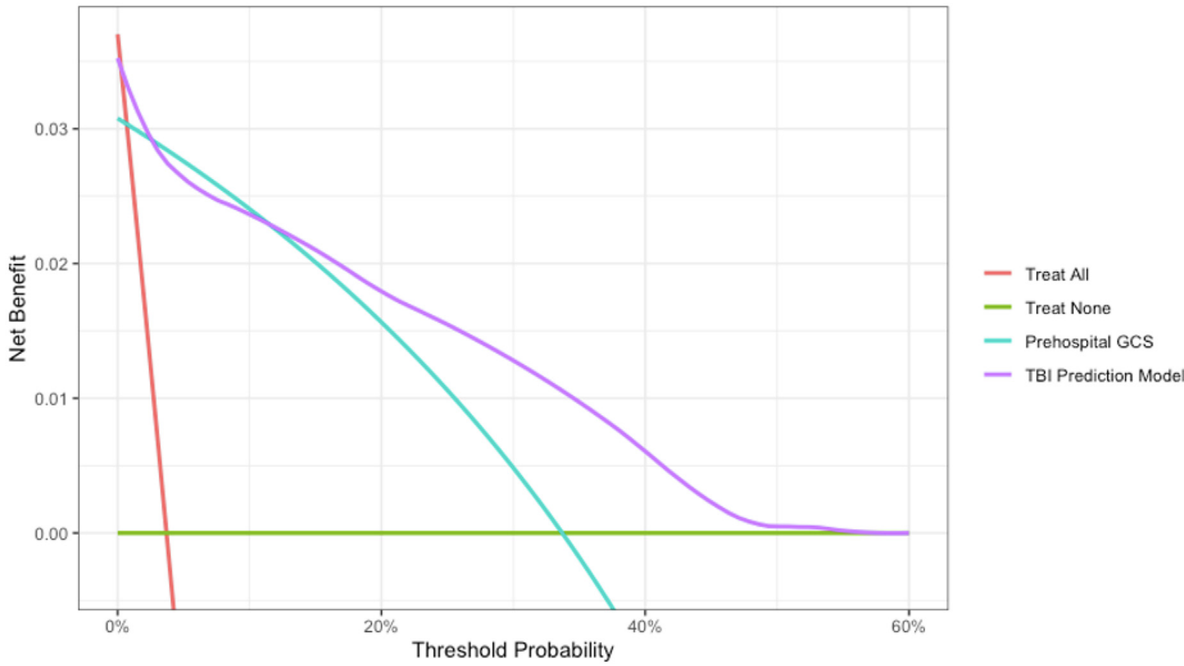

Figure 2. TBI prediction model versus prehospital GCS score alone for moderate to severe TBI. Decision curve analysis comparing strategies to diagnose moderate to severe TBI in the field. Net benefit (Y axis) is the difference between expected benefit (true positives, patients correctly diagnosed) and expected harm (false positives: patients without TBI incorrectly diagnosed with TBI). The highest line is the strategy with the highest net benefit across the range of threshold probabilities (predicted probability of TBI warranting intervention), in this case the TBI Prediction Model relative to Prehospital GCS score alone. The "Treat All" strategy refers to diagnosing all patients with TBI, the "Treat None" strategy refers to diagnosing no patients with TBI, and "Prehospital GCS and "TBI Prediction Model" refers to diagnosing based on those diagnostic criteria, respectively. *GCS*, Glasgow Coma Scale; *TBI*, traumatic brain injury.

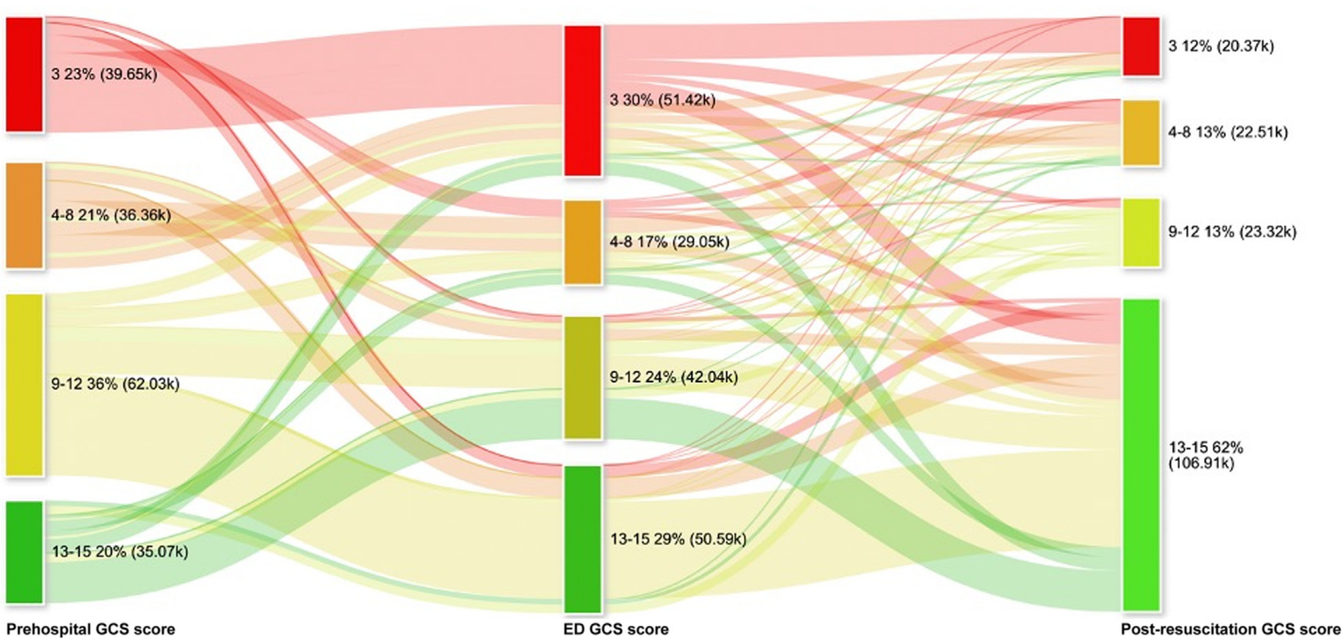

Figure 3. Temporal Changes in GCS score after blunt trauma. Colors of patient trajectories correspond to the original category in the prehospital setting (eg, green are patients with a prehospital GCS score 13–15). Source population is adults in the Trauma Quality Improvement Program (2017–2020) with blunt traumatic mechanism and available data for GCS score over time. For ease of visualization, not included are patients with prehospital, ED, and postresuscitation GCS score all corresponding to 13–15. *ED*, emergency department; *GCS*, Glasgow Coma Scale.

prediction model for TBI,[11] and a small British study that identified an SBP > 160 mm Hg and HR < 60/min as optimal cutoff points for prediction of increased intracranial pressure.[9] A retrospective study in 2014 also examined GCS with prehospital HR and SBP, as well as respiratory rate, to estimate the risk of severe head injury, determining that abnormalities in GCS score, HR, and SBP resulted in a higher likelihood of high-mortality TBI than use of GCS alone.[12] This single-institution study looked at various ranges of vital signs using a multivariate analysis, in relation to high-mortality TBI. Using a large generalizable nationwide database, we sought to demonstrate the utility of GCS alone and in combination with vital signs as a tool for prehospital providers to diagnose moderate to severe TBI. We agree that this tool itself may not change practice; rather, our aim is to draw attention to the limitations of our current diagnostic capabilities for TBI in the prehospital setting. Other proposed alternatives to GCS include the simplified motor score (SMS), a 3-point scale easier to calculate than GCS score and shown to have a similar sensitivity to GCS with regard to prediction of TBI.[13] The FOUR (Full Outline of UnResponsiveness) Score is another method that has been developed to screen for severity of TBI or coma. It considers the eye-opening and motor aspects of the GCS score, removes the verbal to reduce overlap with intoxication and intubation, and adds elements of brain stem reflexes, pupillary and corneal response, and respiration pattern. It has been validated in the ICU and ED regarding inter-relatability and prognostication. This scale has been accepted by many; however, it does include additional assessments that can take valuable prehospital time.[27–30] None of these prediction models are in widespread use, and we do not advocate for replacing the current practice GCS score alone with a complicated algorithm involving elevated SBP and low-normal HR. Rather, our findings underscore the need to consider other factors beyond the GCS score.

Most undertriage deaths, greater than 90% in one series, are due to severe TBI.[31] We report a higher prehospital GCS score for the older adults later confirmed to have a moderate to severe TBI by cross-sectional imaging and postresuscitation GCS score. Identifying prehospital TBI in older adults presents a diagnostic challenge. Older adults tend to have a higher initial GCS score but can rapidly deteriorate because of the presence of cerebral atrophy and the decreased ability of the cranium to buffer hematoma expansion.[16,17] A review of various prehospital scales identified a simplified older adult triage tool composed of alertness and the ability to follow commands as the tool best able to identify injured patients for transfer to a trauma center.[18] However, our evaluation of this tool determined that it still was inadequate to capture some older adults with moderate to severe TBI. Integrating age-specific physiologic criteria into national field triage guidelines to reduce undertriage in older adults and allow more timely access to interventions is necessary, but the current criteria are not yet sufficient.[32,33]

There is a growing recognition in the trauma community that initiating our best treatments in the prehospital phase of care improves survival, such as with whole blood for those in hemorrhagic shock.[34,35] Injured patients with TBI merit the same consideration for precision treatment as close as possible to the time of injury to afford them the highest possibility of a meaningful recovery. Future directions include incorporation of prehospital biomarkers and mobile imaging for increased diagnostic accuracy of prehospital TBI. Blood-based TBI biomarkers such as glial fibrillary acidic protein (GFAP), ubiquitin C-terminal hydrolase L1 (UCH-L1), and S100 calcium-binding protein B (S100B) have all been investigated specifically for use in prehospital diagnosis.[36–38] A combined GFAP–UCH-L1 blood test has been FDA approved to rule out the need for a CT scan in injured patients with a GCS score >12, and this test has recently been cleared for use in a whole blood point-of-care instrument that is well suited to the prehospital setting. Use of a prehospital stroke unit with a mobile CT scan may be another way to appropriately triage transport of injured patients at risk for TBI.[39]

Study limitations

Limitations of the current study include its retrospective nature and the use of TQIP data intended for quality improvement rather than research. We chose to establish the accuracy of GCS alone and in combination with vital signs to predict any TBI and moderate to severe TBI, but we did not evaluate whether a preserved prehospital GCS score missed patients who went on to require neurosurgical intervention, would have benefited from neurosurgical intervention but did not receive it because of undertriage, or delayed diagnosis leading to interval decompensation precluding intervention. We were unable to capture all serial GCS measurements because of the limitations of the retrospective TQIP database. Prehospital guidelines recommend that providers repeat their GCS evaluation at least every 30 minutes or when changes become apparent clinically.[3,22] We were not able to capture other associated physical examination or injury mechanism details that providers may also incorporate to better estimate the pretest probability of an injured patient having a TBI. The nature of the TQIP database also does not account for prehospital treatments and serial assessment of vitals. Neither does it account for GCS score alterations due to intubation, sedation, or intoxicants. Finally, excluding patients without documented prehospital vital signs may have inadvertently introduced bias in our analysis; however, the proportion of patients excluded were small (<5% of the sample). There were a large percentage of patients (42%) that were excluded because of lack of prehospital GCS score. These were excluded in our data set. This is a limitation of the study that cannot be overcome—the structure of the TQIP database, and it may have resulted in selection bias as the GCS score was likely not missing at random.

In conclusion, the primary contribution of this article is to describe the current state of prehospital diagnosis of TBI using GCS score and vital signs alone. This current state is not optimal, particularly for older adults. Better prehospital TBI diagnosis is essential for the appropriate triage of injured patients to trauma centers, for identifying patients for TBI-targeted prehospital care (eg, tranexamic acid), and enrolling patients who have TBI in prehospital TBI clinical trials. For example, less than 60% of the patients enrolled in the Prehospital TXA for TBI study had intracranial blood on computed tomography after hospital arrival.[40] Future work is needed to better identify patients for TBI-specific treatments in prehospital settings, including triage destination. Advances in prehospital diagnosis of TBI must parallel advances in targeted neuroprotective therapies to mitigate secondary brain injury after the primary insult of TBI.

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Conflict of Interest/Disclosure

The authors have indicated that they have no conflicts of interest (or funding) regarding the content of this article.

CRediT authorship contribution statement

Jessica E. Schucht: Writing – review & editing, Writing – original draft. **Shayan Rakhit:** Writing – review & editing, Data curation. **Michael C. Smith:** Writing – review & editing, Data curation. **Jin H. Han:** Writing – review & editing, Data curation. **Joshua B. Brown:** Writing – review & editing, Data curation. **Areg Grigorian:** Writing – review & editing, Data curation. **Stephen P. Gondek:** Writing – review & editing, Data curation. **Jason W. Smith:** Writing – review & editing. **Mayur B. Patel:** Writing –

review & editing, Data curation, Conceptualization. **Amelia W. Maiga:** Writing – review & editing, Writing – original draft, Data curation, Conceptualization.

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