The Role of Magnetic Resonance Imaging in the Prediction of Minimally Conscious State After Traumatic Brain Injury

Weiwei Xu[1], Harpreet Kaur[2], Xiangyu Wang[1], Hengguo Li[1]

■ OBJECTIVE: **To establish a simple and feasible model of magnetic resonance imaging (MRI) for prediction of minimally conscious state in unconscious patients (≥2 weeks) after severe traumatic brain injury (TBI).**

■ METHODS: **MRI examinations were performed in 73 patients 4.5 weeks ± 1.6 (range, 2–8 weeks) after TBI. Brain lesions on MRI, age, sex, cause of injury, Glasgow Coma Scale (GCS) score, and decompressive craniectomy were retrospectively analyzed. Outcome was assessed at 12 months from the onset of TBI.**

■ RESULTS: **Of 73 patients, 39 were minimally conscious and 34 were unconscious at the endpoint. Binary logistic regression demonstrated that cause of injury ($P = 0.036$), GCS score ($P = 0.011$), and lesions of the thalamus ($P = 0.002$) and brainstem ($P = 0.012$) shown on MRI were closely associated with the outcome of minimally conscious state. The overall correct prediction of the logistic model was 90.4%.**

■ CONCLUSIONS: **The combination of MRI findings and other clinical data offers neurosurgeons substantial information about primary and secondary injuries of the patients with TBI, which allows a more accurate prediction of prognosis than a single GCS score or MRI findings alone. The regression model established in this study is simple and effective in predicting long-term unconscious state and minimally conscious state in patients after severe TBI.**

INTRODUCTION

Progress in critical care medicine has resulted in a higher incidence of survival in patients with severe traumatic brain injury (TBI). However, the possibility of recovery from an unconscious state after TBI is still a concern for neurosurgeons because it is critical to decisions regarding the management of medical resource and end-of-life issues. Most patients can regain consciousness within the first month after TBI. However, if patients do not show any signs of awareness after 1 month, they gradually enter into a vegetative state (VS). The chances of recovery are considered close to zero if patients have remained unconscious for >1 year, and these patients are generally considered to be in a permanent vegetative state (PVS).[1] Patients who recover from VS typically progress through different stages, including minimally conscious state (MCS), before completely regaining consciousness.[2] A study of 51 brain-damaged patients suggested that patients in MCS have a significantly better prognosis than patients in VS.[3] However, the misdiagnosis of patients in MCS is >40%.[4] Previously, the assessment of consciousness depended mainly on clinical scales and experience.[5] More recently, the functional neuroanatomy underlying MCS has been investigated with research tools such as quantitative neurophysiologic tools

Key words
- Minimally conscious state
- Outcome
- Prediction
- Traumatic brain injury

Abbreviations and Acronyms
ARAS: Ascending reticular activating system
CI: Confidence interval
DC: Decompressive craniectomy
GCS: Glasgow Coma Scale
MCS: Minimally conscious state
MRI: Magnetic resonance imaging
PVS: Permanent vegetative state
ROC: Receiver operator characteristic curve
TBI: Traumatic brain injury
VS: Vegetative state

[1]Department of Neurosurgery, The First Affiliated Hospital of Jinan University, Guangzhou, Guangdong, China; and [2]Baba Farid University of Health Sciences, Faridkot, Punjab, India

To whom correspondence should be addressed: Xiangyu Wang, M.D., Ph.D. [E-mail: xiangyuwang123@yahoo.com]

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and functional magnetic resonance imaging (MRI).[6-9] Although many of these sophisticated techniques continue to enhance our comprehension of recovery from unconsciousness, prognostication is restricted by the accessibility to sophisticated imaging studies and clinical examinations. Thus, the development of regular tools that reliably predict long-term neurologic outcomes is of crucial importance. MRI has some advantages in the assessment of brain lesions that are invisible on computed tomography, including ischemic stroke, diffuse axonal injury, and cortical laminar necrosis.[10] MRI has become an important optional examination in the study of TBI that possesses a great potential to improve the accuracy of long-term neurologic diagnosis.[11] In the present study, we focus on the prognostic value of MRI in patients with TBI and combine MRI with other clinical data to establish a simple and effective model for the prediction of MCS.

MATERIALS AND METHODS

All patient studies were approved by the Jinan University committee, and all patient representatives gave informed consent before inclusion in this study. Retrospective evaluation was performed of 73 patients with TBI (Glasgow Coma Scale [GCS] score ≤8, 56 males and 17 females) with a mean (±SD) age of 32.7 years ± 12.7 (range, 17–66 years) admitted to our neurosurgical intensive care unit from March 2012 to May 2015 without clinical signs of consciousness >14 days after TBI. Other clinical data, including age, sex, cause of injury, and decompressive craniectomy (DC), were also included in this study.

The criteria for diagnosis of MCS and PVS were based on international standards[12,13] for statistical purposes. Comparison of coma, VS, and MCS from the Consciousness Consortium held in Houston, Texas in 2007 is presented in Table 1.[14] Outcomes were divided into unconscious state (including dead and PVS) and MCS and assessed at 12 months from the onset of TBI. The conscious state after MCS was not discussed in this study.

MRI was performed at 1.5 T 4.5 weeks ± 1.6 (range, 2–8 weeks) after TBI with 10-mm slices acquired in sagittal, coronal, and axial planes (GE Signa; GE Healthcare, Wauwatosa, Wisconsin, USA). T1-weighted spin echo (repetition time 2000 ms, echo time 20 ms) and T2-weighted spin echo (repetition time 3000 ms, echo time 80 ms) images were evaluated by a neuroradiologist (H.L.). Lesions in bilateral frontal lobe, temporal lobe, occipital lobe, parietal lobe, corpus callosum, thalamus, basal ganglia, corona radiata, and brainstem were precisely recorded.

Table 1. Comparison of Coma, Vegetative State, and Minimally Conscious State

	Coma	Vegetative State	Minimally Conscious State
Eye opening	No	Yes	Yes
Sleep/wake cycles	No	Yes	Yes
Visual tracking	No	No	Often
Object recognition	No	No	Inconsistent
Command following	No	No	Inconsistent
Communication	No	No	Inconsistent
Contingent Emotion	No	No	Inconsistent

From Sherer M, Vaccaro M, Whyte J, Giacino JT, and the Consciousness Consortium. *Facts About the Vegetative and Minimally Conscious States After Severe Brain Injury.* 2007. Houston: The Consciousness Consortium.[14]

Statistical Analysis

We used χ^2 test for analysis of the lesions distributed in the dichotomized groups and Student t test for the comparison of GCS score in the 2 groups. Binary logistic regression analysis was performed to screen lesions shown on MRI and other prognostic factors, including age, sex, cause of injury, DC, and initial GCS score. Sensitivity and specificity were calculated according to the receiver operator characteristic (ROC) curve. For external validation, another group of 58 unconscious patients after TBI (GCS score ≤8, 43 males and 15 females) with mean age of 34.3 years ± 14.6 were consecutively collected from September 2012 to February 2015 in another institute (Zhujiang Hospital, Southern Medical University) to verify the established regression model. All statistical analysis was 2-sided and performed using statistical software SPSS for Windows version 13.0 (SPSS, Inc., Chicago, Illinois). A P value <0.05 was considered statistically significant.

RESULTS

Most of the patients with TBI were young men. Motor vehicle accidents are the leading cause of TBI in China (Table 2). Of 73 patients with TBI, 39 entered MCS (4 of 39 patients remained in

Table 2. Clinical Characteristics of 73 Patients with Traumatic Brain Injury

Characteristic	Unconscious	MCS
Age		
≤45 years	29 (39.72%)	32 (43.84%)
>45 years	6 (8.22%)	6 (8.22%)
Sex		
Male	28 (38.36%)	30 (41.10%)
Female	10 (13.70%)	5 (6.85%)
Cause of injury		
Vehicle accident	21 (28.77%)	33 (45.21%)
Fall	5 (6.85%)	2 (2.74%)
Assault	1 (1.37%)	2 (2.74%)
Industrial accident	4 (5.48%)	1 (1.37%)
Unknown	2 (2.74%)	2 (2.74%)
DC		
Yes	26 (35.62%)	26 (35.62%)
No	8 (10.96%)	13 (17.81%)

Values are presented as number of patients (%).
MCS, minimally conscious state; DC, decompressive craniectomy.