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Article

Prognostic Value of NT-proBNP in Extracorporeal Membrane Oxygenation-Assisted Cardiogenic Shock Patients: A 5-Year Single-Center Retrospective Analysis

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Abstract

Background: This study aimed to evaluate the predictive value of N-terminal pro-brain natriuretic peptide (NT-proBNP) for venoarterial extracorporeal membrane oxygenation (VA-ECMO)-assisted clinical outcomes in adult patients with cardiogenic shock (CS). **Methods**: Our study included the demographic information and clinical data of 77 CS patients who underwent VA-ECMO-assisted therapy in our center between January 2016 and January 2021. The prognostic value of NT-proBNP in these patients was assessed. **Results**: Statistical analyses were performed using the chi-square or Fisher's exact tests. Among the study participants, the highest NT-proBNP values after VA-ECMO assistance were observed in CS patients who had died versus those undergoing rehabilitation (21,439.62 vs. 13,568.26 pg/mL). Mean NT-proBNP values at the time of ECMO weaning (18,170.95 vs. 8472.8 pg/mL) and before discharge (22,183.35 vs. 5646.197 pg/mL) were higher in the death group. Age, sepsis-related organ failure assessment (SOFA) scores, creatinine, platelet, urea nitrogen, total bilirubin, and lactic acid levels; mean arterial pressure; creatinine level at the point of ECMO weaning, NT-proBNP value before discharge, percentage of left ventricular ejection fraction were reliable predictors of mortality. The area under the receiver operating characteristic curve (AUC–ROC) was >0.70 ($p < 0.05$). The AUC–ROC of the pre-discharge NT-proBNP was 0.873; these NT-proBNP values had the best predictive ability regarding patient death. **Conclusion**: Among CS patients who received VA-ECMO assistance, NT-proBNP values at each assistance point had important patient-related diagnostic and predictive values. Pre-discharge NT-proBNP values were the best predictors of patient prognosis.

Keywords

NT-proBNP; venoarterial extracorporeal membrane oxygenation; cardiogenic shock; predictive value

Introduction

Cardiogenic shock (CS) is a syndrome that can occur in various cardiac diseases, which involves a significant reduction in cardiac output that causes severe circulatory failure. The mortality rate of CS ranges from 70% to 100% [1]. Venoarterial extracorporeal membrane oxygenation (VA-ECMO) provides cardiac and partial respiratory support for CS patients before further treatment. Nonetheless, there is ongoing debate on the effectiveness of VA-ECMO in treating diseases and the prognosis of patients [2–4]. N-terminal pro-brain natriuretic peptide (NT-proBNP) may act as the gold standard serum marker in indicating cardiac failure to assess the extent, severity, and prognosis of CS patients [5–7]. However, few studies have evaluated the role of NT-proBNP in CS patients assisted by VA-ECMO. Thus, this study aimed to measure the NT-proBNP levels and clinical information of CS patients at various times during VA-ECMO assistance to assess the predictive value of NT-proBNP for clinical outcomes of adult CS patients receiving VA-ECMO.

Materials and Methods

Study Objective

Study Design, Population and Sampling Method

This is a retrospective study; therefore, we selected 113 CS patients who had received VA-ECMO assistance at our center from January 2016 to January 2021. In total, 23 patients who underwent percutaneous coronary intervention (PCI) or transcatheter aortic valve replacement and who were immediately weaned off VA-ECMO, five patients who died in the 24 hours after VA-ECMO administration, and eight patients who were transferred to other centers were not considered for the study. Finally, 77 CS patients were enrolled in this study. The patients were divided into groups related to rehabilitation or death depending on their clinical outcome.

Diagnosis, Inclusion, and Exclusion Criteria

The diagnosis criteria for CS entailed [8]: (1) a systolic blood pressure $<$90 millimeters of mercury (mmHg) for $\geq$30 minutes, or maintenance of systolic blood pressure $\geq$90 mmHg with clinical support measures (through medical and mechanical means); (2) organ hypoperfusion (urine volume $<$30 milliliters per hour (mL/hr) or cold extremities, with a heart rate of $>$60 beats/minute); (3) a hemodynamic index with a cardiac index of $\leq$2.2 liters per minute per square meter (L/min/m^2) and pulmonary capillary wedge pressure of $\geq$15 mmHg.

Inclusion and Exclusion Criteria

Inclusion criteria were as follows: $\geq$18 years of age, having met the diagnostic criteria of CS, requiring VA-ECMO assistance after ineffective medical or surgical treatment, and having received VA-ECMO assistance for $>$24 hours. Exclusion criteria were as follows: age $<$18 years or $>$75 years, severe liver dysfunction, end-stage malignancy, severe coagulation dysfunction, irreversible organ failure, or prolonged ineffective cardiopulmonary resuscitation.

Data Collection Methods

The demographic information and clinical data of patients were collected retrospectively. This information included patient sex, age, disease etiology, left ventricular ejection fraction percentage (LVEF%) before VA-ECMO assistance, sepsis-related organ failure assessment (SOFA) score, duration of VA-ECMO assistance, use of continuous renal replacement therapy (CRRT), use of intra-aortic balloon pump (IABP), PCI, surgery or extracorporeal cardiopulmonary resuscitation (ECPR), length of intensive care unit (ICU) stay, mean arterial pressure (MAP), blood gas analysis results, NT-proBNP levels, routine bloodwork, and liver and renal functions.

The professional extracorporeal membrane oxygenation (ECMO) team comprised cardiovascular surgeons, cardiac intensive care physicians, monitoring nurses, cardiovascular perfusionists, and sonographers. Arteries or veins were selected according to the patient's condition. Punctures or incisions were made to place a suitable type of ECMO cannula, and a distal perfusion tube was routinely placed at the arterial end to ensure blood supply to the lower extremities. The ECMO machine, membrane oxygenator, and tubing used in this study were purchased from Maquet (Gothenburg, Sweden); the blood purification machine and tubing were purchased from Baxter (Chicago, IL, USA); the IABP machine and tubing were purchased from Arrow (Ankara, Turkey). Arterial blood gas analyses were performed using ABL90 FLEX blood gas, blood oxygen, electrolyte, and metabolite analyzers purchased from the Danish Radiometer company (Copenhagen, Denmark). All laboratory tests were performed at the Laboratory Department of Xi'an Jiaotong University Medical College and its affiliated hospital. SOFA scores were independently assessed by the same investigator (Liu). ECMO assistance management and weaning criteria followed the expert consensus on adult ECMO cycle assistance [9].

Statistical Methods

Categorical variables are presented as frequency and rate. Statistical analyses were performed using the chi-square or Fisher's exact tests. Continuous variables conforming to a normal distribution are expressed as the mean $\pm$ standard deviation, and these variables were statistically analyzed using Student's *t*-tests or analysis of variance. Continuous variables that did not conform to a normal distribution are described using the median and interquartile range, and these variables were statistically analyzed using non-parametric tests. A receiver operating characteristic (ROC) curve was used to analyze the predictive value of each variable for patient prognosis. All statistical analyses were performed using R version 3.4.4 (University of Auckland, New Zealand). Statistical significance was set at a *p*-value of $<$0.05.

Results

Demographic Information and Clinical Characteristics of Patients

The patients were divided into rehabilitation and death groups according to their associated clinical outcomes. Of the 77 CS patients enrolled in this study, 35 (45.45%) were placed in the rehabilitation group and 42 (54.55%) in the death group. Compared with the rehabilitation group, the death group had a higher mean age (44 vs. 63 years), SOFA score, and percentage of CRRT and IABP use ($p < 0.05$), and a lower pre-ECMO weaning and discharge LVEF% ($p < 0.05$). However, no significant differences in gender, pre-ECMO implantation LVEF%, length of ECMO use, PCI intervention, surgical intervention, ECPR, or length of ICU stay were observed between the two groups ($p > 0.05$).

Regarding clinical data, the death group had a lower pre-ECMO implantation and weaning platelet (PLT) count, oxygenation index, and pre-ECMO weaning MAP value than the rehabilitation group. Creatinine (Cr), blood urea nitrogen (BUN), pre-ECMO implantation and weaning lactic acid (LA), procalcitonin (PCT), creatine kinase-MB (CKMB), and pre-ECMO weaning total bilirubin (TBIL) levels were higher in the death group than in the rehabilitation group ($p < 0.05$). However, no significant differences in hemoglobin, hematocrit, white blood cell count, pH, albumin, pre-ECMO implantation and weaning C-reactive protein value, PCT, CKMB, oxygenation index, and pre-ECMO implantation MAP value were observed between the two groups ($p > 0.05$; Table 1).

Table 1. Demographic information and clinical data of VA-ECMO-assisted CS patients.

	n = 77	Rehabilitation group (n = 35)	Death group (n = 42)	*t*/*Z*	χ^2	*p*-value
Sex					0.0074	0.9316
Male	48 (62.34)	22 (62.86)	26 (61.90)			
Female	29 (37.66)	13 (37.14)	16 (38.10)			
Primary disease						0.0237
Acute myocardial infarction (AMI)	43 (55.84)	17 (48.57)	26 (61.90)			
Cardiac failure	12 (15.58)	3 (8.57)	9 (21.43)			
Fulminant myocarditis	18 (23.38)	13 (37.14)	5 (11.90)			
Cardiac arrest	1 (1.30)	0	1 (2.38)			
Malignant arrhythmia	1 (1.30)	0	1 (2.38)			
Dilated cardiomyopathy	1 (1.30)	1 (2.86)	0			
Hyperpotassemia	1 (1.30)	1 (2.86)	0			
Age (y), M (IQR)		44 (26)	63 (19)	–3.7405		0.0002
LVEF%, M (IQR)		38 (15)	32.5 (24)	1.1971		0.2313
LVEF% pre-ECMO weaning, M (IQR)		56.5 (18)	40 (20)	3.8025		0.0001
LVEF% before discharge, M (IQR)		61.5 (17)	42.5 (20)	5.2108		<0.0001
SOFA score, M (IQR)		11 (14)	17 (12)	–3.2119		0.0013
The duration of ECMO support (d), M (IQR)		4 (5)	4 (6)	–0.3109		0.7559
CRRT					4.7347	0.0296
Yes	30 (38.96)	9 (25.71)	21 (50.00)			
No	47 (61.04)	26 (74.29)	21 (50.00)			
IABP					5.4372	0.0197
Yes	26 (33.77)	7 (20.00)	19 (45.24)			
No	51 (66.23)	28 (80.00)	23 (54.76)			
PCI					0.4494	0.5026
Yes	34 (44.16)	14 (40.00)	20 (47.62)			
No	43 (55.84)	21 (60.00)	22 (52.38)			
Surgical intervention					2.9841	0.0841
Yes	23 (29.87)	7 (20.00)	16 (38.10)			
No	54 (70.13)	28 (80.00)	26 (61.90)			
ECPR					1.5897	0.2074
Yes	15 (19.48)	9 (25.71)	6 (14.29)			
No	62 (80.52)	26 (74.29)	36 (85.71)			
ICU time (d), M (IQR)		9 (11)	8 (15)	0.7148		0.4748
PCT						
Pre-ECMO implantation, M (IQR)		2 (15.08)	2.785 (15.62)	–0.5218		0.6018
Pre-ECMO weaning, M (IQR)		1.6 (4.184)	4.13 (18.33)	–2.5223		0.0117
HB						
Pre-ECMO implantation ($\bar{x} \pm s$)		117.8 ± 19.50	107.57 ± 27.19	1.92		0.0666
Pre-ECMO weaning ($\bar{x} \pm s$)		102.83 ± 10.56	101.31 ± 16.72	0.48		0.6298
HCT						
Pre-ECMO implantation, M (IQR)		34.7 (8.4)	33.5 (11.7)	0.8236		0.4102
Pre-ECMO weaning, M (IQR)		30.6 (40.1)	30.45 (7.4)	–0.1228		0.9023
CRP						
Pre-ECMO implantation, M (IQR)		23.7 (55.1)	46.1 (74.6)	–1.8211		0.0686
Pre-ECMO weaning, M (IQR)		64 (99.4)	78 (106.5)	–1.8926		0.0584
WBC						
Pre-ECMO implantation, M (IQR)		12.7 (7.42)	13.42 (5.82)	–0.7519		0.4521
Pre-ECMO weaning, M (IQR)		11.51 (8.04)	14.44 (10.04)	–1.8363		0.0663
PLT						
Pre-ECMO implantation ($\bar{x} \pm s$)		200.43 ± 76.56	140.29 ± 73.69	3.5		0.0008
Pre-ECMO weaning, M (IQR)		95 (61)	49.5 (53)	3.5605		0.0004

Table 1. Continued.

	n = 77	Rehabilitation group (n = 35)	Death group (n = 42)	*t*/*Z*	χ^2	*p*-value
CKMB						
Pre-ECMO implantation, M (IQR)		93 (158)	150 (429)	–1.4323		0.152
Pre-ECMO weaning, M (IQR)		18 (31)	53 (291)	–2.8091		0.005
TBIL						
Pre-ECMO implantation, M (IQR)		17 (14.1)	17.5 (25.8)	–0.3439		0.7309
Pre-ECMO weaning, M (IQR)		21.3 (15.5)	45.25 (45.1)	–3.3864		0.0007
ALB						
Pre-ECMO implantation, M (IQR)		32.85 (5)	32.7 (7.5)	0.1202		0.9044
Pre-ECMO weaning, M (IQR)		40 (7)	39.1 (8.2)	1.8709		0.0614
Cr						
Pre-ECMO implantation, M (IQR)		84 (47)	144 (126)	–4.0771		<0.0001
Pre-ECMO weaning, M (IQR)		70 (79)	162.5 (92)	–4.3431		<0.0001
BUN						
Pre-ECMO implantation, M (IQR)		7.16 (2.37)	10.16 (8.5)	–3.064		0.0022
Pre-ECMO weaning, M (IQR)		11.25 (7.04)	15.12 (14.19)	–2.8491		0.0044
PH						
Pre-ECMO implantation, M (IQR)		7.4 (0.13)	7.37 (0.16)	0.6548		0.5126
Pre-ECMO weaning, M (IQR)		7.42 (0.087)	7.41 (0.098)	0.5781		0.5632
LA						
Pre-ECMO implantation, M (IQR)		5.4 (9.1)	11 (14)	–2.5478		0.0108
Pre-ECMO weaning, M (IQR)		1.4 (1)	4.35 (8.7)	–4.9952		<0.0001
PO_2/FiO_2						
Pre-ECMO implantation, M (IQR)		186 (135)	129.5 (115)	1.3402		0.1802
Pre-ECMO weaning, M (IQR)		287 (108)	126.92 (120)	5.4787		<0.0001
MAP						
Pre-ECMO implantation ($\bar{x} \pm s$)		56.97 ± 14.29	56.76 ± 14.83	0.06		0.9507
Pre-ECMO weaning, M (IQR)		83.5 (11)	65 (37)	4.8748		<0.0001

Normal ranges: Cr (creatinine): 41–73 umol/L; BUN (blood urea nitrogen): 2.6–7.5 mmol/L; ALB (albumin): 40–55 g/L; TBIL (total bilirubin): 3.4–17.1 µmol/L; PO_2/FiO_2 (oxygenation index): 400–500 mmHg; LA (lactic acid): 0.5–2.0 mmol/L; HB (hemoglobin): 130–175 g/L; WBC (white blood cell): 3.5–9.5 × 10^9/L; PLT (platelet): 125–350 × 10^9/L; CRP (C-reactive protein): 0–10 mg/L; PCT (procalcitonin): ≤0.5 ng/mL; CKMB (creatine kinase-MB): 0–24 U/L; HCT (hematocrit): 35–45%; ECMO, extracorporeal membrane oxygenation; CRRT, continuous renal replacement therapy; LVEF, left ventricular ejection fraction; SOFA, sepsis-related organ failure assessment; IABP, intra-aortic balloon pump; PCI, percutaneous coronary intervention; ICU, intensive care unit; PCT, procalcitonin; MAP, mean arterial pressure; PH, PH value; IQR, interquartile range; VA-ECMO, venoarterial extracorporeal membrane oxygenation; CS, cardiogenic shock; ECPR, extracorporeal cardiopulmonary resuscitation.

NT-proBNP Levels of the Two Groups by VA-ECMO Stage

The mean values of the highest pre-ECMO implantation NT-proBNP levels were 13,568.26 and 21,439.62 pg/mL in the rehabilitation and death groups, respectively. The mean NT-proBNP levels before ECMO weaning were 8472.8 and 18,170.95 pg/mL in the rehabilitation and death groups, respectively. Mean NT-proBNP levels before discharge were 5646.197 and 22,183.35 pg/mL in the rehabilitation and death groups, respectively. The highest NT-proBNP level values during pre-ECMO implantation, weaning, and discharge were higher in the death group than in the rehabilitation group ($p < 0.05$). However, no significant intergroup differences were found in pre-ECMO implantation NT-proBNP levels ($p > 0.05$; Table 2).

NT-proBNP Prediction Value at Each Stage of VA-ECMO

NT-proBNP levels before ECMO weaning and discharge were noted as reliable predictors of patient death (area under curve (AUC) >0.70; $p < 0.05$). Among these values, NT-proBNP levels before discharge had the best ability to predict patient death. Comparatively, pre-ECMO implantation NT-proBNP values were inadequate diagnostic predictors of patient death (AUC <0.70; Table 3; Fig. 1).

Predictive Values of Different Variables

Age, SOFA scores, Cr, PLT, pre-ECMO implantation BUN, TBIL, PLT, LA, MAP, pre-ECMO weaning Cr, NT-proBNP levels, and LVEF% before discharge were reliable predictors of patient death (AUC >0.70; $p < 0.05$). Among

Table 2. NT-proBNP levels in patients by VA-ECMO stage.

Variable	Rehabilitation group (n = 35)	Death group (n = 42)	*t*/*Z*	*p*-value
Pre-ECMO implantation	8920 (10,569)	9187.5 (20,989)	–1.0085	0.3132
Highest value in ECMO assistance	8920 (20,280)	18,124 (28,104)	–2.5775	0.010
Pre-ECMO weaning	2900 (8762)	15,366.5 (27,097)	–3.7709	0.0002
Before discharge	1651 (5772)	20,120.5 (23,550)	–5.6538	<0.0001

Values are shown as median (interquartile range) pg/mL.

Table 3. The ability of NT-proBNP to predict death in CS patients treated with VA-ECMO.

NT-proBNP (pg/mL)	AUC	*p*-value	95% CI	Best critical	Sensitivity (%)	AUC (%)
Pre-ECMO implantation	0.567	0.311	0.439–0.696	14,026	0.405	0.771
Highest value in ECMO assistance	0.670	0.011	0.548–0.791	11,705	0.738	0.600
Pre-ECMO weaning	0.750	<0.001	0.638–0.862	9605	0.714	0.743
Before discharge	0.873	<0.001	0.791–0.956	7130	0.881	0.771

95% CI, 95% confidence interval;

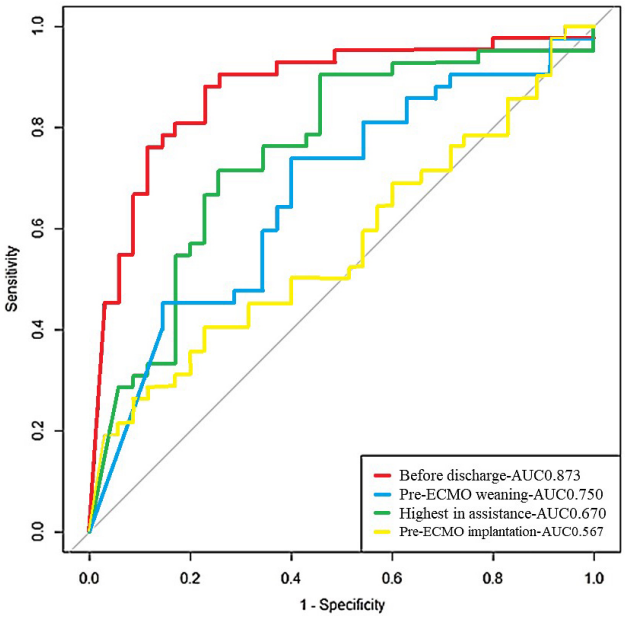

Fig. 1. ROC curves for the NT-proBNP-related prediction of death at each stage. ECMO, extracorporeal membrane oxygenation; AUC, area under curve; ROC, receiver operating characteristic; NT-proBNP, N-terminal pro-brain natriuretic peptide.

them, NT-proBNP had the best predictive ability of patient death (AUC = 0.873; Table 4).

Discussion

This study found that the highest pre-ECMO implantation, pre-ECMO weaning, and pre-discharge NT-proBNP levels were higher in CS patients who had died than in those who were undergoing rehabilitation. Pre-discharge NT-proBNP levels were the best predictor of patient prognosis.

CS is a state of inadequate tissue perfusion due to cardiac dysfunction. The pathophysiology of CS involves a "downward spiral": ischemia causes myocardial dysfunction, which, in turn, worsens ischemia [10]. VA-ECMO introduces blood from the right atrium into the extracorporeal circulation through a catheter; a membrane oxygenator fully oxygenates this blood and is then re-infused from the arterial end to the aorta. Thus, VA-ECMO increases effective circulation and ensures the perfusion of vital organs. However, patients with CS receiving VA-ECMO also often have severe underlying diseases, myocardial cell damage, and necrosis. Hence, heart function may steadily deteriorate despite VA-ECMO support, resulting in disease progression and even death. In this study, the etiology of CS in patients receiving ECMO included heart failure (55.84%), fulminant myocarditis (15.58%), and malignant arrhythmias (23.38%) along with critical primary disease. Therefore, it is important to analyze the associated factors and evaluate the prognosis of CS patients receiving VA-ECMO support to improve their clinical outcomes and more appropriately employ medical resources.

BNP is mainly synthesized and secreted by ventricular myocytes. Moreover, BNP is an important endocrine factor that can promote sodium excretion and diuresis. BNP has strong vasodilatory effects, counteracts the renin–angiotensin–aldosterone system, and protects the body against volume overload and hypertension. NT-proBNP is the precursor of BNP, has a longer half-life and better stability, and presents an important diagnostic and prognostic value in heart failure, especially in cases of CS [11]. NT-proBNP can also be used for physical screening in older individuals and high-risk groups since it has greater diagnostic and prognostic value in early heart failure detection and intervention [11,12].

When VA-ECMO is used in patients with CS, an early and accurate assessment of tissue perfusion is critical for adjusting therapy and determining patient prognosis. The closed-loop system of bodily circulation is disrupted by

Table 4. Predictive value of different variables on patient death in CS patients treated with VA-ECMO.

Variable	AUC	*p*-value	95% CI	Best critical value	Sensitivity (%)	AUC (%)
Age (y)	0.749	<0.001	0.638–0.860	60.5	0.571	0.857
SOFA score	0.714	0.001	0.594–0.834	11.5	0.833	0.6
PLT pre-ECMO implantation	0.722	0.001	0.608–0.837	167.5	0.643	0.743
PLT pre-ECMO weaning	0.737	<0.001	0.622–0.852	73	0.714	0.771
Cr pre-ECMO implantation	0.771	<0.001	0.667–0.875	109.5	0.667	0.829
Cr pre-ECMO weaning	0.789	<0.001	0.683–0.895	110.5	0.810	0.743
BUN pre-ECMO implantation	0.704	0.002	0.585–0.823	9.235	0.619	0.829
NT-proBNP pre-ECMO weaning	0.750	<0.001	0.638–0.862	9605	0.714	0.743
LA pre-ECMO weaning	0.832	<0.001	0.743–0.922	2.85	0.571	0.943
MAP pre-ECMO weaning	0.825	<0.001	0.734–0.917	69	0.548	1
TBIL pre-ECMO weaning	0.726	0.001	0.608–0.843	31.2	0.714	0.771
LVEF% before discharge	0.853	<0.001	0.767–0.940	55	0.875	0.706
NT-proBNP before discharge	0.873	<0.001	0.791–0.956	7130	0.881	0.771

ECMO and the use of sedative, analgesic, and vasoactive drugs. Traditional tissue perfusion indicators (heart rate and urine volume) and invasive hemodynamic monitoring (Swan-Ganz balloon float catheters and pulse-indicated continuous cardiac output monitoring) cannot accurately measure and respond to tissue perfusion. Meanwhile, even critical care ultrasound technology sometimes cannot accurately evaluate tissue perfusion [13]. Notably, NT-proBNP level changes in adults treated with ECMO have rarely been studied except for a few reports in children [14,15]. This study found that pre-ECMO implantation, pre-ECMO weaning, and pre-discharge NT-proBNP values were lower in patients undergoing rehabilitation from CS than in those who had died of CS. These results are consistent with a study by Huang *et al.* [16], whereby children who had survived CS presented significantly lower BNP levels than those who had died of CS. Furthermore, the difference between NT-proBNP values in the death group versus the rehabilitation group gradually increased as the patient's conditions deteriorated, indicating that continuous monitoring of NT-proBNP levels may be useful for patients receiving ECMO.

This study also showed that NT-proBNP levels before ECMO weaning and discharge were predictive of patient death; NT-proBNP levels before discharge were the best predictor of patient death. The high predictive value of the pre-discharge NT-proBNP level may be because patients in the rehabilitation group had significantly improved cardiac function and reduced blood NT-proBNP levels during ECMO weaning and discharge. In contrast, those in the death group (with varying degrees of persistent cardiac dysfunction) displayed continuous high-level secretions of NT-proBNP. Moreover, the ROC curves and patient prognosis differences were also the most accurate at discharge (when the intergroup difference was greatest). These results suggest that NT-proBNP has an important diagnostic and predictive role at each treatment stage in adult CS patients receiving VA-ECMO assistance; the most predictive NT-proBNP values for patient prognosis were those at discharge.

Additionally, age, SOFA score, Cr, PLT, BUN, TBIL, PLT, LA levels, and MAP, as well as the pre-ECMO weaning Cr level, pre-discharge NT-proBNP level, and LVEF% were reliable predictors of patient death. This study also found that pre-discharge NT-proBNP values were the best predictors of patient death among all variables; however, our results differ from those of previous studies [14,17]. This difference could be due to variances in inclusion and exclusion criteria, participant selection, and sample size among studies.

This study has several limitations. First, it was retrospective; thus, prospective studies should be performed to validate our results. Second, the statistical efficacy was relatively limited owing to the small sample size. Finally, NT-proBNP levels were recorded at only four key time points throughout this study. In the future, sample sizes and time points should be expanded upon when obtaining continuous values to investigate further the relationship between changes in NT-proBNP levels and patient prognosis.

Conclusion

Among CS patients who received VA-ECMO assistance, NT-proBNP values at each assistance point had important patient-related diagnostic and predictive values. Pre-discharge NT-proBNP values were the best predictors of patient prognosis.

Availability of Data and Materials

The datasets used and/or analysed during the current study available from the corresponding author on reasonable request.

Author Contributions

YY and ML: Conceptualization and Methodology; JS: Methodology, Project Administration and Data Curation; YZ: Data Curation; FG: Formal Analysis; YS: Formal Analysis; JS and ML wrote the main manuscript text. All authors reviewed the manuscript. All authors have participated sufficiently in the work. All authors contributed to editorial changes in the manuscript. All authors read and approved the final manuscript. All authors agree to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

Ethics Approval and Consent to Participate

The study was carried out in accordance with the guidelines of the Declaration of Helsinki. All methods were carried out in accordance with relevant guidelines and regulations and informed consent was obtained from all subjects and/or their legal guardians. All experimental protocols were approved by Xi'an Jiaotong University Medical College First Affiliated Hospital. This study was exempted from ethical approval by the Ethics Committee of Xi'an Jiaotong University Medical College First Affiliate Hospital because it was a retrospective study.

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Conflict of Interest

The authors declare no conflict of interest.

References

[1] Wayangankar SA, Bangalore S, McCoy LA, Jneid H, Latif F, Karrowni W, *et al*. Temporal Trends and Outcomes of Patients Undergoing Percutaneous Coronary Interventions for Cardiogenic Shock in the Setting of Acute Myocardial Infarction: A Report From the CathPCI Registry. JACC. Cardiovascular Interventions. 2016; 9: 341–351. https://doi.org/10.1016/j.jcin.2015.10.039.

[2] Rihal CS, Naidu SS, Givertz MM, Szeto WY, Burke JA, Kapur NK, *et al*. 2015 SCAI/ACC/HFSA/STS Clinical Expert Consensus Statement on the Use of Percutaneous Mechanical Circulatory Support Devices in Cardiovascular Care: Endorsed by the American Heart Association, the Cardiological Society of India, and Sociedad Latino Americana de Cardiologia Intervencion; Affirmation of Value by the Canadian Association of Interventional Cardiology-Association Canadienne de Cardiologie d'intervention. Journal of the American College of Cardiology. 2015; 65: e7–e26. https://doi.org/10.1016/j.jacc.2015.03.036.

[3] Musiał R, Moncznik P, Śmiałek P, Stoliński J, Sadowski J, Drwiła R. Veno-arterial extracorporeal membrane oxygenation for short-term mechanical circulation support in adults with cardiogenic shock: a single centre experience. Kardiologia Polska. 2016; 74: 1477–1484. https://doi.org/10.5603/KP.a2016.0087.

[4] Luyt CE, Landivier A, Leprince P, Bernard M, Pavie A, Chastre J, *et al*. Usefulness of cardiac biomarkers to predict cardiac recovery in patients on extracorporeal membrane oxygenation support for refractory cardiogenic shock. Journal of Critical Care. 2012; 27: 524.e7–524.e14. https://doi.org/10.1016/j.jcrc.2011.12.009.

[5] Ponikowski P, Voors AA, Anker SD, Bueno H, Cleland JGF, Coats AJS, *et al*. 2016 ESC Guidelines for the diagnosis and treatment of acute and chronic heart failure: The Task Force for the diagnosis and treatment of acute and chronic heart failure of the European Society of Cardiology (ESC)Developed with the special contribution of the Heart Failure Association (HFA) of the ESC. European Heart Journal. 2016; 37: 2129–2200. https://doi.org/10.1093/eurheartj/ehw128.

[6] Yancy CW, Jessup M, Bozkurt B, Butler J, Casey DE, Jr, Colvin MM, *et al*. 2017 ACC/AHA/HFSA Focused Update of the 2013 ACCF/AHA Guideline for the Management of Heart Failure: A Report of the American College of Cardiology/American Heart Association Task Force on Clinical Practice Guidelines and the Heart Failure Society of America. Journal of the American College of Cardiology. 2017; 70: 776–803. https://doi.org/10.1016/j.jacc.2017.04.025.

[7] Chinese Society of Cardiovascular Diseases, Chinese Journal of Cardiovascular Diseases Editorial Board. China Heart Failure Diagnosis and Treatment Guidelines 2014. Chinese Society of Cardiology. 2014; 42: 98–122. (In Chinese)

[8] Hochman JS, Sleeper LA, Webb JG, Sanborn TA, White HD, Talley JD, *et al*. Early revascularization in acute myocardial infarction complicated by cardiogenic shock. SHOCK Investigators. Should We Emergently Revascularize Occluded Coronaries for Cardiogenic Shock. The New England Journal of Medicine. 1999; 341: 625–634. https://doi.org/10.1056/NEJM199908263410901.

[9] Extracorporeal life support professional committee of Chinese Medical Association. Expert consensus on extracorporeal membrane oxygenation circulation assistance in adults. National Medical Journal of China. 2018; 98: 886–894. (In Chinese)

[10] Hollenberg SM, Kavinsky CJ, Parrillo JE. Cardiogenic shock. Annals of Internal Medicine. 1999; 131: 47–59. https://doi.org/10.7326/0003-4819-131-1-199907060-00010.

[11] Santaguida PL, Don-Wauchope AC, Oremus M, McKelvie R, Ali U, Hill SA, *et al*. BNP and NT-proBNP as prognostic markers in persons with acute decompensated heart failure: a systematic review. Heart Failure Reviews. 2014; 19: 453–470. https://doi.org/10.1007/s10741-014-9442-y.

[12] Metra M, Nodari S, Parrinello G, Specchia C, Brentana L, Rocca P, *et al*. The role of plasma biomarkers in acute heart failure. Serial changes and independent prognostic value of NT-proBNP and cardiac troponin-T. European Journal of Heart Failure. 2007; 9: 776–786. https://doi.org/10.1016/j.ejheart.2007.05.007.

[13] Li Y, Zeng W, Sun LB, Han J, Xu CL,Zhang HB, *et al*. Clinical application of extracorporeal membrane oxygenation circuit in place of cardiopulmonary bypass.Clinical Medicine Of China. 2008; 24: 478–480. (In Chinese)

[14] Kaestner F, Rapp D, Trudzinski FC, Olewczynska N, Wagenpfeil S, Langer F, *et al*. High Serum Bilirubin Levels, NT-pro-BNP, and Lactate Predict Mortality in Long-Term, Severely

Ill Respiratory ECMO Patients. ASAIO Journal. 2018; 64: 232–237. https://doi.org/10.1097/MAT.0000000000000610.

[15] Partridge EA, Hanna BD, Rintoul NE, Herkert L, Flake AW, Adzick NS, *et al*. Brain-type natriuretic peptide levels correlate with pulmonary hypertension and requirement for extracorporeal membrane oxygenation in congenital diaphragmatic hernia. Journal of Pediatric Surgery. 2015; 50: 263–266. https://doi.org/10.1016/j.jpedsurg.2014.11.009.

[16] Huang SC, Wu ET, Ko WJ, Lai LP, Hsu J, Chang CI, *et al*. Clinical implication of blood levels of B-type natriuretic peptide in pediatric patients on mechanical circulatory support. The Annals of Thoracic Surgery. 2006; 81: 2267–2272. https://doi.org/10.1016/j.athoracsur.2005.12.061.

[17] Kim HS, Lee KJ, Ha SO, Han SJ, Park KH, Lee SH, *et al*. Brain natriuretic peptide levels predict 6-month mortality in patients with cardiogenic shock who were weaned off extracorporeal membrane oxygenation. Medicine. 2020; 99: e21272. https://doi.org/10.1097/MD.0000000000021272.