The Estimated Verbal GCS Subscore in Intubated Traumatic Brain Injury Patients: Is it Really Better?

Katarina Cheng,¹ Ribal Bassil,¹ Raphael Carandang,^{1–3} Wiley Hall,^{1,2} and Susanne Muehlschlegel^{1–3}

Abstract

The Glasgow Coma Scale (GCS) has limited utility in intubated patients due to the inability to assign verbal subscores. The verbal subscore can be derived from the eye and motor subscores using a mathematical model, but the advantage of this method and its use in outcome prognostication in traumatic brain injury (TBI) patients remains unknown. We compared the validated “Core+CT”-IMPACT-model performance in 251 intubated TBI patients prospectively enrolled in the longitudinal OPTIMISM study between November 2009 and May 2015 when substituting the original motor GCS (mGCS) with the total estimated GCS (teGCS; with estimated verbal subscore). We hypothesized that model performance would improve with teGCS. Glasgow Outcome Scale (GOS) scores were assessed at 3 and 12 months by trained interviewers. In the complete case analysis, there was no statistically or clinically significant difference in the discrimination (C-statistic) at either time-point using the mGCS versus the teGCS (3 months: 0.893 vs. 0.871; 12 months: 0.926 vs. 0.92). At 3 months, IMPACT-model calibration was excellent with mGCS and teGCS (Hosmer-Lemeshow “goodness-of-fit” chi square p value 0.9293 and 0.9934, respectively); it was adequate at 12 months with teGCS (0.5893) but low with mGCS (0.0158), possibly related to diminished power at 12 months. At both time-points, motor GCS contributed more to the variability of outcome (Nagelkerke ΔR^2) than teGCS (3 months: 5.8% vs. 0.4%; 12 months: 5% vs. 2.6%). The sensitivity analysis with imputed missing outcomes yielded similar results, with improved calibration for both GCS variants. In our cohort of intubated TBI patients, there was no statistically or clinically meaningful improvement in the IMPACT-model performance by substituting the original mGCS with teGCS.

Keywords: estimated verbal GCS; Glasgow Coma Scale; motor GCS; outcome prognostication; traumatic brain injury

Introduction

THE GLASGOW COMA SCALE (GCS) is one of the most important clinical scales in physician medical decision-making, patient outcome prognostication, and trauma triaging.¹ It is an integral component of several intensive care unit (ICU) and neurological scoring models, for example, the original and revised Trauma Score,^{2,3} the Acute Physiological and Chronic Health Evaluation (APACHE) scores,⁴ the International Mission for Prognosis and Analysis of Clinical Trials in TBI (IMPACT) score,⁵ the Intracerebral Hemorrhage (ICH) score,⁶ and the FUNC-score.⁷ The GCS is used to inform intervention, predict outcome, and facilitate inter-patient and inter-facility comparison of patients.

An inherent problem of the GCS is the inability to accurately assign verbal subscores in intubated patients. Although there is no accepted standard, the commonly applied method to mitigate this problem by assigning “1” to the verbal subscore ultimately results in an underestimation of the total GCS.^{8,9} Experts agree that the GCS should not be used for prognostication alone.⁹ However, underestimation of the GCS may translate into worse prognostication

scores (such as those listed above), and in practice may be misused by clinicians to prognosticate significantly worse outcomes,¹⁰ therefore potentially impacting treatment recommendations and decisions by physicians and families.

The IMPACT-score, the most widely validated outcome score for moderate to severe traumatic brain injury (TBI), avoids this problem entirely by using the motor subscore only,^{11,12} mostly because of the unreliable and incomplete recording of the verbal and eye subscores in the source population from which this score was derived.¹² Recognizing this “conundrum,” Rutledge and colleagues developed a mathematical model in 665 non-intubated surgical ICU patients to estimate the verbal GCS subscore from the eye and motor subscores.¹³ Recently, several National Institute of Neurological Diseases and Stroke and industry-funded hemorrhagic and ischemic stroke trials have started to apply this verbal GCS subscore estimation when recording the total GCS in intubated patients.^{14–17} However, validation of this mathematical model as well as knowledge about its utility for improving outcome model precision in intubated neurocritically ill patients, in particular TBI patients, are lacking.

Departments of ¹Neurology, ²Surgery, and ³Anesthesiology/Critical Care, University of Massachusetts Medical School, Worcester, Massachusetts.

Therefore, using a TBI patient cohort and the IMPACT model as an example, we aimed to examine the prediction model performance (calibration and discrimination) comparing the motor (mGCS) as originally used in the IMPACT model with the total estimated (teGCS) using the published Rutledge formula to estimate the verbal GCS subscore and the total GCS with the verbal subscore set as “1” (GCS_{total}). We also explored the differences in the relative contribution of the different GCS variants to the outcome by calculating the change in Nagelkerke R^2 (ΔR^2), as well as each model’s Nagelkerke R^2 . We hypothesized that the model performance of the original IMPACT model could be improved by using teGCS, but that no improvement would be achieved by using GCS_{total}.

Methods

Study design and population

This study was conducted at the University of Massachusetts Medical School (UMASS), the only level-1 trauma center in central Massachusetts with a 65-mile catchment area.

All consecutive adult moderate to severe TBI patients (GCS ≤ 12) admitted between November 2009 and May 2015 were prospectively enrolled in the observational Outcome Prognostication in Traumatic Brain Injury (OPTIMISM) study.¹⁸ Data were recorded in the Research Electronic Data Capture (REDCap) platform at UMASS.¹⁹ The local Institutional Review Board (IRB) approved this study with written informed consent obtained from the patient or surrogate decision maker. For non-survivors, the IRB granted a waiver for documentation of written consent.

Of all 393 consecutive OPTIMISM patients enrolled during the study period, five patients were excluded due to “hanging” as their trauma mechanism, resulting in hypoxic ischemic brain injury, which is distinctly different than TBI. We excluded all non-intubated patients on admission ($n = 128$). We further excluded nine patients who had been enrolled in the early part of OPTIMISM prior to having IRB approval to consent and obtain post-discharge follow-up assessments. Our final cohort comprised 251 intubated moderate to severe TBI patients (Fig. 1).

Clinical management

The clinical management has previously been described in detail.¹⁸ Briefly, after initial resuscitation in the emergency department (ED) trauma bay, all TBI patients are admitted to a single, closed neurotrauma intensive care unit (NTICU) and managed in standardized fashion according to Brain Trauma Foundation guidelines²⁰ by the NTICU and trauma teams. All patients with a GCS ≤ 8 with evidence of brain swelling or high-risk lesions receive an intracranial pressure (ICP) monitor. Since 2012, additional brain tissue oxygen (PbtO₂) monitoring is performed (Licor® Brain Tissue Oxygen Monitoring System; Integra, Plainsboro, NJ). Both ICP and PbtO₂ are treated using an institutional protocol that mimics the BOOST II treatment protocol.²¹ Emergency neurosurgery is performed based on clinical indications and the discretion of the treating neurosurgeon. Intracranial hypertension is treated with repeated intravenous 20% mannitol or 23.5% hypertonic saline boluses and a stepwise sedation protocol. Coagulopathies are rapidly corrected by a trauma protocol using blood products, tranexamic acid, and activated factor VII (before 2015) or concentrated 4-factor prothrombin complex concentrate (starting 2015) for patients on warfarin.

Measurements

Baseline demographic variables, trauma mechanism, initial GCS score, pupillary reactivity, and vital signs including presence of hypoxia (oxygen saturation levels $\leq 89\%$) or hypotension (systolic blood pressure ≤ 89 mm Hg) were collected. For hypotension,

FIG. 1. Flow diagram of the final study cohort. We show the flow diagram of the final cohort of 251 intubated TBI patients from the OPTIMISM study. Of 393 consecutive OPTIMISM patients, 5 were excluded due to “hanging” as the trauma mechanism, 128 were excluded as they lacked intubation, and 9 were excluded as they were enrolled in the study early on before we had IRB approval to perform long-term follow-up. We had 199 patients with complete 3-month, and 185 with complete 12-month follow-up GOS available for the primary analysis. Multiple imputation methods were employed to impute the missing GOS for the sensitivity analysis. GOS, Glasgow Outcome Scale; IRB, Institutional Review Board; TBI, traumatic brain injury.

hypoxia, and pupillary reactivity, the worst findings either in the field, outside the hospital, or at UMASS ED were used for data analysis. Out-of-hospital and UMASS ED data were obtained from written ED reports. The trauma attending physician calculated the Injury Severity Score (ISS). The Marshall CT classification was assessed on the first available head computed tomography (CT) by weekly group adjudication between three attending neurointensivists (authors R.C., W.H., S.M.). Patients with non-evacuated mass lesions >25 cc were coded as such, even if they were subsequently surgically evacuated.

GCS variables

For this study, we utilized three different GCS variants: mGCS, GCS_{total}, and teGCS. Per OPTIMISM study protocol, GCS was recorded as the lowest post-resuscitation GCS in the first 24 h of hospital admission after sedation or intoxication subsided with all subscores recorded separately (eye, motor, and “T” for verbal in intubated patients). The enrollment mGCS was utilized in our current study. The GCS_{total} for intubated patients set the verbal component as “1.” Of all three Rutledge formulas developed,¹³ we chose the one with the highest C-statistic yet simplest formula to calculate an estimated verbal GCS subscore using the observed mGCS and eye GCS:

$$\begin{aligned} \text{estimated verbal GCS} = & (2.3976) + [\text{mGCS} \times (-0.9253)] \\ & + [\text{eyeGCS} \times (-0.9214)] + [(\text{mGCS})^2 \times (0.2208)] \\ & + [(\text{eyeGCS})^2 \times (0.2318)]. \end{aligned}$$

The teGCS was the sum of the calculated estimated verbal GCS subscore, and the observed motor and eye GCS subscores.

Outcome assessments

Functional outcomes using the Glasgow Outcome Scale (GOS) were prospectively assessed over the telephone by one of three trained members of the study team at 3 and 12 months after trauma. Interviewers underwent prior training and utilized a published interview guide for the GOS.²² The study principal investigator (PI) conducted data review on randomly selected patients and supervised phone interviews in person at least quarterly to ensure data quality.

Statistical analysis

Baseline characteristics were described by proportions, or medians (interquartile range [IQR]) for the non-normally distributed continuous variables, as appropriate. We employed the “Core+CT” IMPACT logistic regression model¹¹ utilizing the observed data from the OPTIMISM cohort and the GOS assessed at 3 and 12 months. Although the OPTIMISM study also assesses outcomes at the 6-month time-point, this was only added later in the study period, providing a smaller number of patients with outcome data available at this time-point. For the purpose of the current study, we felt that employing the IMPACT model for 3- and 12-month outcomes was adequate, while leveraging the power of the much larger cohort with outcome assessments available at these time-points.

In our primary analysis we performed a complete case analysis using the 3- and 12-month outcomes with mGCS in the logistic regression model (as done in the original IMPACT model). We measured model discrimination using the C-statistic (area under the receiver operating characteristic [ROC] curve) and model calibration using the Hosmer-Lemeshaw “goodness-of-fit” test.^{23–25} The C-statistic is routinely used to quantify the ability of a prediction model to accurately distinguish subjects who will develop a certain outcome from those who will not.²⁴ Values closer to 1 represent models with better discrimination. The Hosmer-Lemeshaw test evaluates whether predicted risk matches observed risk within a pre-specified number of subgroups,²⁴ and *p* values closer to 1 mean better model calibration. Next, we substituted mGCS with GCS_{total} and teGCS, comparing the resulting model discrimination and calibration for both outcome time-points. Using the ROC CONTRAST statement of the SAS command PROC LOGISTIC, we tested for statistically significant differences between the C-statistics, using *p* < 0.05 as the significance level. To determine the relative contribution of the different GCS variants to the outcome, we calculated the Nagelkerke *R*² for each model and its reduction after removal of the GCS variable (ΔR^2). Unlike the *R*² in linear regression where it represents the proportion of how well the model explains the variability of outcome, in logistic regression the Nagelkerke *R*² (“pseudo *R*²”) cannot be interpreted as easily and is thought to represent an approximation of *R*²²⁶. Our cohort had an 80% complete follow-up rate at 3 months and 74% at 12 months, including non-survivors. As a pre hoc determined sensitivity analysis, we re-analyzed the complete cohort including imputed outcomes for missing outcome data. We performed multiple imputations of five random data sets to obtain the missing 3- and 12-month GOS using the variables age, trauma cause, mGCS, Marshall CT-score, pupillary reactivity, hypotension and hypoxia in the field or ED, discharge destination, and discharge GOS.

All analyses were conducted in SAS 9.4 (SAS Institute Inc., Cary, NC).

TABLE 1. BASELINE CHARACTERISTICS

	All intubated patients N=251
<i>Variable (n (%) unless otherwise indicated)</i>	
Age, median (IQR)	51 (29; 67)
Male gender	188 (75)
Race/Ethnicity	
Caucasian	230 (92)
Asian	8 (3)
African American	5 (2)
Other	8 (3)
Latino	19 (8)
Trauma cause	
High-velocity motor vehicle accident	106 (42)
Fall	110 (43)
Assault	25 (10)
Gunshot wound	10 (4)
Hypotension in ED or field	33 (13)
Hypoxia in ED or field	22 (9)
Pupillary reactivity	
None	76 (30)
One	19 (8)
Both	156 (62)
Motor GCS, median (IQR)	4 (1;5)
1. No motor response	100 (40)
2. Extension	13 (5)
3. Flexion	5 (2)
4. Withdrawal	36 (14)
5. Localizing	76 (30)
6. Obeys commands	21 (8)
Eye GCS, median (IQR)	1 (1;1)
1. No eye opening	197 (78)
2. Eyes open to pain	14 (6)
3. Eyes open to verbal command	23 (9)
4. Eyes open spontaneously	17 (7)
Total GCS*, median (IQR)	6 (3;7)
Total estimated GCS, median (IQR)	7 (3;9)
ISS, median (IQR)	29 (25;38)
Marshall CT score	
I. No visible pathology	0
II. Cisterns intact	134 (53)
III. Cisterns compressed	41 (16)
IV. Midline shift >5 mm	16 (6%)
V. Surgically evacuated lesion	0
VI. Non-evacuated lesion >25 cm ³	60 (24)
Traumatic SAH present	199 (79)
Epidural hematoma present	9 (4)
Mortality at 3 months in complete f/u cohort	120 (60)
Unfavorable outcome (GOS 1–3)	159 (80)
at 3 months in complete f/u cohort	
Mortality at 12 months in complete f/u cohort	125 (68)
Unfavorable outcome (GOS 1–3)	138 (75)
at 12 months in complete f/u cohort	

Asterisk (*) indicates total GCS calculated using verbal GCS subscore = 1 for intubated patients.

CT, computed tomography; ED, emergency department; GOS, Glasgow Outcome Score; IQR, interquartile range; ISS, Injury Severity Score; SAH, subarachnoid hemorrhage.

Results

Baseline characteristics of the cohort are shown in Table 1. Among the 251 patients, the median age was 51 years (IQR 29;67), and 75% were men. The trauma causes were predominantly high-velocity motor vehicle accidents (42%) or falls (43%), with small proportions of assaults (10%) and gunshot wounds (4%). The median mGCS was 4 (IQR 1;5), median GCS_{total} was 5 (IQR 3;7), and median teGCS was 7 (IQR 3;9). After calculation of teGCS, 22 patients (8%) had a teGCS >12, and would have been classified as having “mild” TBI, but were included in the analysis for the purpose of our study. Compared with GCS_{total}, the teGCS increased by 1 point in 46 patients (18%), by 2 points in 67 (27%), by 3 points in 18 (7%), and by 4 points in 3 (1%), but remained unchanged in 117 (47%). The complete case analysis included 199 patients with complete outcome data at 3 months, and 185 patients at 12 months.

Model performances

The results for the model discrimination, calibration, pseudo R^2 , and ΔR^2 for the “Core+CT” IMPACT model at 3- and 12-month unfavorable outcomes (GOS 1–3) are shown in Table 2. The corresponding ROC curves are shown in Figure 2.

At the 3-month time-point, there were only very small, statistically non-significant differences in discrimination between mGCS versus teGCS, and mGCS versus GCS_{total}, with mGCS achieving the highest C-statistic. Calibration was excellent for all three variables. The pseudo R^2 and ΔR^2 were highest for mGCS, albeit with only small differences.

Similarly, at the 12-month time-point, results yielded excellent discrimination with no statistically or clinically significant differences in the C-statistics (Table 2, Fig. 2). There was adequate calibration using teGCS, but reduced calibration with GCS_{total} and mGCS. Similarly to the 3-month time-point, pseudo R^2 and ΔR^2 were highest for mGCS compared with the other GCS variants.

In our sensitivity analysis, we included imputed outcomes for 52 patients at the 3-month time-point, and 66 patients at the 12-month time-point. We found no substantive differences in the findings

from the primary analysis, except that at the 12-month time-point calibration was adequate across all different GCS variants (Supplementary Table 1 and Supplementary Fig. 1; see online supplementary material at <http://www.liebertpub.com>). Analogously to our primary analysis, there were no statistically or clinically significant differences in the models’ C-statistics between the three different GCS variants.

Additional calibration plots of probabilities of predicted versus observed outcome in each model in the primary and sensitivity analyses (Supplementary Figs. 2 and 3; see online supplementary material at <http://www.liebertpub.com>) graphically underline the extremely small differences of the IMPACT models with the different GCS variants.

Discussion

Using an intubated prospectively collected TBI cohort and the IMPACT model as an example, we demonstrated that there were no statistically or clinically significant improvements in outcome model discrimination when substituting mGCS with teGCS or GCS_{total}. Further, there were no clinically significant improvements in the pseudo R^2 , but a slightly higher contribution of mGCS to the variability of outcome at the 3- and 12-month time-points. This finding was consistent at both time-points, in both the primary and sensitivity analysis. Calibration was adequate for all models, except in the primary analysis at 12 months using mGCS; however, this is likely due to the known weaknesses of the Hosmer-Lemeshow “goodness-of-fit” test with decreasing power, as well as the fact that we cannot rule out potential interactions within variables in the 12-month model using mGCS, which we did not explore for the purpose of this study.^{23,27}

To our knowledge, this is the first study to apply the Rutledge formula to estimate the verbal GCS subscore in neurocritically ill patients. The original derivation study included non-intubated surgical ICU patients without any neurological injury.¹³ A single validation study was conducted in a cohort of non-intubated, general trauma patients from a state-wide registry with a high reported median GCS (13.6 ± 3.5), therefore not allowing the results to be

TABLE 2. IMPACT-MODEL DISCRIMINATION, CALIBRATION, AND ΔR^2 FOR THE DIFFERENT GCS VARIANTS

Model	3-Month unfavorable outcome (GOS 1–3)				12-Month unfavorable outcome (GOS 1–3)			
	N = 199 (complete case analysis)				N = 185 (complete case analysis)			
	Discrimination	Calibration	Explained variation by model	Explained variation by GCS	Discrimination	Calibration	Explained variation by model	Explained variation by GCS
	C-statistic	Hosmer-Lemeshow chi square (p value)	Pseudo R^2	ΔR^2 for GCS variable	C-statistic	Hosmer-Lemeshow chi square (p value)	Pseudo R^2	ΔR^2 for GCS variable
Original “Core+CT”-IMPACT model with motor GCS	0.893	0.9934	0.481	0.0578	0.926	0.0158	0.6254	0.0505
“Core+CT” IMPACT model with total GCS	0.869	0.8906	0.4238	0.0006	0.918	0.1291	0.5964	0.0215
“Core+CT” IMPACT model with total estimated GCS	0.871	0.9293	0.4276	0.0044	0.92	0.5893	0.6013	0.0264

Shown are measures of model performance using the three different GCS variants in the “Core+CT” IMPACT model using 3- and 12-month unfavorable outcomes (GOS 1–3). Discrimination is measured using C-statistics (higher values represent improved calibration), and calibration is assessed by the Hosmer-Lemeshow “goodness-of-fit” chi square p value (higher values represent improved discrimination). Also shown are the pseudo R^2 values (Nagelkerke R^2) and differences in the Nagelkerke R^2 (ΔR^2) to demonstrate the relative contribution of the different GCS variants to the variation in outcome (higher values represent higher relative contribution to the variation of outcome).

CT, computed tomography; GCS, Glasgow Coma Scale; GOS, Glasgow Outcome Scale.

FIG. 2. Receiver operating characteristic (ROC) curves. Shown are the ROC curves for the complete case analysis for the 3-month (top row, A–C) and 12-month outcomes (bottom row, D–F), and for the three different GCS variants (from left to right: mGCS, GCS_{total}, and teGCS). The corresponding C-statistic (area under the ROC curve) is shown under each graph. Notably, there is minimal or no difference in the ROC curves and the C-statistic between the GCS variants at each time-point. GCS, Glasgow Coma Scale; GCS_{total}, total GCS with the verbal subscore set as “1”; mGCS, motor GCS; teGCS, total estimated GCS.

generalized to intubated, neurocritically ill patients. Further, without stating any reasons, this study validated a simpler, lower-order Rutledge formula with a lower C-statistic than the formula we used here.²⁸

Despite the lack of validation and demonstration of the true advantage of the teGCS for neurological outcome prediction, the estimation of the verbal GCS subscore has been adopted into several large contemporary multi-center clinical trials in intra-cerebral hemorrhage and large ischemic stroke.^{14–17} The data presented in our current study statistically demonstrate no advantage of the teGCS in our cohort of intubated TBI patients. In fact, the ΔR^2 values demonstrate that at both time-points, mGCS contributes more to the model than the other GCS variants teGCS and GCS_{total}. The magnitude of the differences range between 5% and less than 1% between the different time-points and models. This seems small, but is consistent with reports from the original IMPACT cohort.^{26,29} Use of the teGCS is unlikely to translate to clinically meaningful improvements in the outcome prediction for intubated TBI patients, both in research and at the bedside.

One additional aspect to consider is practicality. The calculation of teGCS requires the reliable recording of the eye GCS subscore in addition to the mGCS, which can be limited by illicit drugs, sedatives, or insufficient time during wake-up trials for a proper neu-

rological exam. In the OPTIMISM study, significant attention is paid to the accurate recording of GCS subscores off sedatives, after achieving resuscitation, and after intoxication has worn off.¹⁸ In emergent situations pre-hospital or in the ED, it is likely that this clinical state has not been reached, or little attention is paid to the presence of sedatives during GCS assessment. Although the mGCS may also be impacted in more severe states, the eye GCS subscore seems more sensitive to under-resuscitation, intoxication, or even light sedation. Hence, in the absence of substantial gains in discrimination and calibration in the outcome prediction model by teGCS, using mGCS is more practical.

Two other studies compared mGCS with GCS_{total}, and included intubated patients, albeit not exclusively. When evaluating the utility of both GCS variants for pre-hospital triage in order to identify severe TBI patients requiring transfer to a level-1 trauma center, mGCS was found to be statistically equivalent to GCS_{total}.³⁰ The authors concluded, similarly to our study, that the simpler GCS variant of the two, mGCS, should be the preferred type in order to streamline pre-hospital trauma triage.³⁰ In this study, long-term outcomes were not examined.

A second study also focused on the pre-hospital emergency care of trauma patients, comparing mGCS with GCS_{total}.³¹ Outcomes examined included the need for intubation, survival to hospital

discharge, and neurosurgical interventions. Like in our study, minimal and clinically insignificant differences in the C-statistic were found between mGCS versus GCS_{total} for survival and intubation, whereas there was no difference in the C-statistic of both GCS variants for neurosurgical intervention. In this study, however, only 4% of patients were intubated, the median GCS_{total} was high at 15, and the hospital survival rate was 97%. No multi-variable adjustments were made. Therefore, the results from this study are also not generalizable to a lower GCS patient population with acute neurological injury. The authors concluded that mGCS was equivalent to GCS_{total} because the differences in the C-statistic were so minimal that they did not translate to a clinically meaningful difference in predicting intubation or survival.³¹

Our study has important limitations. Our results are only applicable to intubated moderate to severe TBI patients. In cohorts with mild TBI, the verbal and eye subscores likely considerably add prognostic value.⁹ Similar validation studies are needed in other diseases such as hemorrhagic or ischemic stroke before the findings can be generalized to these. Our patients were enrolled at a single center with little racial diversity. However, data collection is very rigorous, with data adjudication during weekly meetings between three board-certified neurointensivists. Due to the non-compliant nature of the trauma population, we were missing outcomes in a proportion of survivors. Because our primary analysis was a complete case analysis, this additionally explains the mortality rates of 60% and 68% at 3 and 12 months, respectively. Therefore, we may have skewed our findings toward a more compliant and therefore potentially different trauma population. We imputed missing outcomes and performed a pre hoc determined sensitivity analysis to mitigate this problem. Our findings were similar, albeit not exactly the same in the cohort with the imputed outcomes, but this may be explained by the expected inaccuracies associated with imputed outcomes. Finally, the IMPACT-model was developed and validated to predict outcome at 6 months post-trauma, but we applied it to predict outcome at 3 and 12 months post-trauma. Given that our objective was to compare the relative performance of the model with three different GCS variants, rather than actually predict patient outcomes at these time-points, outcomes assessed at 6 months post-trauma are unlikely to yield significantly different results.

While our findings await validation, we have shown in a cohort of intubated TBI patients that there are no statistically significant improvements in discrimination, and no clinically meaningful or practical improvements of the IMPACT model by using teGCS.

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Author Disclosure Statement

No competing financial interests exist.

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Address correspondence to:
 Susanne Muehlschlegel, MD
 University of Massachusetts Medical School
 55 Lake Avenue North, S-5
 Worcester, MA 01655

E-mail: Susanne.Muehlschlegel@umassmemorial.org