A practical method for dealing with missing Glasgow Coma Scale verbal component scores

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OBJECTIVE The Glasgow Coma Scale (GCS) is used for the assessment of impaired consciousness; however, it is not always possible to test each component, most commonly the verbal component. This affects the derivation of the GCS sum score, which has a role in systems for predicting patient outcome. Imputation of missing scores does not add extra information, but it does allow use of tools for predicting outcome that require complete data. The authors devised a simple and practical tool to employ when verbal component data are missing. They then assessed the tool's utility by application to the GCS-Pupils plus age plus CT findings (GCS-PA CT) prognostic model.

METHODS The authors inspected data from the International Mission for Prognosis and Analysis of Clinical Trials in Traumatic Brain Injury (IMPACT) cohort to characterize the frequency of missing verbal scores. The authors identified a single verbal score to impute for each eye and motor combined sum (EM) score from distributions of verbal scores in a published database of 54,069 patients. The effectiveness of the imputed verbal score was assessed using a dataset containing information from the IMPACT and Corticosteroid Randomisation After Significant Head Injury (CRASH) databases. The authors compared the performance of the prognostic model using actual verbal scores with the performance using imputed verbal scores and assessed the information yield using Nagelkerke's R^2 statistic.

RESULTS Verbal data were most commonly missing in patients with no eye opening and with a motor score of 4 or less. The "simple" imputation model that was developed performed as well as a more complex model involving distinct combinations of eye and motor scores. The imputation model consisted of the following: EM scores 2–6, add 1; EM score 7, add 2; EM score 8 or 9, add 4; and EM score 10, add 5 to provide the GCS sum score. Modeling without information about the verbal score reduced the R^2 from 32.1% to 31.4% and from 34.9% to 34.0% for predictions of death and favorable outcome at 6 months, respectively, compared with using full verbal score information.

CONCLUSIONS This strategy is particularly valuable for imputation in clinical practice, enabling clinicians to make a rapid and reliable determination of the GCS sum score when the verbal component is not testable. This will support clinical communication and decisions based on estimates of injury severity as well as enable estimation of prognosis. The authors suggest that external validation of their imputation strategy and the performance of the GCS-PA charts should be undertaken in other clinical populations.

<https://thejns.org/doi/abs/10.3171/2020.6.JNS20992>

KEYWORDS Glasgow Coma Scale; GCS; head injury; missing data; verbal score; traumatic brain injury

THE Glasgow Coma Scale (GCS) has been widely adopted for the assessment of impaired consciousness in patients with a head injury or other types of acute brain damage.¹ Its findings support clinical decision-making, communication, and assessment of severity of brain injury in the acute stage as well as likely outcome.^{2,3} However, for practical reasons, it is not always possible to

test each of the three components of the scale. None can be validly assessed in a pharmacologically sedated and paralyzed patient. Loss of a single component occurs most often with the verbal component,⁴ usually as a result of intubation. This can be documented in clinical practice as "not testable" and can be compensated for by using motor and eye findings to guide the care of the patient.⁵ However,

ABBREVIATIONS CRASH = Corticosteroid Randomisation After Significant Head Injury; EM = eye and motor combined sum; E1–4 = eye scores; GCS = Glasgow Coma Scale; GCS-P = GCS-Pupils; GCS-PA = GCS-Pupils plus age; GCS-PA CT = GCS-Pupils plus age plus CT findings; IMPACT = International Mission for Prognosis and Analysis of Clinical Trials in Traumatic Brain Injury; M1–6 = motor scores; TARN = Trauma Audit and Research Network; TBI = traumatic brain injury; VSTR = Victorian State Trauma Registry; V1–5 = verbal scores.

SUBMITTED March 29, 2020. **ACCEPTED** June 11, 2020.

INCLUDE WHEN CITING Published online September 8, 2020; DOI: 10.3171/2020.6.JNS20992.

an inability to test one of the components of the GCS affects the derivation of its sum score.

The GCS sum score is used clinically as a “shorthand” device to summarize and communicate a patient’s condition and to stratify or grade this condition as a guide to case management. It is also widely used as a component of systems to rate the severity of acute illnesses or injury, such as the Acute Physiology and Chronic Health Evaluation II (APACHE II),⁶ Revised Trauma Score,⁷ Trauma and Injury Severity Score (TRISS),⁸ Simplified Acute Physiology Score (SAPS),⁹ A Severity Characterization of Trauma (ASCOT),¹⁰ and World Federation of Neurosurgical Societies’ Subarachnoid Hemorrhage Scale.¹¹ The GCS sum score also has a key place in formal multivariate systems for predicting outcome. These range in complexity from the GCS-Pupils (GCS-P) score,³ a simple, quick arithmetic calculation, to more complex multivariate models, such as the International Mission for Prognosis and Analysis of Clinical Trials in Traumatic Brain Injury (IMPACT).¹²

A number of imputation methods for dealing with missing GCS data have been proposed, although alternative approaches to imputation can result in different predictions of mortality.^{13–16} These imputation strategies are principally used to support the analysis of trauma registry data, in which missing GCS observations can be as high as 20%¹³ and are most commonly associated with more severely injured patients.¹⁷ Imputation of missing scores does not add any extra information; it simply allows the use of tools that require the data to be complete.

The assignment of a score of 1 to untestable components does not provide a valid index of the patient’s condition and can misleadingly overestimate its severity.⁵ An abridged score based on measurements of only the testable features is similarly deficient. Proposed methods that use an association between findings in the eye, motor, and verbal components of the GCS to mathematically model the missing verbal component^{18–20} may have no advantage over other imputation strategies and are unlikely to improve outcome predication.^{19,21} In summary, the imputation methods described to date may have a role in research, but they are not practical to implement in the clinic.

The aims in this study were to investigate the frequency of the loss of verbal score in head injuries of different severities; establish the pattern of relationships between eye, motor, and verbal scores; and use the findings as a basis for devising a simple, practical, and reliable tool to employ when verbal component data are missing. Finally, the utility of this approach was assessed by application to the GCS-Pupils plus age plus CT findings (GCS-PA CT) prognostic model that we described recently.²² This model enables graphical display of probabilities of outcome in a simple, easy-to-use format that supports and promotes the incorporation of prognostic information in patient care.

Methods

“Missingness”: Frequency and Pattern

Investigations into the frequency and pattern of missing data were conducted using the IMPACT database.¹² The IMPACT core database contains data from 11,989

patients with traumatic brain injury (TBI) that were collected prospectively in 11 different studies including eight randomized controlled trials and three epidemiological studies. We inspected data from the IMPACT cohort to characterize the frequency of missing verbal scores. Using data from all 11,989 patients, all available baseline assessments of the GCS were taken by pooling prehospital, first-hospital, admission-to-study hospital, and post-resuscitation GCS scores.

The distribution of verbal scores for each eye and motor score combination was then determined on the basis of a publication that combined data from three different registries—Trauma Audit and Research Network (TARN), Victorian State Trauma Registry (VSTR), and Corticosteroid Randomisation After Significant Head Injury (CRASH) trial data—to create a larger database than IMPACT; this larger database included 54,069 patients.²³ From this we could identify an appropriate verbal score to impute for each eye and motor score combination.

Effect of Imputation on Information Content

To assess the effectiveness of the imputed verbal score value determined from the aforementioned analysis of 54,069 patients, we used a dataset containing pooled information from the IMPACT and CRASH²⁴ databases, which we previously described in the derivation of the GCS-P score and GCS-PA CT prognostic charts.^{3,22} Patients were identified for whom GCS, concurrent pupil reactivity, age, and CT imaging findings data were available. The proportions of patients who either were dead or had an unfavorable outcome at 6 months (vegetative state or severe disability) according to the Glasgow Outcome Scale were determined. We compared the performance of prognostic models when using actual verbal scores with the performance of models when using imputed verbal scores, according to our strategy described below, and assessed the information yield using Nagelkerke’s R^2 statistic.²⁵

Results

Frequency and Pattern of “Missingness”

From our analysis of the IMPACT data, there were 11,989 patients in which both motor and eye scores were available. We determined how often the GCS verbal score was missing for each combination of eye and motor score (Table 1). Verbal data were most commonly missing in patients with no eye opening (eye score 1 or E1 [73.6% of total patient assessments]) and in patients with a motor score of 4 or less (76.8% of the E1 cohort). The higher the eye and motor scores, the less likely it was that the verbal score would be missing; for example, in patients with a motor score of 6, only 2% of verbal data were missing. Overall, the verbal score was missing for 11% of the assessments.

We next examined the distribution of GCS verbal scores, according to combinations of eye and motor scores, in a published dataset that combined the TARN, VSTR, and CRASH databases. The specificity of a single verbal score for imputation for any given eye and motor score combination was greatest for low eye and motor scores (Table 2).

TABLE 1. Percentage of assessments with a missing GCS verbal score for each combination of GCS eye and motor scores

Motor Score	Eye Score				
	E1	E2	E3	E4	All
M1	18.6 (3421)	12.8 (39)	15.0 (20)	10.3 (29)	18.5 (3509)
M2	12.9 (2467)	12.2 (74)	25.0 (12)	5.0 (20)	12.9 (2573)
M3	12.5 (2563)	5.2 (192)	8.3 (48)	2.8 (36)	11.8 (2839)
M4	12.7 (4198)	5.3 (604)	6.6 (167)	6.4 (218)	11.4 (5187)
M5	10.4 (3713)	7.4 (1007)	4.9 (691)	6.1 (577)	8.8 (5988)
M6	3.7 (108)	6.5 (124)	1.9 (537)	1.2 (1502)	1.8 (2271)
All	13.4 (16,470)	6.8 (2040)	4.4 (1475)	3.0 (2382)	11.1 (22,367)

Assessments made in 11,989 patients were identified in the IMPACT database. Values are expressed as the percentage of the missing verbal scores for each combination of eye score and motor score (total number of assessments for that combination). Each individual patient could contribute up to four GCS assessments used in this analysis.

The summation of eye and motor scores into an EM score (eye and motor combined sum score) made the selection of what verbal score to impute clearer (Table 3). The specificity of the modal value for each EM combination is highest for EM score 2 (94.2%); this specificity decreases

as the EM score increases to 7 (EM scores and associated specificities: 3, 76.7%; 4, 68.3%; 5, 59.8%; 6, 44.5%; and 7, 33.2%, respectively) before increasing again (EM scores and associated specificities: 8, 42.9%; 9, 49.5%; and 10, 64.6%, respectively).

The mode verbal score is 1 for EM scores 2–6 (Tables 2 and 3), which corresponds to GCS sum scores 3–7, which are defined as severe brain injury. This includes the range of motor and eye scores for which verbal scores were most commonly missing (Table 1). The appropriate imputed (mode) verbal score value is less clear in the range of EM scores 7–9, although in this cohort, the average proportion of GCS assessments with a missing verbal score was only 5.1% (Table 1). For no EM score combination was the imputed verbal score 3.

TABLE 2. Distribution of verbal scores for given eye score and motor score combinations

Motor Score	Eye Score	Verbal Score				
		V1	V2	V3	V4	V5
M1	E1	6847	326	32	40	24
	E2	71	41			
	E3	73	15			
	E4	107	24			
M2	E1	1060	233	24	20	26
	E2	63	87			
	E3					25
	E4	28				
M3	E1	969	381	31		
	E2	110	134	62		
	E3	30	55	47	24	
	E4	44	30		29	
M4	E1	1042	517	51	32	
	E2	177	310	149	75	
	E3	79	125	130	117	33
	E4	90	126	70	138	72
M5	E1	1339	927	191	111	
	E2	377	683	501	325	
	E3	241	452	622	1250	175
	E4	335	417	424	990	342
M6	E1	68	77	32	69	36
	E2	31	56	76	164	55
	E3	144	217	385	3456	2265
	E4	223	211	505	6961	14,431

Based on data from the TARN, VSTR, and CRASH databases. The modal verbal score in each row is presented in boldface type.

Information Gained From Imputation

Using the imputed verbal scores, based on both eye and motor scores and also on the EM score, we assessed how the information provided about outcome from the GCS-PA CT prognostic charts was affected by the imputation (Table 4). We examined the effect of substituting the imputed verbal score for the actual verbal score in a model using

TABLE 3. Distribution of verbal scores for given EM scores

EM Score	Verbal Score					% Total of Mode Score
	V1	V2	V3	V4	V5	
2	6847	326	32	40	24	94.2
3	1131	274	24	20	26	76.7
4	1105	483	31			68.3
5	1259	675	113	32	25	59.8
6	1514	1292	387	210		44.5
7	568	915	663	540	69	33.2
8	362	634	768	1552	302	42.9
9	479	634	809	4446	2607	49.5
10	223	211	505	6961	14,431	64.6

Based on data obtained from the TARN, VSTR, and CRASH databases. Modal values for imputation are presented in boldface type.

TABLE 4. Assessment of R² values for models predicting death and favorable outcome based on the GCS score, pupil reactivity, patient age, and CT abnormality count, using actual and imputed verbal scores

	Predicting Death (%)	Predicting Favorable Outcome (%)
Actual verbal score	32.1	34.9
Simple imputation	31.4	34.0
Complex imputation	31.3	34.1

The simple model is based on the EM score, and the complex model uses distinct combinations of eye and motor scores.

the GCS, pupil reactivity, age, and CT abnormality count. This analysis relied on data from the pooled IMPACT and CRASH databases that were used for the original derivation of the GCS-PA CT prognostic charts.^{3,22}

The proportion of variability in outcome “explained” by this approach was assessed using Nagelkerke’s R² statistic. The “simple” imputation determined by selecting the verbal score according to the EM score performed as well as the more complex model using distinct combinations of eye and motor scores. Modeling without information about the verbal score reduced the R² from 32.1% to 31.4% and from 34.9% to 34.0% for predictions of death and favorable outcome at 6 months, respectively, compared with using full verbal score information (Table 4).

Aid to Imputation

Based on the imputed verbal score for each EM score, we have developed a simple visual aid to support imputation of a missing verbal score in the clinic in order to facilitate determination of the GCS-P score and predictions of outcomes using the GCS-PA prognostic charts (Fig. 1). In step 1, the eye and motor component scores are summed. In step 2, the verbal component score is identified and added to the EM score, giving an imputed GCS sum score in step 3.

Discussion

Our findings show that, based on the large IMPACT database, overall all three components of the GCS could be determined in almost 90% of prehospital, first-hospital, admission-to-study hospital, or post-resuscitation GCS assessments. Among assessments in which both eye and motor components were recorded, only 11% did not have

a verbal score. The verbal score was most often missing in patients with a severe head injury, characterized by no eye opening and not obeying commands (a combined EM score of 6 or less); these patients are usually intubated. The verbal score was rarely missing in the remaining assessments of patients with a mild or moderate head injury, who in practice make up the great majority of admitted head injuries.

Our analysis of associations among the three components of the scale demonstrates that if the verbal response cannot be assessed, a simple and accurate strategy for imputing missing GCS verbal score data is possible, based on a combination of eye and motor scores. The pattern of associations among the three GCS components showed that for any combined eye and motor (EM) score of 6 or below, the verbal score was most frequently 1. For EM scores 7 and 8, the most common verbal scores were 2 and 4, respectively, but these were seen in fewer than one-half of the patients. For EM scores 9 and 10, verbal scores of 4 and 5, respectively, were recorded for one-half and two-thirds of patients, respectively. These data support a simple pragmatic strategy for imputing a missing verbal score from the modal value for each combined EM score, as illustrated in Fig. 1.

The appropriate verbal score to impute is unambiguous in severely or mildly head-injured patients, but it is less distinct in moderately head-injured patients. Interestingly, a verbal score of 3 (or V3) was not imputed from any EM combination. This probably reflects our observation that the V3 verbal response was least often recorded in these data and may indicate uncertainty in how the V3 score (intelligible single words) is differentiated in clinical assessment from the V2 (only moans/groans) and V4 (not orientated but communicates coherently) scores.

A consequence of our verbal score imputation strategy is that several possible GCS sum (EVM) score combinations are absent in the visual aid to imputation. The lack of a sum score of 8 is of particular interest, because of its long-established role in defining a severe, as opposed to a moderate, injury. GCS score 8 is customarily equated with a combined score of E1 plus V2 plus M5 (motor score of 5). In the visual score imputation system that we have proposed, an EM score of 6 can be taken to define severe injury. Classification of a patient as having a moderate brain injury (GCS scores 9–12) rather than a mild brain injury (GCS scores 13–15), based on the imputed verbal score, will most likely result from an assessment of the eye score as E2 rather than E3. Treatment decisions should be made from the integration of all available clinical and prognos-

Step 1	E + M	2	3	4	5	6	7	8	9	10
Step 2	+ V	Add 1					2	4	5	
Step 3	EVM	3	4	5	6	7	9	12	13	15

FIG. 1. Visual aid to imputation of a verbal score based on the EM score. In step 1, the eye and motor component scores are summed. In step 2, the verbal component score is identified and added to the EM sum score, giving an imputed GCS sum (EVM) score in step 3. Figure is available in color online only.

tic data, and any change in this information over time, not on the basis of any single score or classification.

We assessed the merit of imputation of a verbal score by analyzing the extent of outcome information modeled using age, total GCS score, pupil reaction, and CT scan findings, as described previously.²² The information yielded by inputting missing verbal information using our simple imputation method is closely comparable to that obtained by estimating a score based on precise eye and motor findings and close to that obtained from full information about the three components of the total GCS score. Our simple imputation approach may obviate the need for more complex imputation approaches when a sum score is needed.^{13–16,18,20}

The purpose of our imputation strategy, to permit the sum score to be determined easily for an individual patient in clinical practice, contrasts with that of existing imputation strategies. Those models were developed to support data registries and calculation of prognostic tools, such as the Trauma Score or APACHE scoring systems.^{13,15,18,20} Their complexity is not suited to the clinic. Direct comparison of our imputation strategy with existing models is therefore not helpful. Further, those models were developed using linear regression approaches, limiting the possibility to directly compare performance to our model, which was built using logistic regression modeling.

A strength of this study is the large number of patient GCS observations that have been used, from several different, carefully collected, and well-characterized databases of head-injured patients. Nevertheless, although the merit of simple verbal imputation is clear in principle, calibration of the findings is very data intensive. Additional observations in other large, contemporary population-based registries of head-injured patients will be useful in fine-tuning the detail and precision of the proposed system for imputation.

We do not propose that imputed verbal scores should be included in clinical charts. The principle of using the GCS for assessment of coma and impaired consciousness is to record what is actually observed. The utility of serial assessment and recording of actual observations to assess for changes in level of consciousness is not necessarily precluded by missing data for one response. An imputed GCS sum score should not be used as a baseline from which to decide if a subsequent full assessment represents a change requiring action. The GCS score that is communicated should be actual and not imputed.

The use of imputed verbal scoring may be best reserved for providing a GCS sum score to enable the calculation of severity and prognostic scoring systems such as the GCS-P score and assessment of a patient's predicted outcome at 6 months using the GCS-PA prognostic charts, which we described recently.^{3,22} The GCS-P and GCS-PA charts are simple arithmetic scores that extend the information provided about patient outcome to an extent comparable to that obtained using more complex methods.^{3,22}

Imputation of missing scores does not add any extra information; it simply allows the use of tools that require the data to be complete. The GCS-PA charts provide a rapid assessment of a patient's predicted outcome at 6 months, which can support clinician decision-making and com-

munication between clinical teams. Although clinicians identify prognosis as a factor in their decision-making, the prognosis remains exposed to personal subjective opinions.^{26,27} Estimates of prognosis are best made using mathematical methods that combine information about multiple aspects of the patient's condition, but such multivariate models have not found widespread acceptance in clinical practice,²⁸ leading to errors in case management. The GCS-PA prognostic charts are presented in a user-friendly way so that they can easily be applied in the clinical scenario and be clinically useful.

Conclusions

Our imputation strategy is particularly valuable for imputation of missing verbal score data in clinical practice. Verbal score imputation will enable clinicians to make a rapid and reliable determination of the GCS sum score in cases in which the verbal component is not testable. This will support communication between clinicians and clinician decision-making based on estimates of severity of brain injury and will enable estimation of prognosis using GCS-P scores and GCS-PA prognostic charts. External evaluation of our imputation strategy and the performance of GCS-PA charts should be undertaken in other clinical populations.²⁹

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Disclosures

The authors report support from a Muriel Cooke bequest to the University of Glasgow for incidental costs.

Author Contributions

Conception and design: Brennan, Teasdale. Acquisition of data: all authors. Analysis and interpretation of data: all authors. Drafting the article: all authors. Critically revising the article: all authors. Reviewed submitted version of manuscript: all authors. Approved the final version of the manuscript on behalf of all authors: Brennan. Statistical analysis: Murray.

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