



BRIEF REPORT

Sensitivity and Specificity of the Coma Recovery Scale—Revised Total Score in Detection of Conscious Awareness

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Abstract

Objective: To describe the sensitivity and specificity of Coma Recovery Scale—Revised (CRS-R) total scores in detecting conscious awareness.

Design: Data were retrospectively extracted from the medical records of patients enrolled in a specialized disorders of consciousness (DOC) program. Sensitivity and specificity analyses were completed using CRS-R—derived diagnoses of minimally conscious state (MCS) or emerged from minimally conscious state (EMCS) as the reference standard for conscious awareness and the total CRS-R score as the test criterion. A receiver operating characteristic curve was constructed to demonstrate the optimal CRS-R total cutoff score for maximizing sensitivity and specificity.

Setting: Specialized DOC program.

Participants: Patients enrolled in the DOC program (N=252, 157 men; mean age, 49y; mean time from injury, 48d; traumatic etiology, n=127; nontraumatic etiology, n=125; diagnosis of coma or vegetative state, n=70; diagnosis of MCS or EMCS, n=182).

Interventions: Not applicable.

Main Outcome Measures: Sensitivity and specificity of CRS-R total scores in detecting conscious awareness.

Results: A CRS-R total score of 10 or higher yielded a sensitivity of .78 for correct identification of patients in MCS or EMCS, and a specificity of 1.00 for correct identification of patients who did not meet criteria for either of these diagnoses (ie, were diagnosed with vegetative state or coma). The area under the curve in the receiver operating characteristic curve analysis is .98.

Conclusions: A total CRS-R score of 10 or higher provides strong evidence of conscious awareness but resulted in a false-negative diagnostic error in 22% of patients who demonstrated conscious awareness based on CRS-R diagnostic criteria. A cutoff score of 8 provides the best balance between sensitivity and specificity, accurately classifying 93% of cases. The optimal total score cutoff will vary depending on the user's objective.

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Patients emerging from coma after severe brain injury often transition through states of altered consciousness, including the vegetative state (VS) and the minimally conscious state (MCS). In VS, there is recovery of eye opening but no behavioral evidence of

self or environmental awareness.¹ MCS is characterized by clearly discernible but inconsistent behavioral signs of conscious awareness.² Distinguishing MCS from VS during the early stages of recovery is critically important because there is strong evidence that functional outcome is significantly more favorable for patients in MCS relative to those in VS, particularly after traumatic brain injury.³ Prior research suggests that when the diagnosis is made based on clinical consensus of the medical team, approximately 40% of patients with diagnosed VS actually retain conscious awareness.⁴ These findings point to the need for more accurate diagnostic procedures.

The Coma Recovery Scale—Revised (CRS-R) is a standardized neurobehavioral assessment measure composed of 6 subscales designed to assess arousal level, audition, language comprehension,

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visuoperception, motor function, oromotor capacity, expressive speech, and yes-no communication in patients with disorders of consciousness (DOC).⁵ The current diagnostic criteria for coma, VS, and MCS are embedded in the CRS-R to provide clinicians with a reliable and valid means of establishing a differential diagnosis. Although the CRS-R total score (TS) has been used for prognostic purposes,⁶ its diagnostic utility has not been investigated. This represents an important evidentiary gap given that prior studies have relied on the CRS-R TS when tracking functional recovery,⁷ investigating the relationship between behavioral and physiological markers of consciousness,⁸ and determining the effectiveness of treatment interventions.⁹

The primary aim of this report is to investigate the sensitivity and specificity of the CRS-R TS in detecting conscious awareness. Results are expected to provide additional empirical support and interpretive guidance for use of the CRS-R TS in clinical practice and research.

Methods

After institutional review board approval to conduct a retrospective medical record review, the research team extracted data from the medical records of patients enrolled in a specialized DOC program. Eligible patients were admitted to either an inpatient rehabilitation facility or a long-term acute care hospital, both of which rely on a standardized assessment protocol. Between May 4, 2011, and September 29, 2014, CRS-R scores obtained at the time of admission into the program were collected for 252 patients (157 men; mean age \pm SD, 49 \pm 19.7y; mean time from injury \pm SD, 48 \pm 53d; traumatic etiology, n=127; mean CRS-R TS \pm SD, 11.27 \pm 5.83 [median TS, 11]; coma/VS, n=70 [mean CRS-R TS \pm SD, 4.64 \pm 2.07]); MCS, n=138 ([mean CRS-R TS \pm SD, 12.21 \pm 3.67]; emerged from minimally conscious state [EMCS], n=44 [mean CRS-R TS \pm SD, 18.89 \pm 3.41]). Nontraumatic etiologies included hypoxia/anoxia, aneurysm, tumors, and hemorrhage.

Sensitivity and specificity analyses were completed using CRS-R—derived diagnoses of MCS/EMCS (as denoted by an asterisk or cross, respectively, on the facesheet of the scale) as the reference standard for conscious awareness and the total CRS-R score as the test criterion. In this context, sensitivity (or true positive rate) represents the proportion of patients who retain conscious awareness (ie, have a diagnosis of MCS/EMCS) and are correctly identified by the CRS-R TS. Specificity (or true negative rate) is the proportion of patients who are unconscious (ie, do not have a diagnosis of MCS/EMCS) and are correctly identified as not in MCS/EMCS by the CRS-R TS (see [supplemental fig S1](#) for the method used to calculate sensitivity, specificity, and accuracy; available online only at <http://www.archives-pmr.org/>). A receiver operating characteristic curve was constructed to demonstrate the optimal CRS-R total cutoff score for maximizing sensitivity and specificity for detection of conscious awareness. All analyses were

conducted using the R statistical software package^a and SPSS version 20.0.^b

Results

A CRS-R TS of 10 or higher yielded a sensitivity of .78 for correct identification of patients in MCS/EMCS, and a specificity of 1.00 for correct identification of patients who did not meet criteria for either of these diagnoses (ie, were diagnosed with VS or coma). Thus, all patients who obtained a CRS-R TS of 10 or higher demonstrated conscious awareness (ie, met existing diagnostic guidelines for MCS/EMCS). A cut score of 10 or higher also misclassified as unconscious 22% of those who actually retained conscious awareness.

Table 1 indicates that the optimal combination of sensitivity and specificity is obtained with a CRS-R cutoff score of 8. A TS of 8 yields a true positive rate of 93%, a true negative rate of 96%, and a diagnostic accuracy rate of 93%.

As shown in [figure 1](#), the area under the curve in the receiver operating characteristic curve analysis is .98. Areas under the curve of 0.9 to 1.0 are considered to have excellent diagnostic accuracy, based on standard classification guidelines. This finding suggests that CRS-R TSs provide excellent accuracy in differentiating individuals who meet diagnostic criteria for conscious awareness from those who do not.

Discussion

Our findings indicate that a total CRS-R score of 10 or higher provides strong evidence of conscious awareness as defined by existing diagnostic criteria.⁵ All patients who received a CRS-R TS in this range were in MCS or had emerged from MCS. On the other hand, a cutoff score of 10 resulted in a false-negative diagnostic error (ie, unconscious state) in 22% of cases who actually retained conscious awareness. Thus, approximately 1 in 5 patients who demonstrate conscious awareness score below 10. A cutoff score of 8 provides the best balance between sensitivity and specificity (or true-positive and true-negative rates, respectively), accurately classifying 93% of cases. The optimal TS cutoff will vary depending on the user's objective. For example, an investigator wishing to conduct a treatment study focusing exclusively on patients who retain conscious awareness would be advised to adopt a cutoff score of 10, since this will guarantee ascertainment of a homogeneous sample of participants in MCS/EMCS. On the other hand, a clinician involved in differential diagnostic assessment might adopt a cutoff score of 8, which offers the best odds of concurrently avoiding false-positive and false-negative errors. Clinicians should rely on the full subscale profile when available to ensure

List of abbreviations:

CRS-R	Coma Recovery Scale—Revised
DOC	disorders of consciousness
EMCS	emerged from minimally conscious state
MCS	minimally conscious state
TS	total score
VS	vegetative state

Table 1 Sensitivity, specificity, and accuracy rates for detection of conscious awareness at CRS-R TS cutoffs between 7 and 11

Parameter	CRS-R TS Cutoff				
	7	8	9	10	11
Sensitivity	.97	.93	.88	0.78	0.73
Specificity	.80	.963	.97	1	1
Accuracy	.921	.937	.905	0.841	0.802

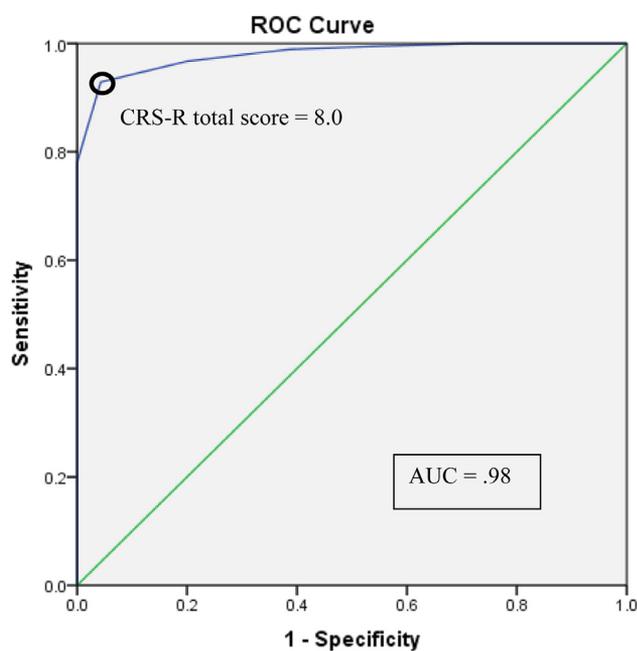


Fig 1 ROC curve indicating sensitivity and specificity of CRS-R TSs highlighting the optimal cutoff score of 8. This score yields a sensitivity of 93% and specificity of 96%. The AUC is .98, indicating that the CRS-R TS accurately differentiates patients who meet diagnostic criteria for conscious awareness from those who do not. Abbreviations: AUC, area under the curve; ROC, receiver operating characteristic.

the most accurate diagnosis. When relying on TS only, clinicians should be aware that the further the TS falls below 10, the lower the likelihood that the patient retains conscious awareness.

Study limitations

The findings from this study should be viewed in the context of the limitation that the results may not be generalizable to all patients with DOC. Our sample was composed of inpatients undergoing rehabilitation during the postacute phase of recovery, most of whom were in MCS or had emerged from MCS. This may not reflect the larger pool of patients with DOC who are more acutely injured and are receiving care in the intensive care setting. Future studies will need to replicate these results in a larger sample of patients with more variable lengths of time since injury who are receiving treatment across a variety of health care settings.

Conclusions

Accurate detection of conscious awareness using the CRS-R is best achieved through analysis of the full CRS-R performance profile, which includes all 6 subscale scores. In the absence of a full CRS-R profile, the total CRS-R score can be interpreted as a

marker of conscious awareness with confidence when the score is 10 or higher. CRS-R users should be aware of the advantages and limitations of selecting different TS cutoffs. This report provides data that may help guide decision-making for both clinicians and researchers who wish to use the CRS-R for diagnostic purposes.

Suppliers

- R statistical software package; R Foundation for Statistical Computing, Vienna, Austria. Available at: <http://www.R-project.org>.
- SPSS version 20; IBM Corp.

Keywords

Brain injuries; Consciousness disorders; Rehabilitation; Sensitivity and specificity

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Supplemental Fig S1

$$\text{Sensitivity} = \frac{TP}{TP+FN} = \frac{\text{MCS/EMCS* cases correctly identified based on TS}}{\text{MCS/EMCS cases correctly identified based on TS} + \text{MCS/EMCS cases identified as non-MCS/EMCS based on TS}}$$

$$\text{Specificity} = \frac{TN}{TN+FP} = \frac{\text{non-MCS/EMCS* cases correctly identified based on TS}}{\text{non-MCS/EMCS cases correctly identified based on TS} + \text{non-MCS/EMCS cases identified as MCS/EMCS based on TS}}$$

$$\text{Accuracy} = \frac{TP+TN}{TP+FP+TN+FN} = \frac{\text{MCS/EMCS* cases correctly identified based on TS} + \text{non-MCS/EMCS* cases correctly identified based on TS}}{\text{sum of all cases}}$$

Supplemental Fig S1 Method used to calculate the sensitivity, specificity, and accuracy of the CRS-R total score in detecting conscious awareness. *Clinical diagnosis established based on standardized criteria. Abbreviations: FN, false negative (CRS-R total score incorrectly identifies cases diagnosed with MCS and EMCS as not MCS or EMCS); FP, false positive (CRS-R total score incorrectly identifies cases not diagnosed with MCS or EMCS as MCS or EMCS); TN, true negative (cases not diagnosed with MCS or EMCS correctly identified by CRS-R total score); TP, true positive (cases diagnosed with MCS or EMCS correctly identified by CRS-R total score); TS, total score.