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ORIGINAL RESEARCH

Paroxysmal Sympathetic Hyperactivity, Volume Status, and Neurological Prognosis in Acute Brain Injury: A Prospective Cohort Analysis

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Objective: In this study, we enrolled patients with acute brain injury (ABI) to examine the relationship between paroxysmal sympathetic hyperactivity (PSH) and volume status, right heart function, and pulmonary edema, and their impact on prognosis.

Methods: Thirty patients with ABI were prospectively enrolled. A correlation analysis between Paroxysmal Sympathetic Hyperactivity Assessment Measure (PSH-AM) score and clinical indicators was performed using Pearson's or Spearman correlation coefficient. Receiver operating characteristic (ROC) curves were used to assess the prediction of 6-month Glasgow Outcome Scale Extended (GOSE) score. Inferior vena cava (IVC) diameter was evaluated as a marker of intravascular volume status, and its correlation with 6-month GOSE score in ABI patients was analyzed.

Results: There was no statistically significant difference in PSH-AM over time in patients with ABI ($P = 0.791$). The PSH-AM scores on Days 3 ($R = 0.474$, $P = 0.08$) and 5 ($R = 0.460$, $P = 0.011$) were positively correlated with pulmonary edema score. Early diastolic velocity (EDV) on Days 3 ($R = -0.429$, $P = 0.018$) and 5 ($R = -0.452$, $P = 0.012$) was negatively correlated with pulmonary edema score. Ejection time (ET) on Day 5 was positively correlated with inferior vena cava (IVC) ($R = -0.381$, $P = 0.038$). The ability to assess the 6-month GOSE score and the ROC curve (AUC) was observed for IVC on Day 1 (AUC = 0.785± 0.120, 95% confidence interval 0.550–1.000, $P = 0.012$).

Conclusion: IVC diameter assessed on day 1 is a useful indicator of neurological prognosis in patients with ABI. There was no statistically significant difference in PSH over time in patients with ABI. Regarding the study's sample size and potential operator bias in IVC diameter measurement, the findings require validation in larger, multicenter studies with standardized measurement protocols.

Keywords: acute brain injury, paroxysmal sympathetic hyperactivity, volume status, right heart function, right cardiogenic pulmonary edema, Glasgow outcome scale extended

Introduction

Neurocritical care is provided for life-threatening neurological and neurosurgical diseases. Such diseases are catastrophic, with a mortality rate as high as 27.97% and a high and prolonged incidence of adverse outcomes. Chronic diseases contribute to 80% of deaths in the Chinese population. Of these, cerebrovascular accidents account for approximately one-third.[1–3] Common diseases encountered in neurocritical care in China include cerebral infarction, cerebral hemorrhage, intracranial infection, and neuromuscular diseases, amongst others.

Acute brain injury (ABI) encompasses a series of injury-induced diseases of the central nervous system. ABI is an important condition that affects human health in modern society. It is a worldwide problem that requires urgent attention. Traumatic brain injury (TBI) is one type of ABI, and it is a major global medical and socioeconomic challenge.[4] A previous systematic review showed that patients with craniocerebral injuries have high rates of mortality and

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disability.[5] TBI is the leading cause of mortality among veterans and the elderly.[6,7] Data from 4509 patients in 18 countries showed that 47% of TBI admissions to the intensive care unit (ICU) were for mild TBI with a Glasgow Outcome Scale (GOS) score ranging from 13 to 15 in 36% of patients, while 84% of patients admitted to the ICU with TBI did not fully recover. Among the patients with moderate-to-severe TBI who were admitted to the ICU, 55% had a poor prognosis with a GOS Extended (GOSE) score of <5 at 6 months.[8] A cohort study recruited trauma patients from 18 Level 1 trauma centers in the United States between 2014 and 2018 and followed them for 5 years after injury. The study found that functional recovery remained low at 1–5 years after mild TBI, and it was even lower in patients with moderate-to-severe TBI, with similar improvements in quality of life in both groups.[9] Therefore, for patients with ABI, it is necessary to minimize complications and improve prognosis with treatment.

Studies have been conducted to examine the prognosis and complications of patients with TBI. For patients with TBI, simple prognostic models based on age and GOS have shown reasonably good value in predicting 6-month mortality in ICU-treated patients with TBI. However, more complex scoring systems, such as the Acute Physiology and Chronic Health Evaluation II (APACHE II) and the Sequential Organ Failure Assessment (SOFA), have demonstrated little prognostic performance.[10] Age, admission GOS score, heart rate, tracheotomy, and platelet count are considered as independent predictors of clinical prognosis in patients with severe TBI combined with extracranial trauma.[11] A prospective observational study conducted in China showed that age, GOS score, injury severity score, pupillary light reflex, computed tomography findings (basilar pterygoid sinus compression with midline shift ≥5 mm), hypoxia, systemic hypotension, altitude >500 m, and gross domestic product per capita were significantly correlated with survival in patients with TBI.[12] In another study, patients with a high score on the TBI Frailty Index had a significantly increased risk of developing a poor prognosis.[13] Among patients with moderate-to-severe brain injury, certain variables, such as motor score on admission, hypotension, pupil reaction to light, age, blood creatinine concentration, and limb movement (mild hemiparesis), were the most predictive prognostic factors for mortality and functional outcomes.[14] However, there is still a long way to go to identify simple and appropriate indicators to assess the prognosis of patients with TBI.

Sympathetic nervous system hyperactivity, collectively known as paroxysmal sympathetic hyperactivity (PSH), can occur after severe acquired brain injury, 80% of cases of which occur after TBI and is associated with poor outcomes.[15] In the neurological ICU, PSH episodes are seen in one-third of patients with TBI. They are more common in younger patients and are associated with a prolonged duration of fever.[16] Seminal work on hyperadrenergic states associated with non-traumatic intracranial hemorrhage was published by Neil-Dwyer et al and has been validated in patients with severe TBI.[17–21] Severe excessive autonomic hyperactivity occurs in a subgroup of acquired brain injury survivors, most of whom exhibit bursts of sensorineural and motor hyperactivity. Another study showed that delayed recognition of PSH after brain injury may increase morbidity and long-term disability.[22] Perkes et al identified two distinct groups of PSH in a large number of young patients with ABI. One was characterized by relatively pure sympathetic overactivity and the other with mixed parasympathetic/sympathetic feature disease. TBI is the main etiology of PSH, followed by hypoxia and stroke.[15] Regardless of the underlying diagnosis, the prevalence of PSH in patients with other brain injuries varies from 8% to 33% and may change over time during the acute or chronic disease phases. Therefore, assessment and intervention for PSH are essential in patients with ABI. In 2014, the Paroxysmal Sympathetic Hyperactivity Assessment Measure (PSH-AM) was developed, which consists of two components: the Clinical Feature Scale (CFS), which assesses the degree of clinical symptoms of PSH, and the Diagnosis Likelihood Tool (DLT), which confirms the likelihood that the observed symptoms are caused by PSH.[23] Many studies have examined the occurrence of PSH after ABI, but its incidence and pathogenicity are still extremely high, and early detection and control of PSH are imperative to improve the prognosis of ABI.

Previous studies have shown that the TBI-associated hyperadrenergic state with elevated plasma catecholamine concentrations is proportional to the degree of intracranial injury and appears to be most pronounced in the first week after TBI.[21,24,25] Another study showed that significant norepinephrine elevation predicts outcomes in patients with TBI.[26] Moreover, stress-induced hyperglycemia is associated with higher mortality in patients with severe TBI.[27] It follows that early administration of propranolol in patients with TBI is associated with reduced mortality,[28,29] and a meta-analysis showed a significant mortality advantage with β-blockers in adult patients with acute TBI.[30] Other studies have shown that the treatment with β-blockers slows the cascade of sympathetic activation after TBI.[31,32] However, another retrospective study showed that the use of

sympathetic agents to reduce cardiovascular stress did not improve survival in patients with isolated severe TBI.[33] Nevertheless, it appears that sympathetic arousal after TBI can be limited by propranolol administration.[34]

It has been shown that acute stress predisposes to adverse cardiac events.[35] Emotional and somatic stress can induce stress cardiomyopathy,[36] with catecholamines being involved in stress cardiomyopathy development.[37] Catecholamine surge induces changes in cardiomyocyte contractility through the β-adrenergic pathway,[38] and atrial fibrillation is observed in patients with stress cardiomyopathy.[39] Therefore, the effects of stress on right heart function need to be investigated.

Right heart function can be assessed according to systolic, diastolic, and global function.[40] Ueti et al found that the amplitude and velocity of tricuspid annular motion can be used to evaluate overall right ventricular (RV) systolic function, and the tissue Doppler index (TDI), peak systolic velocity (SM), systolic time–velocity integral (TVI), and tricuspid annular plane systolic excursion (TAPSE) of tricuspid annular motion correlate with RV ejection fraction (EF).[41] TAPSE is simple to measure, and it is routinely used to assess RV function, with a TAPSE of <16 mm being considered as the lower limit of impaired RV function.[42] The RV myocardial performance index (MPI; also known as the Tei index) is another index used to assess the overall RV function. A pulsed Doppler MPI of >0.4 or a tissue Doppler MPI of >0.55 is suggestive of RV insufficiency.[43–45] Moreover, SM is a simple, reproducible measurement that can be used to assess the function of the basal segment of the RV free wall and RV function. If SM is <10 cm/s, abnormal RV function is suspected, especially in younger adult patients.[46] Several comparative studies have shown that TAPSE and tricuspid SM had good linear relationship with RVEF measured by magnetic resonance imaging.[47] Tricuspid tissue Doppler velocity, EM, and peak atrial systolic velocity (AM) are also used to assess RV diastolic function.[48] In critically ill patients with TBI, aggressive fluid balance is associated with poor outcomes.[49] IVC diameter serves as an indicator of volume status and was also associated with cardiac function.[50]

The incidence of PSH is high in patients with craniocerebral injury, and we believe that the degree of PSH in patients with ABI may reflect the degree of change in right heart function. In this study, we enrolled patients with ABI to examine the relationship between PSH and volume status, right heart function, and pulmonary edema, and their impact on prognosis.

Methods

Study Design

This prospective observational clinical study was conducted at the ICU of our hospital from January 2021 to January 2022. The study was approved by the institutional review board of Tibet Autonomous Region People's Hospital (approval number: ME-TBHP-21-014). All procedures were performed in accordance with the ethical standards of the local ethics committee on human experimentation and with the Helsinki Declaration of 1975. We obtained informed consent from all enrolled patients through the next of kin of each patient. We screened and categorized 30 patients within 24 hours after their admission to the ICU based on strict inclusion and exclusion criteria. Patients who met the criteria for enrolment were required to have ultrasound data at three time points: Day 1, Day 3, and Day 5.

Inclusion and Exclusion Criteria

Only adult patients (>18 years of age) were included. The other inclusion criteria were 1) definite cerebrovascular accident or craniocerebral injury (a clear change in consciousness or suggestive imaging); 2) the ability to undergo ultrasound to obtain information on volume status and cardiac and pulmonary monitoring.

The exclusion criteria were 1) presence of severe valvular disease or an EF of <30%; 2) pregnancy or breastfeeding; 3) history of β-blocker use; 4) death or discharge from hospital within 5 days of hospitalization.

Assessment of Stress Levels

The PSH-AM score is the sum of the CFS and DLT scores, and assesses the likelihood of a diagnosis of PSH. A score of <8 means that PSH is unlikely, 8–16 suggests that PSH is likely, and ≥17 suggests that PSH is highly likely.

Ultrasound Data Acquisition

Ultrasound Evaluation of Volume Status

The cardiac ultrasound probe was placed under the xiphoid process, and the probe was moved from the upper abdominal position to the standard four-chamber view of the heart under the xiphoid process, where the right ventricle is first seen. The probe was rotated downward and toward the spine, with the directional marker pointing toward the patient's head, showing the inferior vena cava (IVC) entering the right atrium and the hepatic vein converging into the IVC. The IVC diameter was measured 2 cm from the entrance of the right atrium, and the ultrasound images were frozen at the end of expiration and at the end of inspiration to measure the maximum IVC diameter. Simultaneous measurement of central venous pressure (CVP) was obtained.

Ultrasound Evaluation of Right Heart Function

In the apical four-chamber view, a TDI sample volume was placed on the RV free wall at 1 cm from the tricuspid annulus. The following measurements were calculated from the TDI: SM, early diastolic velocity (EM), and AM; isovolumic contraction time (ICT) and Isovolumic relaxation time (IRT); ejection time (ET); and MPI. The MPI was determined according to Equation (1).[51]

$$MPI = \frac{ICT + IRT}{ET} \tag{1}$$

For TAPSE measurement, in M-mode, the sampling line was adjusted to pass through the root of the tricuspid annulus at the apex and lateral wall of the right ventricle, and the longitudinal peak displacement of the tricuspid annulus was measured from end-diastole to end-systole. For ultrasound assessment of pulmonary edema, the six-zone method was used. The healthy hemithorax was divided into the anterior, middle, and posterior zones by the anterior axillary line and posterior axillary line, and six zones were divided by the third rib. The B lines of each zone were recorded, and semiquantitative rating was made by reference to the latest International Lung Ultrasound Scoring Scale.

Clinical Data Collection

Patients' admission information (age, primary disease, history, length of hospital stay, length of ICU stay), basic vital signs (blood pressure, heart rate, respiratory rate, body temperature), biochemical examination (white blood cells, hemoglobin, procalcitonin), SOFA score, APACHE II score, ventilator parameters, vasoactive drugs, Lactate, central venous-to-arterial carbon dioxide difference, and central venous oxygen saturation were collected.

Statistical Analysis

The statistical analyses were performed using SPSS software, version 26.0 (IBM Corp., Armonk, NY, US) and R software 4.2.2 (R Foundation, Vienna, Austria). The Shapiro–Wilk test was used to examine whether the data were normally distributed. Normally distributed data are expressed as mean ± standard deviation and were compared by a one-way analysis of variance or the *t*-test. Non-normally distributed data are expressed as median (P25, P75) and were compared using the Kruskal–Wallis test or the Mann–Whitney *U*-test. A variance homogeneity test was also performed, and non-parametric tests were used when the variances were uneven. Count data are expressed as number (percentage) and were compared between the groups using the χ^2 test. Pearson's correlation analysis was used for normally distributed data, and Spearman's rank correlation analysis was for non-normally distributed data. Receiver operating characteristic (ROC) curves were used to analyze the diagnostic efficacy of various indicators. $P < 0.05$ was considered statistically significant.

Results

Thirty patients were included in the analysis. Twenty-six of the patients had acute cerebral hemorrhage, three had acute cerebral infarction, and one had plateau cerebral edema. The characteristics of the patients are shown in Table 1.

Table 1 Patients' Characteristics

	n (30)
Age (y)	53.30±13.64
Sex (male, %)	17(48.6%)
Past medical history (n, %)	
Hypertension	13(37.1%)
Cardiovascular disease	1(2%)
T (°C)	36.60±0.36
HR (bpm)	80.66±20.18
SBP (mmHg)	158.07±38.25
DBP (mmHg)	96.21±19.77
MAP (mmHg)	89.30±21.05
SOFA	5.72±2.99
APACHE II	13.93±6.16
NE (ug/kg/min)	0.10±0.17
Pituitary retroleptin (IU/h)	0.23±0.81
Fentanyl (ug/h)	55.24±17.78
Morphine (mg/h)	0.24±1.09
Isopropylphenol (mg/h)	116.19±44.77
Midazolam (mg/h)	1.95±3.01
P*(V-A)* CO_2 (mmHg)	4.17±2.32
$ScvO_2$ (%)	80.14±6.94
Lactate (mmol/L)	1.81±0.88
BIS	52.50±16.03
Length of ICU stay (days)	14.43±7.519
Length of hospital stay (days)	48.4±49.924
28-day mortality rate (n, %)	8(26.7%)

Notes: Values are expressed as the mean ± standard deviation or number (percentage).

Abbreviations: T, temperature; HR, heart rate; SBP, systolic blood pressure; DBP, diastolic blood pressure; MAP, mean arterial pressure; APACHE II, Acute Physiology and Chronic Health Evaluation II; SOFA, Sequential Organ Failure Assessment; NE, norepinephrine; P*(v-a)* CO_2, central venous-to-arterial carbon dioxide difference; $ScvO_2$, central venous oxygen saturation; PI, pulsatility index; BIS, bispectral index.

PSH and Clinical Indicators Dynamics in Patients with ABI

The characteristics of relevant indices in patients with ABI over time are shown in Table 2. CVP ($F = 3.864$, $P = 0.025$), ICT ($F = 4.221$, $P = 0.018$), IRT ($F = 4.327$, $P = 0.016$), and total fluid balance ($F = 13.533$, $P = 0.000$) showed a significant decreasing trend over time. Although the pulmonary edema score showed a decreasing trend over time ($F = 1.795$, $P = 0.172$), the difference was not statistically significant. The differences in PSH-AM, IVC diameter, TAPSE, SM, AM, EM, ET, and MPI over time were not statistically significant.

Correlation Between PSH and Clinical Indicators in Patients with ABI

In patients with ABI, the PSH-AM scores on Days 3 ($R = 0.47$, $P = 0.008$; Figure 1(a)) and 5 ($R = 0.46$, $P = 0.011$; Figure 1(b)) were positively correlated with the pulmonary edema score, whereas there was no significant correlation between the two on Day 1. EM on Days 3 ($R = -0.43$, $P = 0.018$; Figure 1(a)) and 5 ($R = -0.45$, $P = 0.012$; Figure 1(b)) was negatively correlated with the pulmonary edema score, while there was no significant correlation on Day 1. ET was positively correlated with IVC diameter on Day 5 ($R = -0.38$, $P = 0.038$; Figure 1(c)), whereas no significant correlation was observed on Days 1 and 3.

Table 2 Comparison of Volume Status, Right Heart Function, and Pulmonary Edema Parameters at Different Time Points in Patients with ABI

	D1	D3	D5	*F, P*
PSH-AM	2.47±1.22	2.80±2.63	2.67±1.54	0.235, 0.791
CVP (mmHg)*	7.03±2.58	6.55±1.78	5.57±1.53	3.864, 0.025
IVC (cm)	1.75±0.42	1.79±0.35	1.71±0.31	0.345, 0.709
TAPSE (cm)	2.24±0.50	2.39±0.56	2.16±0.37	1.788, 0.173
SM (cm/s)	15.74±8.64	17.32±11.86	16.03±3.41	0.281, 0.755
AM (cm/s)	18.17±16.17	20.51±16.89	16.92±5.17	0.523, 0.595
EM (cm/s)	13.49±13.09	15.47±16.54	11.93±4.40	0.612, 0.545
ICT (s)*	0.07±0.02	0.06±0.02	0.06±0.01	4.221, 0.018
IRT (s)*	0.07±0.02	0.06±0.01	0.07±0.01	4.327, 0.016
ET (s)	0.27±0.05	0.25±0.04	0.24±0.08	1.654, 0.197
MPI (%)	54.77±11.91	50.45±8.88	54.05±9.90	1.518, 0.225
Pulmonary oedema score	6.16±1.64	5.53±1.38	5.63±1.09	1.795, 0.172
Volume balance (mL)*	−620.56	−1906.77	−2524.40	13.533, 0.00

Notes: Values are expressed as the mean ± standard deviation or number (percentage). * indicates statistical significance ($P < 0.05$).

Abbreviations: PSH-AM, Paroxysmal Sympathetic Hyperactivity Assessment Measure; CVP, central venous pressure; IVC, inferior vena cava; TAPSE, tricuspid annular plane systolic excursion; SM, peak systolic flow rate of the myocardium; AM, late diastolic velocity; EM, early diastolic velocity; ICT, isovolumic contraction time; IRT, isovolumic relaxation time; ET, ejection time; MPI, myocardial performance index.

Prognostic Assessment of Clinical Parameters in Patients with ABI

The ability to assess PSH-AM with related metrics for 6-month GOSE assessment of prognosis is shown in Figure 2 and Table 3. The patients were divided into favorable and unfavorable outcome groups based on whether the GOSE score was >3 (cut-off value for a favorable prognosis). Logistic regression analysis of the relevant parameters in Table 2 revealed that IVC and pulmonary oedema score were independent risk factors for GOSE, so an analysis of the value of both in assessing the prognosis of GOSE was performed. The area under the ROC curve (AUC) was greatest for IVC diameter on Day 1 (AUC = 0.785, 95% confidence interval [CI] 0.550–1.000; $P = 0.012$). Based on the cut-off value of 1.665 cm, the sensitivity and specificity of IVC diameter were 85.7% and 100%, respectively. The AUC for the pulmonary edema score on Day 1 also had significant (AUC = 0.143 ± 0.126, 95% CI 0.000–0.389; $P = 0.042$).

Discussion

In critically ill patients with TBI, aggressive fluid balance is associated with poor outcomes.[49] IVC diameter serves as an indicator of volume status.[50] However, the relationship between IVC and neurological functional prognosis in patients with ABI remains unclear at present. In a previous study, among patients with moderate-to-severe TBI in the ICU, 55%

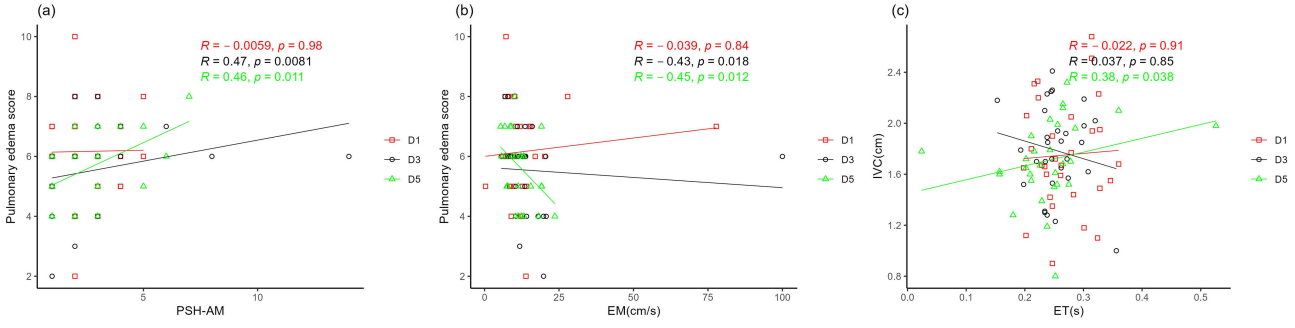

Figure 1 Correlations between Paroxysmal Sympathetic Hyperactivity Assessment Measure (PSH-AM) and clinical indicators in patients with ABI. (**a**) Correlation between PSH-AM and pulmonary edema score. (**b**) Correlation between early diastolic velocity (EM) and pulmonary edema score. (**c**) Correlation between ejection time (ET) and inferior vena cava (IVC) diameter. $P < 0.05$ was considered statistically significant.

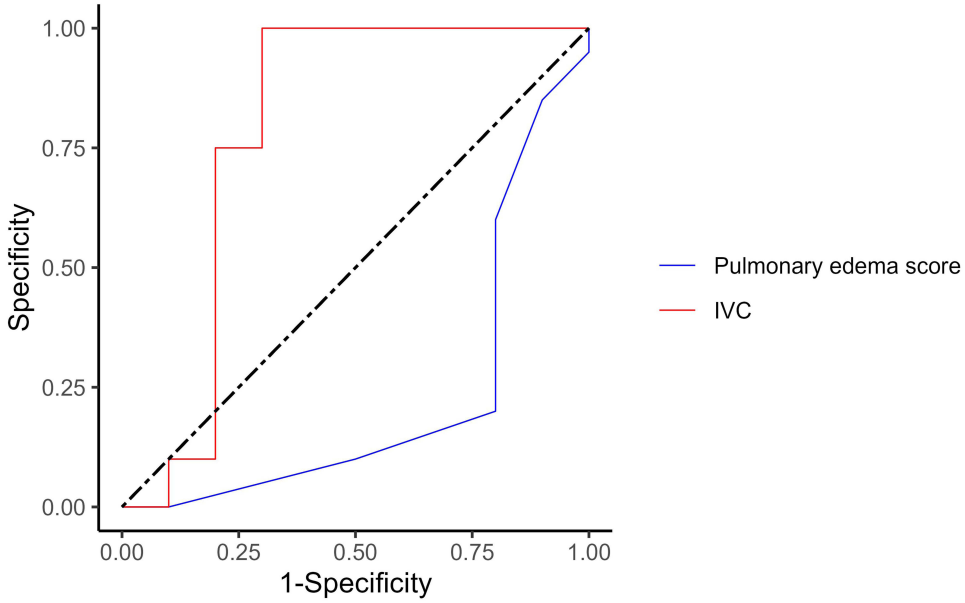

Figure 2 Prediction of the GOSE score using receiver operating characteristic curves.

had a poor prognosis (GOSE < 5) at 6 months.[8] In addition, a cohort study found that functional recovery remained low at 1–5 years after mild TBI and was even lower in patients with moderate-to-severe TBI, with similar improvements in quality of life between the groups.[9] For patients with ABI, it is extremely important to assess the prognosis of neurological function. GOSE, as a commonly used prognostic assessment index for craniocerebral injury, is divided into favorable and unfavorable divisions, with cut-off points ranging from 3 to 7 points worldwide. There is no obvious basis for how to divide them.[52,53] In this paper, we used a 6-month GOSE of ≤3 to indicate an unfavorable outcome and >3 to indicate a favorable outcome. We found that IVC diameter assessed by Doppler ultrasound on Day 1 had very high predictive value for assessing prognosis based on the GOSE score, with an IVC diameter cut-off value of 1.665 cm. This study identified the importance of monitoring the Day 1 IVC diameter in patients with ABI to assess the prognosis of neurological function in patients with ABI.

In this study, we investigated the level of stress in patients with ABI and examined its relationship with volume status, right heart function, and pulmonary edema. There was no statistically significant difference in PSH-AM over time in patients with ABI. However, CVP, an indicator of volume status, showed a decreasing trend over time, suggesting negative fluid balance. The differences over time in the right heart function indices of ICT and IRT were also statistically significant; however, the overall indices representing right heart systolic and diastolic function did not change significantly over time. The possible explanation for these findings is that the population included patients with ABI who were transferred to the ICU after surgical treatment. The baseline characteristic at admission to the ICU was an overall state of relatively deep sedation. On Days 3 and 5 after ICU admission, patients mostly remained in a state of sedation, which meant that these patients demonstrated no significant changes in PSH or right cardiac function. Most of the patients

Table 3 Area Under the Receiver Operating Characteristic Curve for Various Indicators

	AUC±SE	*P*-value	95% CI
IVC	0.785±0.120	0.012*	0. 550–1.000
Pulmonary oedema score	0.143±0.126	0.042*	0.000–0.389

Notes: Values are expressed as the mean ± standard deviation or number (percentage). * indicates statistical significance ($P < 0.05$).
Abbreviation: IVC, inferior vena cava.

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admitted to the ICU had cerebral edema. As such, they were hydrated to achieve negative fluid balance to reduce cerebral edema on a daily basis. CVP and IVC diameter are commonly used in the ICU to assess volume status, and the CVP results showed a decreasing trend, presumably due to negative fluid balance.

We found that the PSH-AM scores of patients with ABI on Days 3 and 5 were positively correlated with the pulmonary edema scores, suggesting that patients with ABI who were in a state of stress were prone to pulmonary edema. Right heart function, represented by the early diastolic function index of EM, was negatively correlated with the pulmonary edema score. This finding suggests that right heart diastolic insufficiency is associated with the occurrence of pulmonary edema. The right heart function index of ET was positively correlated with IVC diameter. Specifically, the shorter the ET, the wider the IVC diameter. Based on these results, the present study could not conclude the effect of PSH on right heart function. Previous studies have observed the effect of stress on left heart function.[36,37] However, due to the small sample size of this study and the low PSH levels of the included patients, no conclusion could be drawn as to whether PSH has an effect on right heart function. Therefore, this needs to be explored in future large-sample studies.

This study found that monitoring the IVC diameter on the first day was associated with the 6-month GOSE score in patients with ABI, suggesting that IVC can serve as an effective indicator for evaluating neurological functional prognosis in ABI patients. Early assessment of IVC diameter in patients with ABI can evaluate their prognosis based on the GOSE score and guide clinical treatment.

This study has some limitations that should be considered. First, this was a small-sample single-center prospective study. Second, Doppler ultrasound was performed by physicians who were aware of the patients' clinical information. Third, the study population included postoperative patients without typical PSH. Therefore, further large-sample studies are needed to elucidate the changes observed in these variables and their relationships with each other.

Conclusion

Day 1 Doppler ultrasound assessment of IVC diameter has very high predictive value for assessing prognosis based on the GOSE score, and early assessment of volume status in patients with ABI is important to determine patient prognosis and to guide clinical treatment. There was no statistically significant difference in PSH over time in patients with ABI. Regarding the study's sample size and potential operator bias in IVC diameter measurement, the findings require validation in larger, multicenter studies with standardized measurement protocols.

Data Sharing Statement

No additional data available.

Author Contributions

All authors made a significant contribution to the work reported, whether that is in the conception, study design, execution, acquisition of data, analysis and interpretation, or in all these areas; took part in drafting, revising or critically reviewing the article; gave final approval of the version to be published; have agreed on the journal to which the article has been submitted; and agree to be accountable for all aspects of the work.

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Disclosure

The authors report no conflicts of interest in this work.

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