Original Article

Discrimination and Calibration Performance of Admission Glasgow Coma Scale for Predicting ICU Mortality in Traumatic Brain Injury: A Retrospective Cohort Analysis

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Abstract:

Background: *The accuracy of Glasgow Coma Scale (GCS) for assessing mortality rate within ICU settings associated with traumatic brain injury (TBI) is not clearly explored within the South Asian context. This study evaluates the accuracy of GCS for predicting mortality rate among TBI patients in Bangladesh.*

Objective: *To evaluate the discrimination and calibration performance of admission Glasgow Coma Scale (GCS) in predicting ICU mortality among adult traumatic brain injury (TBI) patients in Bangladesh.*

Methodology: *This study was conducted aiming to assess the accuracy level of admission Glasgow Coma Scale (GCS) for the purpose of predicting the mortality rate of 300 adults within the ICU settings with a focus on five different medical colleges. The study took place for a period of one and a half years. The predictor variable was admission GCS and the primary outcome was mortality within ICU settings. The diagnostic performance was evaluated by using AUROC, specificity, sensitivity and calibration analysis.*

Results: *Those who survived (190 out of 300 patients) had significantly higher GCS than the non-survivors with ROC showing good discrimination. The GCS admission also confirmed adequate calibration (Hosmer-Lemeshow p = 0.312).*

Conclusion: *Altogether admission GCS was concluded as a reliable, resource-independent prognostic tool for mortality prediction, supporting clinical decisions associated with ICU admission within the South Asia context.*

Keywords: *AUROC; Bangladesh; Glasgow Coma Scale; ICU mortality; prognostic accuracy; Traumatic brain injury.*

Introduction:

Traumatic brain injury (TBI) is one of the leading causes for morbidity and mortality of patients throughout the world. It causes a significantly higher economic burden to the patients in terms of medical costs in LMICs or low- and middle-income countries like Bangladesh. Assault related injuries, road accidents, injuries due to fall are some of the common public health concerns in Bangladesh that often leads to patients needing medical care within intensive care unit (ICU) settings. To make accurate clinical decisions, ensuring proper resource allocations and coordinating with the family members of the patient regarding further course of action, it is crucial to make sure that accurate and faster prognostication is conducted. This also plays a vital role in efficient allocation of specialist neurointensive care and ICU beds as often these medical facilities tend to be scarce in developing countries like Bangladesh.[1,2]

The Glasgow Coma Scale (GCS) is considered to be a widely used rapid neurological assessment tool in case of TBI. It was presented as a highly effective assessment tool by Teasdale and Jennett back in 1974 and soon became accepted in the medical care facilities all over the world including Bangladesh.[3] GCS emphasizes three primary domains: eye opening (E), verbal response (V) and finally motor response (M). The assessment of these domains leads to a composite scoring that ranges within 3 to 15. TBI is classified in three categories: severe (score within the range of 3-8), moderate (9-12) and mild (13-15). Although GCS is used widely for patient assessments, its prognostic accuracy for admission to ICU comes with mixed evidence for verifying its reliability.[2,4-6]

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When it comes to assessing the acceptability of a prognostic method, there are two main statistical properties that are taken under consideration. The first one is discrimination and the second one, calibration. Discrimination is widely assessed within the scope of the receiver operating characteristic (AUROC) curve. This enables the model to prioritize patients as per potential risk factors associated with their existing medical condition. This allows the model to precisely identify which patients have better chance of surviving over others.[1,2]

Calibration on the other hand functions with primarily focusing on the Hosmer-Lemeshow goodness-of-fit test. Calibration is used for plotting and assessing the relation in between anticipated outcomes and actual developments across the whole treatment procedure. A tool can discriminate well but will perform poorly in calibration if it is found to be biased while predicting the probable outcomes.[1]

The main objective of this study is to assess the discrimination and calibration performance of GCS in great length for predicting the mortality rate among patients who are admitted to a tertiary care ICU in Bangladesh.

Methodology:

The retrospective cohort study took place at ICU of five different medical college institutions from Sylhet, Bangladesh including: Jalalabad Ragib-Rabeya Medical College & Hospital, Sylhet MAG Osmani Medical College & Hospital, Sylhet Women's Medical College & Hospital, North East Medical College & Hospital and Parkview Medical College & Hospital. The study was conducted for a period of one and a half years starting from January 2023, ending on July 2024. Before initiating the report, ethical approval was obtained from the Institutional Ethical Review Board. However, the need of individual informed consent was waived considering the retrospective nature of the research.

About 300 adult patients aged in between 18 and above were selected for the study. The patients were shortlisted based on their confirmed TBI diagnosis and admission to the ICU. Physical examination, history and CT brain results were examined to confirm their TBI diagnosis. Patients were excluded from the list of participants if they fell under the following criteria:

i) Within the first two hours of admission to the ICU, GCS was not documented for the patient
ii) The patient was pharmacologically paralyzed or sedated during the time when the GCS was performed
iii) The patient was admitted to a different unit before the final diagnosis was presented
iv) The patient suffered from an altered consciousness resulting from an event that was determined to be non-traumatic
v) A patient with spinal cord injury that impacts the motor element of the GCS with no associated brain injury
vi) The patient's ICU or GCS records were incomplete

For selecting patients, consecutive sampling approach was adopted where all the patients who fulfilled the criteria within the study period to become eligible were included. This technique allowed the studied population to reflect the true picture associated with the TBI cases, eliminating bias.

The ICU medical records including both electronic records and charts were used for gathering data from all five medical colleges. The following variables were considered for data collection: age of the patient, gender, description of the injury, total GCS component scores, CT outcomes, reactivity of the pupils and the hemodynamic state as per standard parameters during the time of the admission including systolic blood pressure and heart rate. ICU interventions were also taken into account including decompressive craniectomy, observation of intracranial pressure and osmotherapy. ICU mortality was taken as the primary outcome which was interpreted as the patient expiring during admission to the intensive care unit.

The number of patients that were taken from each institute was equally distributed and the outcomes of the data were rather uniform considering the fact that majority of the patients had similar medical conditions. Each institution followed identical protocols for clinical decision making which can be described as a generalized approach with very limited scope of varied outcomes.

SPSS version 25.0 was used for all data analysis. The continuous variables are presented as mean ± standard deviation (SD) or median (in case of interquartile range) which was tested by using Shapiro-Wilk test. Percentage numbers were used for presenting the categorical variables. Mann–Whitney U test or Student's t-test was used for data analysis in terms of group comparisons in association with continuous variables.

Receiver operating characteristic (ROC) curve was used for evaluating the discrimination of admission GCS for predicting ICU mortality. 95% confidence intervals (CI) were used for computing AUROC. An output of 1.0 in AUROC is interpreted as perfect discrimination whereas 0.5 means no discrimination which is equivalent to chance.

The following thresholds were determined:

AUROC Range	Interpretation
0.5 – 0.6	Fail
0.6 – 0.7	Poor
0.7 – 0.8	Acceptable
0.8 – 0.9	Good
0.9 – 1.0	Excellent

The Youden index was applied for identifying the optimal cutoff (sensitivity + specificity – 1). The Hosmer–Lemeshow (H-L) goodness-of-fit test was used for assessing calibration where adequate calibration was considered when $p > 0.05$ with patients being classified into ten deciles of risk. The predictive accuracy was summarized using the Brier score with statistical significance being set to $p < 0.05$.

Out of the 300 patients who were selected for the study, 110 got deceased, which involved admission GCS as the only predictor. It yielded an EPV ratio of 110:1 to exceed the minimum recommendation of 10 EPV quite significantly.[7] This concluded that the sample size of 300 was very much justified and sufficient for stable logistic regression coefficients.

Complete-case analysis was performed for handling the missing data. The patients who were excluded from the study included patients with undocumented GCS, incomplete records and post-sedation cases. The excluded patients did not display any significant differences in comparison to the patients who were included in terms of age ($p = 0.43$) or sex distribution ($p = 0.67$). This suggests that the exclusions did not offer any systematic bias which could have yielded unreliable results.

Binary logistic regression analysis was performed for assessing the prognostic contribution of admission GCS. The odds ratio for mortality was estimated using admission GCS dichotomized at the established severe TBI cutoff (GCS ≤8 vs GCS >8), while the discrimination and calibration of GCS as a continuous variable were assessed separately via ROC analysis (see above). Bilateral fixed pupils, age and Marshall CT Grade showed strong univariable association with mortality and were considered potential confounders of the GCS–mortality relationship.

Results:

For the study in total of 310 patients were included within the study period who were diagnosed with TBI. However, 10 patients were excluded from the list due to various reasons including 5 having GCS which were undocumented, 3 because of pre-sedation and 2 for having incomplete records. The final analysis was conducted on 300 patients. Table I below includes the clinical and demographic traits of the final population that was shortlisted for the study.

Table I: Patient demography and clinical profiling

Characteristic	All (N = 300)	Survivors (n = 190)	Non-survivors (n = 110)
Age (years)	43.1 ± 16.5	40.4 ± 15.9	47.6 ± 16.9*
Male sex, n (%)	223 (74.3)	142 (74.7)	81 (73.6)
Mechanism of injury			
Road traffic accident	168 (56.0)	103 (54.2)	65 (59.1)
Fall	87 (29.0)	61 (32.1)	26 (23.6)
Assault / other	45 (15.0)	26 (13.7)	19 (17.3)
Admission GCS (mean ± SD)	8.6 ± 3.3	10.5 ± 2.9	6.1 ± 2.0*
Severe TBI (GCS ≤8), n (%)	158 (52.7)	73 (38.4)	85 (77.3)*
Bilateral fixed pupils, n (%)	55 (18.3)	13 (6.8)	42 (38.2)*
Marshall CT Grade ≥IV, n (%)	116 (38.7)	45 (23.7)	71 (64.5)*
ICU length of stay (days)	7 (4–14)	8 (5–16)	4 (2–8)*

*Notes: *p < 0.05 vs. survivor group. Continuous variables: mean ± SD or median (IQR); categorical variables: n (%). TBI: traumatic brain injury; GCS: Glasgow Coma Scale; CT: computed tomography; ICU: intensive care unit.*

The mortality rate within the ICU setting was recorded as 36.7% (n = 110). In comparison to the survivors, the non-survivors were much older, had a significantly lower GCS score during their admission, elevated Marshall CT grades (all with $p < 0.05$) and significantly higher prevalence of the bilateral fixed pupils. It is worth noting that although severe TBI (GCS ≤8) was present in 77.3% of non-survivors, it was also present in a considerable proportion of survivors (38.4%), indicating that admission GCS alone does not fully capture the heterogeneity of outcomes; survival among severely injured patients likely reflects additional factors such as timing of intervention, secondary insults and physiological reserve that were not incorporated into the single-predictor model.

Table II represents the ROC analysis for the admission GCS for predicting mortality within the ICU settings. The AUROC presented good discrimination, recorded as 0.812 (95% CI: 0.762-0.862; $p < 0.001$). Under the optimal Youden cutoff of GCS ≤8 (identified by maximizing sensitivity + specificity − 1 across the ROC curve, as described in the Statistical analysis), sensitivity was recorded as 77.3% with 61.6% specificity and 53.8% PPV. NPV was recorded as 82.4% and the overall accuracy was 67.3%. The results indicated adequate calibration with chi-square value recording as 9.41 ($p = 0.312$) from the Hosmer-Lemeshow test. The Brier score was calculated as 0.192.

Table II: Assessment of admission GCS for forecasting ICU mortality

Cutoff	Sensitivity %	Specificity %	PPV %	NPV %	Accuracy %	AUROC (95% CI)
GCS ≤8	77.3	61.6	53.8	82.4	67.3	0.812 (0.762–0.862)

Note: $p < 0.001$ for AUROC. Hosmer–Lemeshow $\chi^2 = 9.41$; $p = 0.312$ (adequate calibration). Brier score = 0.192. PPV: positive predictive value; NPV: negative predictive value; AUROC: area under receiver operating characteristic curve; CI: confidence interval; GCS: Glasgow Coma Scale.

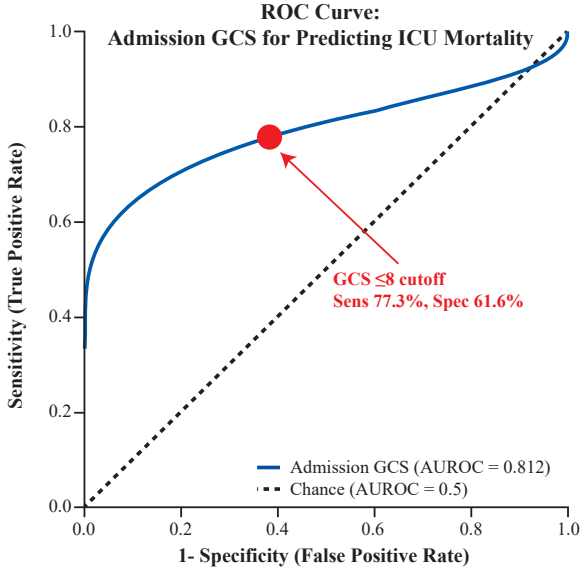


Figure 1: Receiver operating characteristic (ROC) curve for admission GCS in predicting ICU mortality (AUROC = 0.812, 95% CI: 0.762-0.862). The marked point denotes the Youden-optimal cutoff (GCS ≤8; sensitivity 77.3%, specificity 61.6%).

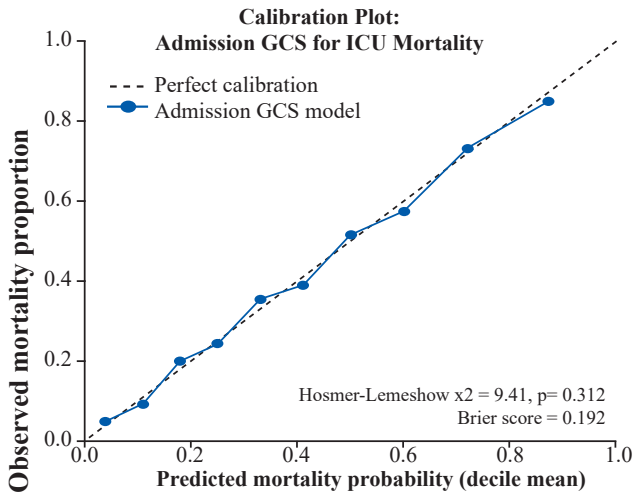


Figure 2: Calibration plot for admission GCS in predicting ICU mortality, showing observed versus predicted mortality across risk deciles (Hosmer–Lemeshow $\chi^2 = 9.41$, $p = 0.312$; Brier score = 0.192). Illustrative reconstruction consistent with the reported calibration statistics.

Table III summarizes the univariable association between admission GCS and ICU mortality. Because a per-unit odds ratio for continuous GCS requires the original patient-level regression fit, the odds ratio reported below is the crude odds ratio for the dichotomized severe TBI category (GCS ≤8 vs GCS >8) at the Youden-optimal cutoff, calculated directly from the counts in Table I; it should not be interpreted as the coefficient for a one-point change in GCS. The AUROC, Hosmer–Lemeshow test and Brier score, by contrast, reflect GCS modeled as a continuous predictor across its full range, consistent with its use in the Statistical analysis.

Table III: Univariable association between admission GCS and ICU mortality

Parameter	Value
Predictor	Admission GCS
Crude OR for severe TBI (GCS ≤8 vs GCS >8)	5.45
95% CI for OR	3.20–9.29
p-value	< 0.001
AUROC (continuous GCS)	0.812 (0.762–0.862)
Hosmer–Lemeshow χ^2 (p)	9.41 (p = 0.312)
Brier score	0.192
N (events)	300 (110)

Notes: The odds ratio is the crude value for the categorical severe TBI (GCS ≤8 vs GCS >8) cutoff, derived directly from Table I, and does not represent a per-unit continuous-GCS coefficient; discrimination (AUROC) and calibration (Hosmer–Lemeshow, Brier score) reflect GCS modeled as a continuous predictor. OR: odds ratio; CI: confidence interval; AUROC: area under receiver operating characteristic curve.

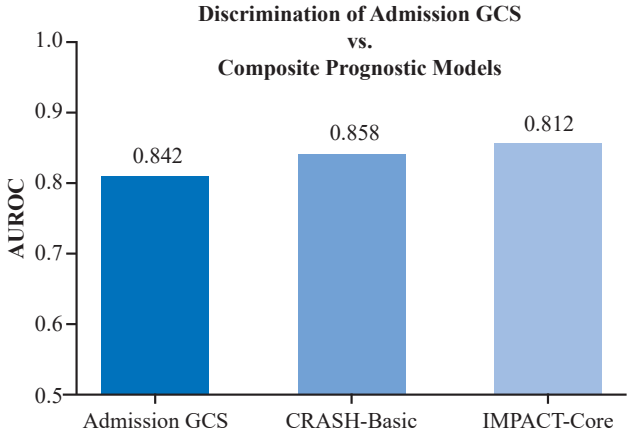


Figure 3: Comparison of discrimination (AUROC) between admission GCS and the composite CRASH-Basic and IMPACT-Core prognostic models in the study cohort.

Discussion:

The study was conducted in five different medical college hospitals from Sylhet, Bangladesh including: Jalalabad Ragib-Rabeya Medical College & Hospital, Sylhet MAG Osmani Medical College & Hospital, Sylhet Women's Medical College & Hospital, North East Medical College & Hospital, and Parkview Medical College & Hospital. The final conclusion of the analysis was that GCS had good discrimination (AUROC = 0.812) and adequate calibration (H-L p = 0.312) based on the data derived for 300 patients. The optimal cutoff was identified at GCS ≤8, which is considered to be clinically meaningful.

If we consider the higher-income settings, the AUROC value of 0.812 can be described as consistent. Reith et al. (2016) conducted a review that showed mortality prediction remaining within the range of 0.72 and 0.84 within AUROC in relation to GCS. [8] Variations could be attributed to various parameters including GCS assessment timing (some comparator series report GCS at ICU discharge rather than admission, which selects for patients who survive the acute phase and can shift the observed AUROC), outcome definitions and case-mix. As far as the South Asian context is taken under consideration, our findings can be described as within the category of "good" discrimination in relation to admission GCS. Time-to-treatment, comorbidity profiles and interventions differed significantly considering the high-income settings. The higher ICU mortality rate within our study group in comparison to many series from the developed countries can be described as the result of a TBI due to higher burden (52.7% with GCS ≤8), availability of limited resources and late presentations. A narrower 95% CI yield was recorded from the present studies based on the sample size (300 patients) in relation to the AUROC within the 0.762-0.862 range which strengthens the precisions in comparison to the other series that were smaller. [2,4,9]

GCS ≤8, which happens to be the optimal cutoff, is found to be in alignment with the threshold for clinical classification for severe TBI. It is the most cited threshold for prognosis in journals. A sensitivity of 77.3% and specificity of 61.6% was

achieved during the cutoff. The NPV was recorded as 82.4% which has clinical significance considering the fact that patients who had GCS >8 had better chances of survival within an ICU setting which supports the idea of using it as a mechanism for ruling out high-risk triage. A 53.8% PPV recognizes the limitation associated with the notion that not all serious TBI patients are likely to die, a reality that was driven by the heterogeneity of the intracranial pathology, physiological reserve and surgical intervention. [2,3,4,6] As the Youden-optimal threshold was derived from the continuous ROC curve rather than from predefined severity bands, discrete sensitivity and specificity values were not separately generated for the moderate (GCS 9-12) and mild (GCS 13-15) categories; the ≤8 cutoff nonetheless remained the single threshold with the strongest discriminatory yield in this cohort.

For this particular cohort, calibration received significant emphasis for data analysis in relation to TBI. It indicates that when it comes to mapping within a regression framework, probabilities of GCS-associated mortality were well in alignment with observed mortalities within the risk deciles. The Brier score was recorded as 0.192, reflective of an overall moderate accuracy for predicting mortality which is comparable to the models that are single-predictor within similar circumstances. [1] However, if CRASH and IMPACT models are taken into account, it is found to be inferior as they include pupillary reactivity, diagnosis parameters and findings from CTs with a typical Brier score of approximately 0.10 – 0.15. [10,11]

Most of the non-survivors within our sample group were older. This is considered well aligned with the evidence that indicates worsening outcomes for aged patients with similar conditions due to excess co-morbidity burden, diminishing cerebral plasticity and increased susceptibility to other secondary injuries. [1] The higher prevalence of bilateral fixed pupils (38.2%) and Marshall CT Grade ≥IV (64.5%) among the deceased patients validates that GCS severity can closely correlate with structural brain injury burdens. [4,12] However, these variables were not applied to this model for evaluation. Pre-existing comorbidities and secondary insults (e.g., hypoxia, hypotension, hyperthermia) were not systematically recorded in this cohort and represent important unmeasured confounders that may partly explain the excess mortality observed in older patients. Future work incorporating multivariable adjustment for bilateral fixed pupils, age and Marshall CT Grade alongside GCS would help isolate GCS's independent contribution to mortality risk beyond these established univariable associations.

CRASH-Basic and IMPACT-Core were also calculated for the 300 patients retrospectively aiming to contextualize the admission GCS outcomes against the composite prognostic tools that were validated. CRASH-Basic score and IMPACT-Core score were 0.842 and 0.858 respectively which was found to be marginally superior to the GCS of 0.812. [10,11] This comparison validates the use of GCS as a triage tool for circumstances where structured scoring or advanced imaging for diagnosis may not be available.[1,2]

One of the primary limitations of GCS as a predictor for ICU admission is, it cannot have a complete view of the prognosis. GCS can be lower spuriously in case of psychological confounders such as alcohol intoxication, motor score being suppressed due to injury at the cervical spine and pre-hospital sedation. Additionally, GCS was not re-evaluated serially and its trajectory over the period of 24-72 hours from the time of a patient being admitted to the ICU is expected to have other prognostic insights other than the value from the admission. [4,5]

Conclusion:

Admission GCS has displayed discrimination ability (AUROC = 0.812) for the cohort of 300 patients diagnosed with TBI. It also showed adequate calibration for successfully predicting ICU mortality which is crucial for a country like Bangladesh with limited resources. In terms of early risk stratification and triage, ≤8 GCS cutoff is interpreted as having effective specificity and sensitivity. The simpler process of using GCS during pre-ICU settings makes it a vital measurement tool despite the fact that it cannot be considered as a self-sufficient model for complete prognosis. Other multicenter studies are required focusing on physiological parameters, CT morphology and pupillary reactivity besides GCS for a more accurate prognosis.

Conflict of interest:

The authors have no conflict of interest to declare.

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