

Predictors of Survival to Discharge After Successful Weaning From Venoarterial Extracorporeal Membrane Oxygenation in Patients With Cardiogenic Shock

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Background: This study identified predictors of hospital mortality after successful weaning of patients with cardiogenic shock off venoarterial (VA) extracorporeal membrane oxygenation (ECMO) support.

Methods and Results: Adult patients who received peripheral VA ECMO from January 2012 to April 2017 were reviewed retrospectively. After excluding patients who died on ECMO support, predictors for survival to discharge were investigated in patients who were successfully weaned off ECMO. Of 191 patients successfully weaned off ECMO, 143 (74.9%) survived to discharge. The prevalence of a history of stroke and coronary artery disease, as well as ECMO-related complications, including newly developed stroke and sepsis, was higher in patients who did not survive to discharge than in those who did. On the day of ECMO weaning, Sequential Organ Failure Assessment score and serum lactate were higher in patients who did not survive to discharge, although there was no significant difference in blood pressure and the use of vasoactive drugs between the 2 groups. On multivariable analysis, stroke and sepsis during ECMO support, a lower Glasgow Coma Scale and acute kidney injury requiring continuous renal replacement therapy after weaning were significant predictors for in-hospital mortality.

Conclusions: Complications that occurred during ECMO and the presence of extracardiac organ dysfunction after weaning were associated with in-hospital mortality in patients with cardiogenic shock who were successfully weaned off ECMO.

Key Words: Cardiogenic shock; Extracorporeal membrane oxygenation; Mortality

Venoarterial (VA) extracorporeal membrane oxygenation (ECMO) provides the circulatory support to maintain life in patients with refractory cardiogenic shock (CS) while allowing time for myocardial recovery or time until heart transplantation or implantation of a left ventricular assist device.¹ There has been a rapid increase in the use of ECMO in CS patients recently, but half the patients who receive ECMO do not survive to discharge.²

In particular, several studies have reported that a substantial proportion of patients do not survive to discharge despite successful weaning from ECMO.^{3–6} In addition to underlying comorbidities in CS patients undergoing ECMO,

it is believed that adverse complications during ECMO and a patient's condition after weaning also affect the clinical outcome. Thus, strategies to prevent ECMO-related complications such as bleeding, systemic embolization, limb ischemia, and pulmonary edema or hemorrhage caused by left ventricular distension and general intensive care may be required to improve clinical outcomes, even in patients successfully weaned off ECMO. However, limited data are available on the predictors of survival to discharge after successful weaning from ECMO in CS patients.

Therefore, the aim of the present study was to investigate the clinical features and predictors of in-hospital mortality

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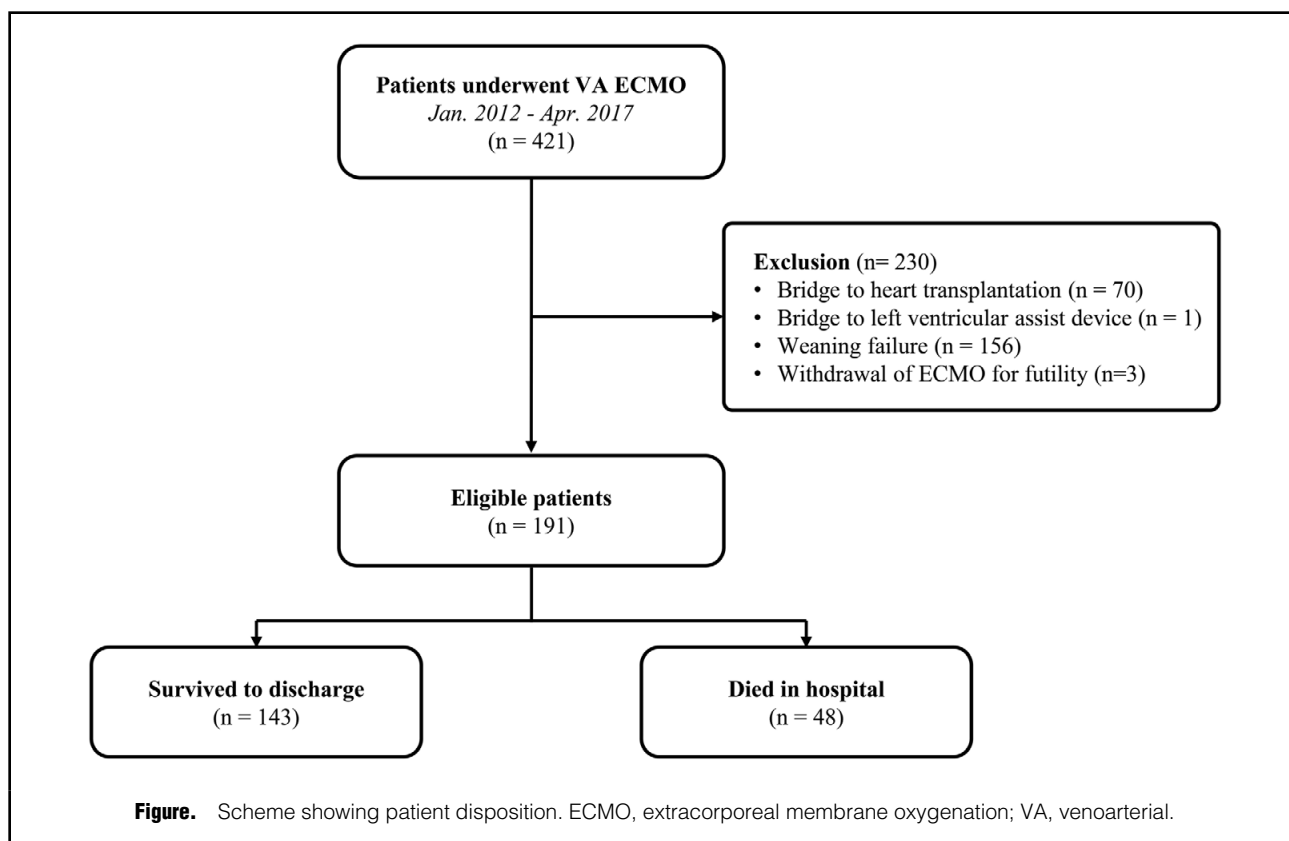
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in refractory CS patients who were successfully weaned from ECMO support.

Methods

Study Population

A retrospective cohort study was conducted on 421 adult patients aged >18 years who received peripheral VA ECMO between January 2012 and April 2017. Patients who underwent ECMO as bridge to heart transplantation or left ventricular assist device implantation, those who could not be weaned off ECMO, or those in whom ECMO was withdrawn because it was medical futile were excluded from the study. This left 191 patients for analysis. These patients were divided into 2 groups based on whether they survived to discharge (survivor group, n=143; non-survivor group, n=48; **Figure**).

This study was approved by the Institutional Review Board of Samsung Medical Center. Because of the retrospective nature of the study, the requirement for written informed consent was waived.

Implantation, Management and Weaning off ECMO

We have previously reported the ECMO procedure in detail.^{7,8} The decision to initiate ECMO was determined by an experienced cardiologist or cardiovascular surgeon. In general, ECMO support was considered in refractory CS patients who could not maintain adequate peripheral perfusion despite medical treatment. Pre-existing severe neurological disease or damage and extremely short predicted life expectancy due to malignancy or other comorbidities were considered contraindications to ECMO. In addition,

ECMO was not initiated in patients who had previously signed ‘do-not-resuscitate’ orders or in cases where patients or their families had expressed a preference against it.

Pump blood flow rate was adjusted to maintain a target blood pressure, and additional fluid, blood products, inotropes or vasopressors were infused, if needed. Neurological function, including the level of consciousness and motor and sensory function, was assessed daily using the Glasgow Coma Scale (GCS) and motor scoring scale. If a patient was under sedation, sedation was interrupted daily to assess neurological status. The multidisciplinary ECMO team performed daily rounds and assessed the circuit, the development of ECMO-associated complications, and the possibility of weaning.

When patients were hemodynamically stable with or without low levels of pharmacologic support and were oxygenated with adequate natural lung oxygenation, hemodynamics status was evaluated at an ECMO flow of 1 L/min; ECMO was withdrawn if the patient was judged to have sufficient ability to maintain perfusion without mechanical circulatory support. Successful weaning was defined as weaning from ECMO followed by survival without reinsertion beyond 24 h.

Data Collection and Definitions

Clinical, laboratory, and outcome data were collected by a trained study coordinator by reviewing hospital medical records. Laboratory findings were collected just before initiation of VA ECMO. The Sequential Organ Failure Assessment (SOFA) score was calculated using the worst value within the 24-h period after weaning. Failure of weaning off ECMO was defined as reinitiation of ECMO

Table 1. Baseline Characteristics and In-Hospital Managements Before Weaning Off ECMO in Patients Who Survived or Not to Discharge

	Non-survivors (n=48)	Survivors (n=143)	P value
Age (years)	59.7±16.2	55.1±16.6	0.094
Male sex	29 (60.4)	91 (63.6)	0.821
BMI (kg/m²)	24.6±3.7	24.5±3.8	0.866
Comorbidities			
Hypertension	16 (33.3)	54 (37.8)	0.705
Diabetes	20 (41.7)	46 (32.2)	0.307
Hyperlipidemia	3 (6.2)	10 (7.0)	0.999
Current smoker	7 (14.6)	35 (24.5)	0.219
Chronic kidney disease	6 (12.5)	9 (6.3)	0.283
Peripheral artery disease	3 (6.2)	3 (2.1)	0.343
Previous stroke	9 (18.8)	5 (3.5)	0.001
Previous myocardial infarction	16 (33.3)	18 (12.6)	0.002
Previous coronary artery revascularization	20 (41.7)	28 (19.6)	0.004
Malignancy	10 (20.8)	22 (15.4)	0.515
ECMO indication			0.695
Ischemic cardiomyopathy	23 (47.9)	72 (50.3)	
Non-ischemic cardiomyopathy	20 (41.7)	53 (37.1)	
After cardiotomy	3 (6.2)	5 (3.5)	
Refractory ventricular arrhythmia	2 (4.2)	11 (7.7)	
Other	0 (0.0)	2 (1.4)	
Duration of ECMO support (days)	5.4±5.3	4.1±4.5	0.112
Extracorporeal cardiopulmonary resuscitation	29 (60.4)	72 (50.3)	0.297
In-hospital management during ECMO			
Left heart decompression with venting	3 (6.2)	10 (7.0)	>0.999
Distal perfusion	17 (35.4)	57 (39.9)	0.707
Anticoagulation	40 (83.3)	112 (78.3)	0.590
Vasopressor	45 (93.8)	122 (85.3)	0.203
Mechanical ventilator	47 (97.9)	103 (72.0)	<0.001
Continuous renal replacement therapy	33 (68.8)	46 (32.2)	<0.001
Intra-aortic balloon pump	7 (14.6)	15 (10.5)	0.612
Complications			
Limb ischemia	6 (12.5)	8 (5.6)	0.205
ECMO insertion site bleeding	8 (16.7)	14 (9.8)	0.303
Stroke	15 (31.2)	5 (3.5)	<0.001
Gastrointestinal bleeding	4 (8.3)	3 (2.1)	0.122
Sepsis	10 (20.8)	5 (3.5)	<0.001
Rhabdomyolysis	6 (12.5)	3 (2.1)	0.011

Unless indicated otherwise, data are given as the mean ± SD or n (%). ECMO, extracorporeal membrane oxygenation.

or death within 24 h.

The primary outcome was in-hospital mortality. The following complications during ECMO were recognized: (1) lower limb ischemia, which included cases requiring surgical management or those involving long-term sequelae rather than cases of simple distal perfusion; (2) bleeding at the ECMO insertion site, defined as cases requiring surgical wound repair; (3) bleeding at non-cannula sites, which included cases of gastrointestinal bleeding and cerebral hemorrhage; (4) thrombosis, identified by duplex ultrasonography; and (5) sepsis, defined as bacteremia induced by cannula-related infections.

Statistical Analysis

Categorical variables are presented as numbers and percentages, whereas Continuous variables are presented as

the mean ± SD or as the median and interquartile range (IQR). To compare characteristics between survivors and non-survivors, categorical variables were analyzed using χ^2 tests or Fisher's exact tests, when applicable, whereas continuous variables were compared using the t-test or Mann-Whitney U-test.

Regression analysis was used to identify risk factors for hospital mortality. First, univariable logistic regression for each risk factor was performed to select meaningful clinical variables that appeared to be related to hospital mortality. Variables with $P < 0.2$ were considered relevant and were included in the multivariable logistic regression model as initial independent predictors. Finally, risk factors with statistical significance at the 0.05 level were retained in the final model. Odds ratios (ORs) are reported for each variable with 95% confidence intervals (CIs). The goodness of

Table 2. Clinical Characteristics and Management After Successful Weaning Off ECMO in Patients Who Survived or Not to Discharge

	Non-survivors (n=48)	Survivors (n=143)	P value
Vital signs on day of weaning			
SBP (mmHg)	89.6±21.8	86.4±16.8	0.288
DBP (mmHg)	47.1±12.2	47.6±11.0	0.775
mAP (mmHg)	61.3±14.6	60.6±11.8	0.732
PP (mmHg)	42.5±13.9	38.7±12.8	0.086
Laboratory findings and scores after weaning			
LVEF (%)	41.4±13.6	46.7±15.0	0.031
Hemoglobin (g/L)	9.7±1.3	10.3±1.5	0.031
Creatinine (mg/dL)	1.4±0.8	1.4±0.8	0.676
Total bilirubin (mg/dL)	5.4±6.4	2.5±3.4	<0.001
Prothrombin time (%)	79.8±17.8	76.0±17.7	0.196
Lactic acid (mmol/L)	4.6±5.6	2.7±2.6	0.001
In-hospital management after weaning			
Anticoagulation	10 (20.8)	24 (16.8)	0.677
Vasopressor	31 (64.6)	79 (55.2)	0.335
Mechanical ventilator	45 (93.8)	105 (73.4)	0.006
Continuous renal replacement therapy	22 (45.8)	22 (15.4)	<0.001
Intra-aortic balloon pump	8 (16.7)	16 (11.2)	0.460
SOFA	13.5±4.2	8.6±3.8	<0.001
Final cerebral performance category score	3.9±0.9	1.2±0.6	<0.001

Unless indicated otherwise, data are given as the mean±SD or n (%). DBP, diastolic blood pressure; ECMO, extra-corporeal membrane oxygenation; LVEF, left ventricular ejection fraction; mAP, mean arterial pressure; PP, pulse pressure; SBP, systolic blood pressure; SOFA, Sequential organ failure assessment.

fit and the discriminative power of the prediction model were assessed using the Hosmer-Lemeshow goodness-of-fit test and the area under the receiver operating characteristic (ROC) curve (C-statistic), respectively.^{9,10}

For all analyses, 2-tailed $P<0.05$ was considered significant. Statistical analyses were performed using R version 3.2.5 (R Foundation for Statistical Computing, Vienna, Austria).

Results

Baseline Clinical Characteristics

Of the 191 patients who were successfully weaned off ECMO support, 48 died in hospital and 143 survived to discharge. In non-survivors, the median duration from successful weaning off ECMO to death was 11 (3–40) days. Twelve (25.5%) patients died from cardiac causes, 21 (42.6%) died from neurological causes, and 15 (31.9%) died from non-cardiac causes. Baseline characteristics of the non-survivors and survivors are given in **Table 1**; there were no significant differences in clinical characteristics between non-survivors and survivors except for a history of adverse cardiovascular events, such as previous stroke (18.8% vs. 3.5%, respectively; $P=0.001$), myocardial infarction (33.3% vs. 12.6%, respectively; $P=0.002$), and coronary artery revascularization (41.7% vs. 19.6%, respectively; $P=0.004$). In addition, the primary diagnosis of the cause of CS was similar between the 2 groups. Ischemic cardiomyopathy and non-ischemic cardiomyopathy were common primary diagnoses, accounting for the cause of CS in 49.7% and 38.2% of patients overall, respectively. There was no significant difference in the proportion of patients in whom ECMO was initiated during cardiac arrest between

2 groups (60.4% vs. 50.3% in non-survivors and survivors, respectively; $P=0.297$).

Treatments and Complications During ECMO

During ECMO support, there was no significant difference between non-survivors and survivors in the use of vasoactive drugs (93.8% vs. 85.3%, respectively; $P=0.203$) and intra-aortic balloon pumps (14.6% vs. 10.5%, respectively; $P=0.612$; **Table 1**). However, non-survivors required mechanical ventilation (97.9% vs. 72.0%; $P<0.001$) and continuous renal replacement therapy (68.8% vs. 32.2%; $P<0.001$) more frequently than survivors. In addition, the proportion of patients who experienced complications during ECMO was higher among non-survivors. Although differences between non-survivors and survivors in the occurrence of stroke (31.2% vs. 3.5%, respectively; $P<0.001$) and sepsis (20.8% vs. 3.5%, respectively; $P<0.001$) were found to be significantly different, the occurrence of complications of all categories tended to be higher among non-survivors than survivors.

Clinical and Treatment Characteristics After Weaning Off ECMO

On the day of weaning, there were no differences in vital signs between the non-survivors and survivors (**Table 2**). However, GCS was lower (7.8 vs. 12.9; $P<0.001$) and the SOFA score were higher (13.5 vs. 8.6; $P<0.001$) in non-survivors than survivors. Left ventricular ejection fraction in the non-survivors and survivors was 41.4% and 46.7%, respectively ($P=0.031$). Even after weaning off ECMO, non-survivors were more likely to receive mechanical ventilation (93.8% vs. 73.4%; $P=0.006$) and continuous renal replacement therapy (45.8% vs. 15.4%; $P<0.001$) than survivors, but there was no difference in the use of vasoactive

Table 3. Predictors of Hospital Mortality in Patients Who Were Successfully Off ECMO

	Univariable analysis		Multivariable analysis	
	OR (95% CI)	P value	aOR (95% CI)	P value
Clinical factors				
Age	1.02 (0.99–1.04)	0.090		
Previous stroke	6.37 (2.02–20.12)	0.002		
Previous myocardial infarction	3.47 (1.59–7.56)	0.002		
Coronary revascularization history	2.93 (1.45–5.95)	0.003		
PP after weaning	1.022 (0.99–1.05)	0.087		
Factors associated with management after weaning				
Mechanical ventilator	5.43 (1.59–18.50)	0.007		
Continuous renal replacement therapy	4.65 (2.25–9.63)	<0.001	5.14 (2.04–12.93)	<0.001
Factors associated with ECMO complications				
Stroke	12.55 (4.26–36.98)	<0.001	5.11 (1.40–18.63)	0.013
Gastrointestinal bleeding	4.24 (0.91–19.69)	0.065		
Sepsis	7.26 (2.34–22.53)	0.001	7.19 (1.75–29.55)	0.006
Rhabdomyolysis	6.67 (1.59–27.81)	0.009		
Laboratory findings after weaning				
LVEF	0.98 (0.95–0.99)	0.033		
Hemoglobin	0.77 (0.60–0.98)	0.033		
Total bilirubin	1.13 (1.05–1.22)	0.001		
Lactic acid (maximum after weaning)	1.14 (1.04–1.26)	0.008		
Glasgow Coma Scale score	0.78 (0.71–0.84)	<0.001	0.76 (0.69–0.84)	<0.001
Final cerebral performance category score	6.39 (3.99–10.22)	<0.001		
SOFA score	1.36 (1.23–1.51)	<0.001		

aOR, adjusted odds ratio; CI, confidence interval; OR, odds ratio. Other abbreviations as in Table 2.

drugs (64.6% vs. 55.2%; $P=0.335$) or intra-aortic balloon pumps (16.7% vs. 11.2%; $P=0.460$) between the 2 groups.

Prognostic Factors for In-Hospital Mortality

Multivariable analysis revealed that the occurrence of stroke (OR 5.11; 95% CI 1.40–18.63; $P=0.013$) and sepsis (OR 7.19; 95% CI 1.75–29.55; $P=0.006$) during ECMO, a lower GCS on the day of weaning (OR 0.76; 95% CI 0.69–0.84; $P<0.001$), and the need for continuous renal replacement therapy after weaning (OR 5.14; 95% CI 2.04–12.93; $P<0.001$) were significant prognostic predictors for in-hospital mortality (Table 3). The prediction model had a good discrimination with a C-statistic of 0.88 (95% CI 0.82–0.94; $P<0.001$) in the ROC analysis for the prediction of in-hospital mortality. Overall goodness of fit of the model was also verified using the Hosmer-Lemeshow test ($P=0.16$).

Discussion

In this study we investigated the characteristics of patients who survived to hospital discharge and the independent predictors for mortality in CS patients who were successfully weaned off ECMO. The findings demonstrated that the need for extracardiac organ support, the incidence of complications during ECMO, and the severity of organ dysfunction at the time of ECMO weaning were significantly higher in non-survivors than survivors. In addition, the occurrence of stroke and sepsis during ECMO support, the presence of central nervous system dysfunction, and need for renal replacement therapy after ECMO weaning were independent prognostic factors for in-hospital mortality among patients who were successfully weaned off

ECMO.

Within the study cohort, 45.5% of all adult patients who received VA ECMO support were successfully weaned off ECMO without cardiac replacement therapy during the study period; of these, 74.9% were alive at the time of hospital discharge. In patients with refractory circulatory failure, ECMO ensured maintenance of adequate peripheral perfusion while providing time for cardiac recovery. Given this opportunity, approximately 50–70% of patients return to a condition whereby they can maintain perfusion without mechanical cardiac support and ECMO support can be withdrawn successfully.^{3–6,11} However, despite successful weaning off ECMO, and as demonstrated in this study, 20–30% of patients who are weaned of ECMO die in hospital.^{3–6} That is, successful ECMO weaning does not guarantee survival and it is important to identify prognostic factors for in-hospital mortality after weaning off ECMO. To date, most studies on patients receiving ECMO support for refractory CS considered only pre-ECMO factors as predictors of prognosis (Supplementary Table).^{5,12–14} However, relationships between a patient's physiological factors during ECMO support or at the time of weaning and clinical outcomes should also be evaluated in this population.

In CS patients, ischemic injury to other major organs, such as the brain, liver, and kidney, is often accompanied by circulatory failure^{15–17} and the presence of extracardiac organ dysfunction before ECMO is known as a prognostic factor for increased mortality in patients receiving ECMO support.^{5,12,13,18} In fact, it is difficult to distinguish whether the organ dysfunction remaining after weaning off ECMO is the result of ischemic injury during initial circulatory shock or a complication arising during ECMO support. In the present study, non-survivors were more likely to require

mechanical ventilation and renal replacement therapy during and even after ECMO support, whereas there was no difference in the use of vasoactive drugs and intra-aortic balloon pumps between the 2 groups. It seems that the extracardiac organ dysfunction, regardless of the onset or cause of organ dysfunction, is more closely related to clinical outcomes in patients who survived on VA ECMO when it is possible to maintain tissue perfusion, even if vasoactive drugs or intra-aortic balloon pumps are required.

During ECMO support, there is a risk of developing various circuit-related and patient complications that can become life threatening.² Nosocomial infections have been reported to occur in 10–50% of patients on ECMO support, and mortality rates were higher in patients who developed infections during ECMO support than in those who did not.^{19–22} In particular, Schmidt et al identified that infection with severe sepsis or septic shock is a significant risk factor for death in the intensive care unit for adult CS patients supported by VA ECMO.²¹ In the present study, patients who experienced infection during ECMO support had a poorer prognosis even after a successful weaning from ECMO, which provides further supporting evidence for the importance of efforts to prevent, monitor, and properly manage infection during ECMO. Neurologic complications, including stroke, intracranial hemorrhage, and encephalopathy, are also common and are associated with higher mortality.^{23,24} Such complications raise questions as to whether ECMO support and other life-sustaining treatments are futile, and affect decisions regarding the withdrawal of ECMO.²⁵ The results of the present study suggest that this dilemma persists even after patients are weaned off ECMO.

To the best of our knowledge, the present study is the first to provide information on the effects of complications during ECMO and extracardiac organ dysfunction at the time of weaning on clinical outcomes in CS patients who are successfully weaned off ECMO support. This study has several limitations. First, because it was a retrospective cohort study in a single center, there is a potential risk of confounding variables and selection bias. Although we followed the recommendations and protocols for weaning in the guidelines of the Extracorporeal Life Support Organization and previous studies,²⁶ we cannot exclude the possibility that decision to wean patients off ECMO was made for patients in different physiologic conditions between the survivor and non-survivor groups because there were no predefined criteria for weaning and the decision was left to the discretion of physicians. Therefore, it is difficult to rule out the concern that complications that occurred during ECMO support may have pressured physicians to proceed with weaning when patients were still in a state where cardiac function had not recovered sufficiently. Next, all patients were full code at the time ECMO was initiated, but we could not collect data changes in code status during ECMO support in this study, and the effect of limiting life-sustaining treatment on prognosis was not evaluated. Finally, our prognosis model showed sufficient predictive performance but was not validated in another population. Further investigations in larger study populations and external validation are needed before the findings of this study can be extrapolated to other populations.

Conclusions

Approximately one-quarter of patients who were success-

fully weaned off ECMO died in hospital, and sepsis and stroke during ECMO support and residual organ failure after weaning were independent predictors for in-hospital mortality. Therefore, physician needs to be aware of the need to prevent ECMO-related complications and preserve extracardiac organ function, in addition to the recovery of native cardiac function, to maximize survival to discharge of patients successfully weaned off ECMO support.

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Disclosures

The authors have no competing interests to declare.

IRB Information

This study was approved by the Institutional Review Board of Samsung Medical Center. Because of the retrospective nature of this study, the requirement for written informed consent was waived.

References

1. Werdan K, Gielen S, Ebelt H, Hochman JS. Mechanical circulatory support in cardiogenic shock. *Eur Heart J* 2014; **35**: 156–167.
2. Thiagarajan RR, Barbaro RP, Rycus PT, McMullan DM, Conrad SA, Fortenberry JD, et al. Extracorporeal Life Support Organization Registry international report 2016. *ASAIO J* 2017; **63**: 60–67.
3. Beiras-Fernandez A, Deutsch MA, Kainzinger S, Kaczmarek I, Sodian R, Ueberfuhr P, et al. Extracorporeal membrane oxygenation in 108 patients with low cardiac output: A single-center experience. *Int J Artif Organs* 2011; **34**: 365–373.
4. Formica F, Avalli L, Colagrande L, Ferro O, Greco G, Maggioni E, et al. Extracorporeal membrane oxygenation to support adult patients with cardiac failure: Predictive factors of 30-day mortality. *Interact Cardiovasc Thorac Surg* 2010; **10**: 721–726.
5. Peigh G, Cavarocchi N, Keith SW, Hirose H. Simple new risk score model for adult cardiac extracorporeal membrane oxygenation: Simple cardiac ECMO score. *J Surg Res* 2015; **198**: 273–279.
6. Carroll BJ, Shah RV, Murthy V, McCullough SA, Reza N, Thomas SS, et al. Clinical features and outcomes in adults with cardiogenic shock supported by extracorporeal membrane oxygenation. *Am J Cardiol* 2015; **116**: 1624–1630.
7. Park TK, Yang JH, Jeon K, Choi SH, Choi JH, Gwon HC, et al. Extracorporeal membrane oxygenation for refractory septic shock in adults. *Eur J Cardiothorac Surg* 2015; **47**: e68–e74.
8. Ha TS, Yang JH, Cho YH, Chung CR, Park CM, Jeon K, et al. Clinical outcomes after rescue extracorporeal cardiopulmonary resuscitation for out-of-hospital cardiac arrest. *Emerg Med J* 2017; **34**: 107–111.
9. Lemeshow S, Hosmer DW Jr. A review of goodness of fit statistics for use in the development of logistic regression models. *Am J Epidemiol* 1982; **115**: 92–106.
10. DeLong ER, DeLong DM, Clarke-Pearson DL. Comparing the areas under two or more correlated receiver operating characteristic curves: A nonparametric approach. *Biometrics* 1988; **44**: 837–845.
11. Aubron C, Cheng AC, Pilcher D, Leong T, Magrin G, Cooper DJ, et al. Factors associated with outcomes of patients on extracorporeal membrane oxygenation support: A 5-year cohort study. *Crit Care* 2013; **17**: R73.
12. Schmidt M, Burrell A, Roberts L, Bailey M, Sheldrake J, Rycus PT, et al. Predicting survival after ECMO for refractory cardiogenic shock: The survival after veno-arterial-ECMO (SAVE)-score. *Eur Heart J* 2015; **36**: 2246–2256.
13. Muller G, Flecher E, Lebreton G, Luyt CE, Trouillet JL, Bréchet N, et al. The ENCOURAGE mortality risk score and analysis of long-term outcomes after VA-ECMO for acute myocardial infarction with cardiogenic shock. *Intensive Care Med* 2016; **42**: 370–378.
14. Huang M, Ong BH, Hoo AEE, Gao F, Chao VTT, Lim CH, et

- al. Prognostic factors for survival after extracorporeal membrane oxygenation for cardiogenic shock. *ASAIO J* 2020; **66**: 141–145.
15. Koenig MA. Brain resuscitation and prognosis after cardiac arrest. *Crit Care Clin* 2014; **30**: 765–783.
16. Nikolaou M, Parissis J, Yilmaz MB, Seronde MF, Kivikko M, Laribi S, et al. Liver function abnormalities, clinical profile, and outcome in acute decompensated heart failure. *Eur Heart J* 2013; **34**: 742–749.
17. Liang KV, Williams AW, Greene EL, Redfield MM. Acute decompensated heart failure and the cardiorenal syndrome. *Crit Care Med* 2008; **36**: S75–S88.
18. Combes A, Leprince P, Luyt CE, Bonnet N, Trouillet JL, Leger P, et al. Outcomes and long-term quality-of-life of patients supported by extracorporeal membrane oxygenation for refractory cardiogenic shock. *Crit Care Med* 2008; **36**: 1404–1411.
19. O'Neill JM, Schutze GE, Heulitt MJ, Simpson PM, Taylor BJ. Nosocomial infections during extracorporeal membrane oxygenation. *Intensive Care Med* 2001; **27**: 1247–1253.
20. Sun HY, Ko WJ, Tsai PR, Sun CC, Chang YY, Lee CW, et al. Infections occurring during extracorporeal membrane oxygenation use in adult patients. *J Thorac Cardiovasc Surg* 2010; **140**: 1125–1132.e1122.
21. Schmidt M, Brechot N, Hariri S, Guiguet M, Luyt CE, Makri R, et al. Nosocomial infections in adult cardiogenic shock patients supported by venoarterial extracorporeal membrane oxygenation. *Clin Infect Dis* 2012; **55**: 1633–1641.
22. Grasselli G, Scaravilli V, Di Bella S, Biffi S, Bombino M, Patroniti N, et al. Nosocomial infections during extracorporeal membrane oxygenation: Incidence, etiology, and impact on patients' outcome. *Crit Care Med* 2017; **45**: 1726–1733.
23. Omar HR, Mirsaedi M, Mangar D, Camporesi EM. Duration of ECMO is an independent predictor of intracranial hemorrhage occurring during ECMO support. *ASAIO J* 2016; **62**: 634–636.
24. Fletcher-Sandersjoo A, Thelin EP, Bartek J Jr, Elmi-Terander A, Broman M, Bellander BM. Management of intracranial hemorrhage in adult patients on extracorporeal membrane oxygenation (ECMO): An observational cohort study. *PLoS One* 2017; **12**: e0190365.
25. Smedira NG, Moazami N, Golding CM, McCarthy PM, Apperson-Hansen C, Blackstone EH, et al. Clinical experience with 202 adults receiving extracorporeal membrane oxygenation for cardiac failure: Survival at five years. *J Thorac Cardiovasc Surg* 2001; **122**: 92–102.
26. General Guidelines for all ECLS Cases, Extracorporeal Life Support Organization. <https://www.elseo.org/resources/guidelines.asp> (assessed August 2017).

Supplementary Files

Please find supplementary file(s);
<http://dx.doi.org/10.1253/circj.CJ-20-0550>