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Original Article

Outcomes and risk factors of transported patients with extracorporeal membrane oxygenation: An ECMO center experience

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ABSTRACT

Background: Extracorporeal membrane oxygenation (ECMO) has been proven to be a support method and technology for patients with cardiopulmonary failure. However, the transport of patients under ECMO support is challenging given the high-risk technical maneuvers and patient-care concerns involved. Herein, we examined the safety of ECMO during the transport of critically ill patients and its impact on mortality rates, to provide more secure and effective transport strategies in clinical practice.

Method: To assess the safety of ECMO patient transport, this study conducted a retrospective analysis on critically ill adults who required ECMO support and transport at the intensive care unit (ICU) center between 2017 and 2023. The study utilized standard ECMO transport protocols and conducted a comprehensive statistical analysis of the collected clinical data and transport processes. The 28-day survival rate for ECMO patients was determined using Kaplan–Meier analysis, while logistic regression identified prognostic factors.

Result: Out of 303 patients supported with ECMO, 111 (36.6%) were transported. 69.4% of the transport group were male, mean age was (42.0±17.0) years, mean body mass index was (24.4±4.6) kg/m^2, and veno-arterial-ECMO accounted for 52.5%. The median transportation distance was 190 (interquartile range [IQR]: 70–260) km, and the longest distance was 8100 km. The median transit time was 180 (IQR: 100–260) min, and the maximum duration was 1720 min. No severe adverse events including death or mechanical failure occurred during transportation. The 28-day survival rate was 64.7% (n=196) and ICU survival rate was 56.1% (n=170) for the entire cohort; whereas, the 28-day survival rate was 72.1% (n=80) and ICU survival rate was 66.7% (n=74) in the transport group. A non-significant difference in 28-day survival was observed between the two groups after propensity score matching (P=0.56). Additionally, we found that acute physiology and chronic health evaluation II score (odds ratio [OR]=1.06, P <0.01), lactate levels (>5 mmol/L, OR=2.80, P=0.01), and renal replacement therapy initiation (OR=3.03, P <0.01) were associated with increased mortality risk.

Conclusion: Transporting patients on ECMO between medical facilities is a safe procedure that does not increase patient mortality rates, provided it is orchestrated and executed by proficient transport teams. The prognostic outcome for these patients is predominantly influenced by their pre-existing medical conditions or by complications that may develop during the course of ECMO therapy. These results form the basis for the creation of specialized ECMO network hubs within healthcare regions.

Introduction

Extracorporeal membrane oxygenation (ECMO) is now recognized as an important process in the treatment of severe reversible refractory respiratory or circulatory failure.[1] With the improvement of equipment and advanced technology, the use of ECMO in patients with refractory cardiopulmonary failure has increased.[2] With the widespread use of ECMO implantation in

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local hospitals, the need for transport of patients supported with ECMO is also increasing, as smaller or less experienced centers often have neither a multidisciplinary intensive care team nor an ECMO specialist team.[3] Cianchi et al.[4] reported their 8-year experience in referral centers and mobile teams and showed that there is still a significant clinical need for veno-venous (VV)-ECMO support and transport in patients with severe respiratory failure. Transport clinicians are being increasingly asked to transport patients on ECMO. Similar to the development of trauma centers and stroke centers, Vieira et al.[5] suggested the development of high-volume ECMO centers to serve the communities around them. However, the development of ECMO centers depends on safe critical transport. Recent guidelines recommend the management of these patients only in experienced centers or transportation to the closest ECMO facility.[3,4] The transportation of a patient supported with ECMO involves a series of sequential steps and is a resource-intensive operation.[6] Specialized departments provide ECMO, and these patients often have to be transferred for treatment.[7] The dawning ECMO-era with the potential of decentralizing ECMO treatment has stressed the need for research on the safety of ECMO transportation. Organizing the ECMO transport program requires an experienced on-call transport service with the ability to assess the patient, cannulate or commence ECMO on-site, and transfer the patient to a dedicated ECMO facility.[8]

Published articles in this field are increasing, but the total number of transports worldwide remains uncertain, and the majority of authors describe diminishing numbers of transports over time. Since 2018, approximately 50% of patients reported to the Extracorporeal Life Support Organization (ELSO) Registry were transported to an ECMO center. In 2022, 8.8% of pediatric and 14.7% of adult patients were transported on ECMO. Conversely, in the same year, more patients were not transported in the Asia-Pacific (AP) and the South West Asia and Africa Chapter (SWAAC) (approximately 65%).[9] Bonadonna et al.[10] have described the elements and methods of providing a safe and efficient mobile ECMO service from the perspective of an experienced, high-volume tertiary ECMO center of excellence in the southeastern USA. The characteristics and outcomes of transported patients compared with non-transported ECMO patients have been rarely reported in China, although several studies have reported their interfacility ECMO transportations and described successful outcomes.[1,3]

There is now an increased need for further research to elucidate issues in the ECMO transport process and its relative survival rate compared to non-transported patients. Therefore, the aim of this study was to provide a comprehensive overview of ECMO transports conducted by our department. The primary objective of this investigation was to assess survival rate outcomes between transported and non-transported patients receiving ECMO support.

Methods

Data source and study population

This retrospective observational study included all critically ill adult patients who received ECMO in the Department of Intensive Care Medicine of the Zhongda Hospital affiliated to Southeast University between January 2017 and December 2023. Medical records, clinical notes, and original transport protocols were collected and reviewed. Records of repeated hospitalizations and patients with missing primary ECMO-related information were excluded. Outcomes and variables associated with the prognosis were analyzed.

Transport logistics and equipment

The ECMO center of Zhongda Hospital Southeast University (Department of Critical Care Medicine) offers both VV- and veno-arterial (VA)-ECMO to all patients and for all indications. VA-ECMO should be considered under the following conditions: inadequate tissue perfusion manifested as hypotension and low cardiac output despite adequate intravascular volume; and shock persists despite volume administration, inotropes and vasoconstrictors, and intra-aortic balloon counterpulsation if appropriate. VV-ECMO should be considered under the following conditions: severe hypoxemia for at least 6 h in patients with potentially reversible respiratory failure; and uncompensated hypercapnia with acidemia (pH <7.15) despite the best accepted standard of care for management with a ventilator. The indication for VV-ECMO changed after 2018; the inclusion criteria for ECMO support (both VA and VV) are provided in Appendix 1.[11–13] The majority of transfers performed at our center are primary ECMO transportation. The process commences with an initial communication, typically a telephone exchange, between the two medical centers involved, followed by an initial assessment. Subsequently, the patient is transported to our facility for the administration of supportive therapies. Our transport team typically consists of an ECMO specialist physician, an experienced critical care physician, and an ECMO specialist nurse. The ECMO specialist physician is an experienced ECMO practitioner who often serves as the team leader and cannulation provider and oversees the overall plan execution, mission coordination, and communication with the command center. The experienced critical care physician commonly functions as a cannulation provider and ECMO caregiver, responsible for patient transportation, handling, and communication with transportation services. The ECMO specialist nurse is tasked with patient assessment and data evaluation and helps with medical stabilization and managing the ECMO circuit from implantation to arrival at the destination center. The transport team is task-specific and all members have extensive experience in ECMO support, which ensures their competence. All transport equipment is post-packaged in the storage facility at our department.

Measurements of variables

The following data were retrospectively collected: year, age, sex, height, weight, body mass index (BMI), transport distance, transit time, transport scope, primary diagnosis, comorbidities, baseline acute physiology and chronic health evaluation II (APACHE II) score, baseline sequential organ failure assessment (SOFA) score, baseline laboratory testing data, ECMO mode, continuous renal replacement therapy (CRRT) support, anticoagulation status, duration of mechanical ventilation before ECMO, intubation duration, ECMO duration, length of intensive care unit (ICU) stay, length of hospital stay, 28-day survival rate, ICU survival rate, and hospital survival rate. The primary endpoint was the 28-day survival rate.

Statistical analysis

Quantitative variables were reported as mean ± standard deviation or median (interquartile range [IQR]), while qualitative variables were recorded as percentage and frequency distribution. Mann–Whitney *U* test and chi-squared test were used to compare continuous and categorical variables, respectively. To evaluate the prognosis of ECMO-supported patients, the Kaplan–Meier method and propensity score matching were used to calculate the 28-day overall survival rate for patients. *P*-values were calculated with the log-rank test. Multivariate logistic regression models generated odds ratios (ORs) to identify factors associated with outcomes in ECMO patients. All statistical tests were two-sided, and a *P*-value <0.05 was considered to indicate statistically significant differences. All analyses were performed using R software (version 4.3.1).

Results

Patients and characteristics

This study retrospectively enrolled 111 ECMO patients transferred from regional hospitals to Zhongda Hospital affiliated to Southeast University and 192 patients without transportation from January 1, 2017, to December 31, 2023 (Supplementary Figure S1). The most common transport scope was intra-provincial transport, which accounted for 61.3%, while inter-provincial transport accounted for 15.3% and intra-city accounted for 21.6%. We also carried out two cases of transnational transport from Vietnam and Australia. Only these two were transported by fixed-wing aircraft, while the others were transported by ground ambulance; no severe adverse events including death or mechanical failure occurred in any case. The median transportation distance was 190 (IQR: 70–260) km, and the longest distance was 8100 km. The median transit time was 180 (IQR: 100–260) min and the maximum duration was 1720 min (Supplementary Figure S2).

Patients' characteristics showed some differences between the non-transport and transport groups. The mean age was (42.0±17.0) years in the transport group and (49.0±17.8) years in the non-transport group (*P* <0.01). The adult cohort (30–60 years old) accounted for 61.3% (*n*=68) of the transport group, compared to 56.8% (*n*=109) in the non-transport group. In the entire cohort, the mean height was (167.9±11.8) cm, the mean weight was (68.8±16.1) kg, and 69.6% (*n*=211) patients were male. Severe pneumonia (43.9%, *n*=133), myocarditis (16.5%, *n*=50), myocardial infarction (12.2%, *n*=37), and cardiopulmonary arrest (12.2%, *n*=37) were the common primary diagnoses in the entire ECMO cohort. There was no significant difference in ECMO type between the two groups, and VA-ECMO accounted for 52.5% of the total cohort (Table 1).

The most common comorbidities in the entire cohort were hypertension (30.7%, *n*=93), coronary heart disease (16.5%, *n*=50), diabetes (14.9%, *n*=45), and chronic heart failure (11.2%, *n*=34). However, the proportion of comorbidities in the transport group was lower than that in the non-transport group, especially with respect to chronic heart failure (4.5% *vs.* 15.1%) and hypertension (23.4% *vs.* 34.9 %) (Supplementary Table S1).

Table 1
Baseline characteristics of patients admitted to the ICU.

Variables	Overall (*n*=303)	Non-transport group (*n*=192)	Transport group (*n*=111)	*P*-value
Age (years)	47.0±17.8	49.0±17.8	42.0±17.0	<0.01
Sex				1.00
Female	92 (30.4)	58 (30.2)	34 (30.6)	
Male	211 (69.6)	134 (69.8)	77 (69.4)	
Height (cm)	167.9±11.8	167.7±11.8	168.2±11.9	0.75
Weight (kg)	68.8±16.1	68.3±15.5	69.7±17.0	0.45
BMI (kg/m^2)	24.2±4.4	24.0±4.3	24.4±4.6	0.53
Primary diagnosis				0.16
Acute cholecystitis	1 (0.3)	1 (0.5)	0 (0.0)	
Airway stenosis	4 (1.3)	3 (1.6)	1 (0.9)	
Amniotic fluid embolism	3 (1.0)	1 (0.5)	2 (1.8)	
Aortic dissection	3 (1.0)	3 (1.6)	0 (0.0)	
Cardiomyopathy	2 (0.7)	1 (0.5)	1 (0.9)	
Cardiopulmonary arrest	37 (12.2)	21 (10.9)	16 (14.4)	
Congenital heart disease	2 (0.7)	2 (1.0)	0 (0.0)	
Intestinal obstruction	1 (0.3)	1 (0.5)	0 (0.0)	
Intrauterine infection	1 (0.3)	1 (0.5)	0 (0.0)	
Multiple injury	11 (3.6)	5 (2.6)	6 (5.4)	
Myocardial infarction	37 (12.2)	27 (14.1)	10 (9.0)	
Myocarditis	50 (16.5)	30 (15.6)	20 (18.0)	
Postpartum hemorrhage	2 (0.7)	2 (1.0)	0 (0.0)	
Pulmonary embolism	8 (2.6)	2 (1.0)	6 (5.4)	
Severe asthma	1 (0.3)	0 (0.0)	1 (0.9)	
Severe pancreatitis	2 (0.7)	0 (0.0)	2 (1.8)	
Severe pneumonia	133 (43.9)	88 (45.8)	45 (40.5)	
Valvulopathy	5 (1.7)	4 (2.1)	1 (0.9)	
ECMO type				1.00
VA	159 (52.5)	101 (52.6)	58 (52.3)	
VV	144 (47.5)	91 (47.4)	53 (47.7)	

Data are expressed as mean±standard deviation or *n* (%).
BMI: Body mass index; ECMO: Extracorporeal membrane oxygenation; ICU: Intensive care unit; VA: Veno-arterial; VV: Veno-venous.

There were also differences in baseline laboratory tests upon ICU admission between the two groups. The transport group had lower hemoglobin and platelet levels, and higher prothrombin time, international normalized ratio, procalcitonin, C-reactive protein, total bilirubin, and creatinine levels than the non-transport group. The characteristics of laboratory tests in the two groups are presented in Supplementary Table S2. The median SOFA and APACHE II scores were 11.0 (IQR: 9.0–13.0) and 22.0 (IQR: 16.5–27.5) in the transport group and 10.0 (IQR: 8.0–12.0) and 24.0 (IQR: 18.0–29.0) in the non-transport group, respectively. The SOFA coagulation score and SOFA liver score were also significantly different between the two groups (Supplementary Table S3).

The overall utilization rate of heparin was 88.4%, and 42.9% of patients required CRRT support, with the median CRRT duration being 8 (IQR: 2–19) days. The median duration of mechanical ventilation (before ECMO) was 1 (IQR: 0–2) day, and the median ventilation volume (MV) duration was 8 (IQR: 3–12) days in the entire cohort (Supplementary Table S4). The 28-day survival rate was 64.7% (*n*=196) and the ICU survival rate was 56.1% (*n*=170) for the entire cohort; whereas, the 28-day survival rate was 72.1 % (*n*=80) and the ICU survival rate was 66.7% (*n*=74) in the transport group. The median duration of ECMO was 7.0 days (IQR: 4.0–11.0), while the median length of stay in the ICU and hospital were 15.0 days (IQR: 6.0–27.0) and 18 days (IQR: 9.0–31.5) respectively for the entire cohort. A minimally significant difference was found in the length of hospital stay (LOS) and ICU stay between the two groups (Table 2). In general, patients supported by VA-ECMO demonstrated significantly lower survival rates than those on VV-ECMO, both in

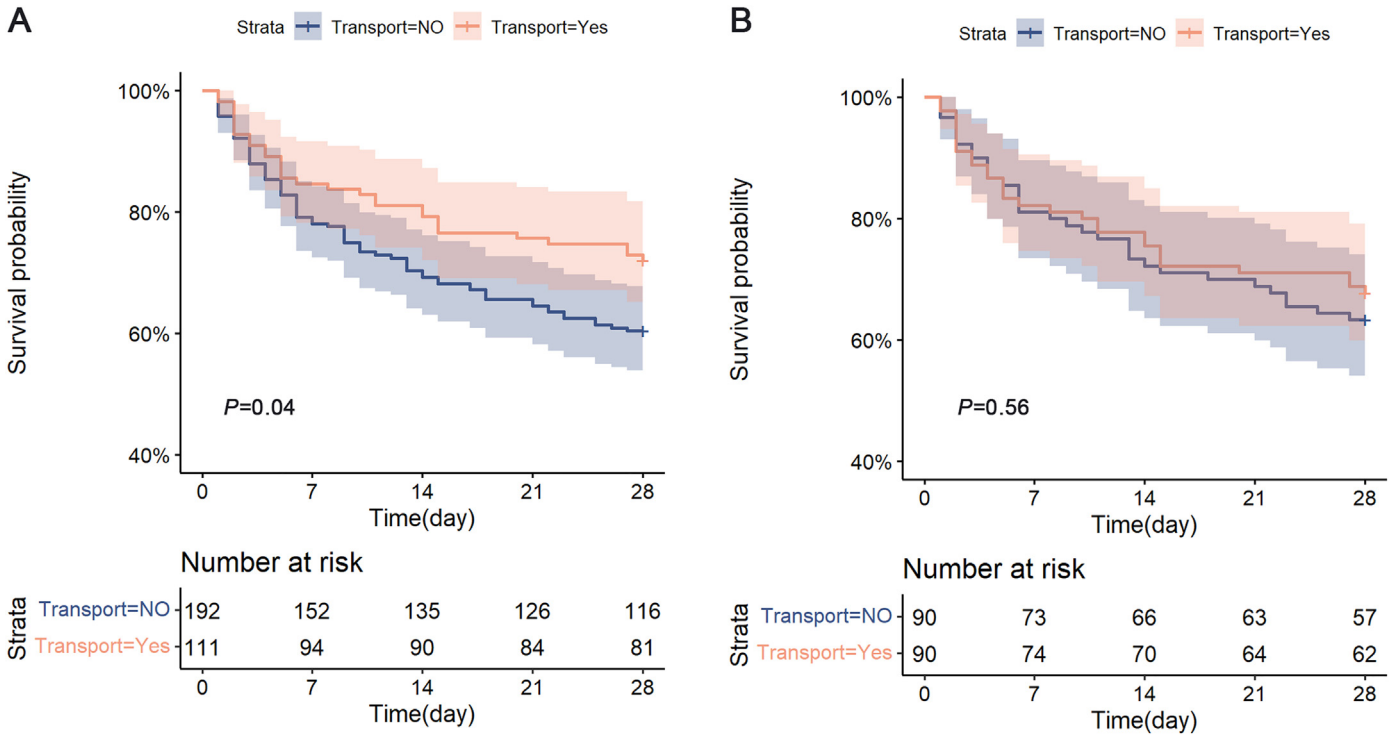

Figure 1. Kaplan–Meier survival curves before and after propensity score matching. A: The Kaplan–Meier survival curves before propensity score matching. B: The Kaplan–Meier survival curves after propensity score matching. Kaplan–Meier method was used to calculate the 28-day overall survival rate for patients, and *P*-values were calculated using the log-rank test. Propensity score matching for age, year, comorbidity, and APACHE II and SOFA scores in both groups of patients. APACHE II: Acute physiology and chronic health evaluation II; SOFA: Sequential organ failure assessment.

Table 2
The patient outcome between transport and non-transport group.

Variables	Overall (*n*=303)	Non-transport group (*n*=192)	Transport group (*n*=111)	*P*-value
28-day survival	196 (64.7)	116 (60.4)	80 (72.1)	0.06
ICU survival	170 (56.1)	96 (50.0)	74 (66.7)	0.01
ECMO duration (days)	7.0 (4.0–11.0)	7.0 (4.0–11.0)	7.0 (5.0–11.0)	0.38
LOS hospital (days)	18.0 (9.0–31.5)	18.0 (8.8–33.0)	17.0 (10.5–28.0)	0.66
LOS ICU (days)	15.0 (6.0–27.0)	14.0 (5.0–26.3)	16.0 (9.5–27.0)	0.26

Data are expressed as median (interquartile range) or *n* (%).
ECMO: Extracorporeal membrane oxygenation; ICU: Intensive care unit; LOS: Length of stay.

the entire cohort (VA-ECMO 55.3% *vs.* VV-ECMO 75.0%) and in the transport group (VA-ECMO 67.2% *vs.* VV-ECMO 77.4%) (Supplementary Table S5).

Survival outcome

Kaplan–Meier survival analysis was conducted to compare the 28-day survival rate between the two groups. We found that the 28-day survival rate of the transport group was significantly higher than that of the non-transported group (*P*=0.04; Figure 1A). Considering the inherent differences in baseline characteristics between the transport and non-transport group, we performed propensity score matching for age, year, comorbidity, and APACHE II and SOFA scores in both patient groups, with the match allocated in a 1:1 ratio (Supplementary Figure S3). Following matching, a non-significant difference in 28-day survival rate between the two groups was observed in the subsequent Kaplan–Meier survival analysis (*P*=0.56; Figure 1B).

Risk factors associated with outcome

All baseline characteristics were selected for univariable and multivariable logistic regression analysis. The results of the multivariable analysis indicated that baseline APACHE II score (OR=1.06, *P* <0.01), lactate levels (>5 mmol/L, OR=2.80, *P*=0.01), albumin (OR=0.95, *P*=0.04), anticoagulation (with heparin, OR=0.12, *P* <0.01), and initiation of CRRT (OR=3.03, *P* <0.01) were associated with mortality risk (Table 3 and Figure 2).

Discussion

Since the 20th century, advancements in equipment safety and technology have facilitated the expansion of ECMO applications to remote regions, resulting in increased prevalence of ECMO transport. In our study, over a period of 7 years, 111 patients with ECMO were transported to our ECMO center. This retrospective analysis showed that interhospital transport of patients receiving ECMO was safe, with no severe complications or deaths occurring during transport. In addition, our study has shown that the interhospital transportation of patients on ECMO is not only safe but also yielded favorable and similar early- and mid-term outcomes than patients in a propensity score-matched population, which confirms previous reports.[1,2]

In our study, the majority of these transports occurred with 52.5% of patients supported with VA-ECMO; however, the main

Table 3
Logistic regression analysis models.

Variables	Survival (*n*=196)	Death (*n*=107)	Univariable		Multivariable	
			OR (95% CI)	*P*-value	OR (95% CI)	*P*-value
Age (years)	45.1±17.4	49.4±18.3	1.01 (1.00 to 1.03)	0.05	1.01 (0.99 to 1.03)	0.29
APACHE II	20.7±7.7	27.3±7.9	1.11 (1.08 to 1.15)	<0.01	1.06 (1.02 to 1.11)	<0.01
Lac (mmol/L)						
<2	98 (50.0)	27 (25.2)	Reference		Reference	
>5	32 (16.3)	49 (45.8)	5.56 (3.00 to 10.29)	<0.01	2.80 (1.25 to 6.25)	0.01
2–5	66 (33.7)	31 (29.0)	1.70 (0.93 to 3.12)	0.08	1.62 (0.80 to 3.25)	0.18
ALB (g/L)	31.4±6.0	29.0±7.3	0.95 (0.91 to 0.98)	<0.01	0.95 (0.91 to 1.00)	0.04
Heparin						
No	6 (3.1)	29 (27.1)	Reference		Reference	
Yes	190 (96.9)	78 (72.9)	0.08 (0.03 to 0.21)	<0.01	0.12 (0.04 to 0.35)	<0.01
CRRT						
No	127 (64.8)	46 (43.0)	Reference		Reference	
Yes	69 (35.2)	61 (57.0)	2.44 (1.51 to 3.95)	<0.01	3.03 (1.62 to 5.68)	<0.01

Data are expressed as mean±standard deviation or *n* (%).
Multivariate logistic regression models generated ORs to identify factors associated with outcomes in ECMO patients.
ALB: Albumin; APACHE II: Acute physiology and chronic health evaluation II; CRRT: Continuous renal replacement therapy; CI: Confidence interval; ECMO: Extracorporeal membrane oxygenation; Lac: Lactate; NA: Not available; ORs: Odds ratios.

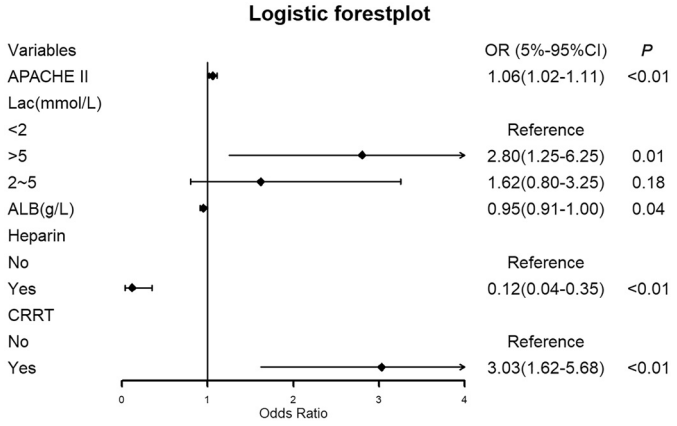

Figure 2. Forest plot of logistic analysis associated with 28-day survival rate.
ALB: Albumin; APACHE II: Acute physiology and chronic health evaluation II; CI: Confidence interval; CRRT: Continuous renal replacement therapy; Lac: Lactate; OR: Odds ratio.

primary diagnosis and ECMO type did not differ significantly between the transport and non-transport groups. Importantly, patients supported by VA-ECMO exhibited significantly lower survival rates than those receiving VV-ECMO. In general, patients in the transport group had worse laboratory measures on admission to the central ICU, which may be related to the initiation of ECMO and fatigue during transport. Nevertheless, the main laboratory measures that differed statistically between the two groups did not affect survival rate. Patients in our cohort had a high level of SOFA and APACHE II scores on arrival at the ICU. Despite their critical condition, no severe adverse events including death or mechanical failure occurred during the transport, and the 28-day survival rate was 72.1%. Despite the absence of adverse events during transport in our study, ECMO transport has potential risks for numerous adverse events. Barrigoto et al.[14] categorized the adverse events as related to the patient, equipment, staff, or vehicle. The implementation of a checked-list system, equipment simplification, and the use of a dedicated ambulance equipped for ECMO transports decreased the number of complications. The presence of a solid experienced staff allowed us to promptly overcome the severe, non-preventable complications. Our transport team often comprises an ECMO specialist physician, an experienced intensive care physician, and an ECMO specialist nurse. In previous ECMO transport studies, the transport team was mostly composed of 3–4 clinicians and nurses. Interestingly, in a retrospective cohort study of the transport of patients with ECMO, there was no correlation between the overall incidence of major adverse events during transport and the presence or absence of an additional clinician.[15] Furthermore, another retrospective observational cohort study showed that the initiation of ECMO with subsequent transport by a two-person team was safe and efficient, with a good prognosis.[16] Although transport-related complications were not documented in detail in this study, most studies have shown that severe complications during transportation seem to be preventable, easily resolved, and do not affect ICU mortality, thereby indicating that complications during transportation are often managed effectively.[17,18]

In our research, the 28-day survival rate showed no significant difference between the two propensity score-matched groups (68.8% [*n*=62] in the transport group *vs.* 63.3% [*n*=57] in the non-transport group, *P*=0.56; Figure 2). These results are consistent with or slightly superior to the Extracorporeal Life Support Organization Registry International Report 2022 (survival rate to hospital discharge was 57.0% [27,701/48,338] for adult respiratory, 44.0% [20,264/45,830] for adult cardiac, and 30.0% [4162/14,097] for adult Extracorporeal Cardiopulmonary Resuscitation).[9] In a natural experiment, death before hospital discharge occurred in 15 (42.9%) of the 35 patients for whom health system capacity permitted transfer to receive ECMO at a specialized center compared with 49 (89.1%) of the 55 patients for whom the health system capacity did not permit transfer to receive ECMO.[19] Multiple studies have reported an overall ICU survival rate of 44.0%–86.0% in ECMO transport cohorts, with lower survival rates in adults than in pediatric and neonatal populations.[20,21] In line with previous studies, the ICU survival rate of the transport group was 66.7% in our mixed cohort. Bryner et al.[22] reported an adult survival-to-discharge rate of 55.0% in a mixed cohort of 52.0% VA-ECMO and 48.0% VV-ECMO patients. Prior to matching baseline characteristics, patients in the transport group had a higher rate of survival

than those in the non-transport group. However, after matching the two groups for year, age, comorbidity, and APACHE II and SOFA scores, the 28-day survival rate of patients in the transport group was still higher than that in the non-transport group, but the difference was not statistically significant.

Overall, it could be seen that patients in the transport group were younger, had fewer comorbidities, and had lower APACHE II scores than those in the non-transport group. However, there was no significant difference in survival rate between the two groups after matching scores, indicating that ECMO transport is safe and feasible when overseen by an experienced team. Unfortunately, we were not able to determine the survival rate of patients who refused transport from low-volume centers. In a retrospective analysis from France, patients who were denied ECMO transport to a high-volume ECMO center only on account of being >65 years old or because of being on mechanical ventilation for >10 days at the time of referral had mortality rates of 84.0%.[23]

Duration of mechanical ventilation and ECMO support and length of ICU and hospital stay did not differ significantly between patients transported with ECMO and patients receiving ECMO directly at the centers. This is consistent with the results of the study by Mang et al.[18] The ECMO type in our cohort was more homogeneously distributed, but their primary population was patients with acute respiratory distress syndrome. The median duration of overall ECMO support in our cohort was 7.0 days (IQR: 4.0–11.0), which is generally consistent with data reported by the ELSO in 2022.[9]

One of the main factors in the success of an ECMO transport program is experience. Our center maintains an average ECMO transport number of 15 patients per year. In addition, a good collaborative relationship between the ECMO center and the surrounding hospitals and departments is essential for timely intervention and to ensure a high level of treatment.[24] The use of ECMO for rescue missions requires a high level of labor and resource commitment. The individuals involved must possess expertise in prehospital emergency medicine, critical care, ECMO physiology, ECMO technology, and ECMO cannulation. Our cohort included 109 ECMO transports conducted mainly by ambulance (109/111, 98.2%) and two ECMO transports conducted by fixed-wing aircraft involving long distances. In 2015, a large US study of 322 ECMO transports found that 60.0% of patients were transported by air, with distances ranging from 6.9 km to 13,477 km. However, because China has a high density of ECMO centers, medical transportation beyond 400 km is rarely necessary. In our research, the maximum inter-hospital transfer distance for ECMO patients within China was 396 km, with a maximum transfer duration of 320 min. Importantly, the mode of transportation did not impact the incidence of complications during ECMO transport, and there was no statistically significant disparity in mortality rates between transported and hospitalized patients.[25] We also included two cases of international transport by fixed-wing aircraft with the farthest distance of 8100 km and a duration of 1720 min. No serious adverse events occurred during the transport, and the two patients were discharged successfully. Nevertheless, it should be noted that there are potential implications with respect to expanding ECMO support in the future to those being treated at facilities away from large-volume ECMO centers.[26]

The severity and nature of patients' illnesses are important factors affecting the survival rate of transported patients. The logistic regression model showed that APACHE II score, lactate levels, and CRRT utilization were associated with mortality risk. Patient survival rate under ECMO treatment in the literature has been reported in a relatively heterogeneous manner, which might be explained by various factors. The severity of lactic acidosis is a marker of hypoperfusion associated with higher mortality in patients including those receiving ECMO. A previous study showed that while a lactate level of >2.2 mmol/L was associated with increased mortality (OR=4.94, 95% confidence interval: 1.41 to 17.39), a lactate level of >7.7 mmol/L was associated with a 12-fold significantly increased mortality (OR=12.61, 95% confidence interval: 3.62 to 43.96).[27] Furthermore, the absolute level of lactic acid while on ECMO support is more important for prognosis than a pre-ECMO level or the magnitude of decline from pre-ECMO to on-ECMO.[28] We also observed particularly poor outcomes for patients who received CRRT, consistent with previous studies. Acute renal failure necessitating CRRT has been identified as a risk factor for mortality in patients who receive ECMO. Notably, as highlighted in the previously mentioned studies, CRRT should not be considered a direct cause of death. Instead, it serves as an indicator of critical illness and is associated with relatively poor prognosis in these patients.[29] ICU scoring systems, such as the SOFA and APACHE II scores, have been validated as prognostic tools to predict mortality in severely ill ICU patients. However, the prognostic value of these scoring systems to predict poor outcome seems rather limited in patients supported with ECMO.[30]

In the present study, we were unable to detect a significant difference in SOFA admission scores between survivors and non-survivors. However, a higher APACHE II admission score can be a risk factor for mortality. Our research indicates that patients who use heparin anticoagulation are associated with a lower risk of mortality. This may be linked to the fact that patients without anticoagulation therapy have more severe underlying conditions and a significantly higher risk of bleeding. Additionally, there is a substantial difference in the proportion of patients receiving anticoagulation compared to those who do not, resulting in a higher bias. Further studies are needed to confirm the impact of anticoagulation on the prognosis of ECMO patients. In our study, survival rate is dependent on multiple variables but ECMO transportation is not a predictor related to 28-day survival rate, as revealed by earlier studies.[3]

The most recent guidelines on transportation do not provide any indication regarding the specific populations that are most likely to derive benefits from ECMO transport.[31] In this study, higher APACHE II scores were independently associated with ECMO mortality, but there was no independent correlation between SOFA scores and ECMO mortality. Therefore, this suggests that a combination of multiple prognostic scores should be employed for patient assessment. Prolonged MV before ECMO has been known as a poor prognostic factor of in-hospital mortality. Based on clinical observation, Wu et al.[32] proposed a 7-day period as an acceptable limit on MV time before institution of VV-ECMO, compared to the patients receiving MV for ≤7 days; the patients receiving MV for >7 days before ECMO showed a higher in-hospital mortality rate (77.0% *vs.* 38.0%, P <0.001). A retrospective observational study showed that the OR for all-cause 28-day mortality and in-hospital mortality was

significantly reduced in patients who received VV-ECMO within the first 5 days of MV.[33] In our study, the median duration of MV before ECMO was 1 day, and multivariate analysis did not show an association with a high mortality risk, which may suggest the importance of early ECMO initiation after receiving MV. In short, our results suggest a feasible benefit of ECMO support in the above subgroups of critically ill patients who have exhausted all other possibilities and are too unstable to endure conventional transport. Furthermore, coronavirus disease 2019 (COVID-19) cases were not specifically segregated for subgroup analysis in our study because, according to Blanco-Schweizer et al.'s [34] study, no significant difference in ECMO transport outcomes was noted between COVID-19 and non-COVID-19 patients. In addition, although few of the patients enrolled at our center were transported for heart-lung transplantation, the study by Yeo et al.[35] showed that transportation with ECMO to a transplantation center is an effective strategy for rescuing patients with cardiopulmonary failure who may require transplantation, thereby providing an additional means of improving their chances of survival.

This study has several strengths. First, our research represents a comprehensive analysis of 7 years of ECMO experience, constituting one of the largest cohorts delineating ECMO transports in China, elucidating the characteristics and outcomes of transported patients. Second, we performed propensity score matching for patient outcomes and examined risk factors associated with survival rate, suggesting that transportation did not prominently influence prognosis and that pre-existing factors or conditions during ECMO treatment may play a more significant role in determining patient outcomes. Our findings highlight the importance of retrospective analysis of patient data from centers to identify the necessity of ECMO transport and to develop protocols for safe ECMO transport. Importantly, this retrospective clinical study was conducted with the aim of demonstrating clinical efficacy and favorable prognosis of ECMO patients, summarizing experiences, and laying the groundwork for the establishment of a regional ECMO center. Consequently, these centers facilitate collaboration among healthcare providers, promote standardized practices, and enhance research opportunities to advance ECMO-related knowledge and treatment protocols.

The study also has a few limitations: First, this was a retrospective and non-randomized study performed at a single hospital and hence, the conclusions drawn from our cohort may not be generalizable to other centers. However, our institution is a regional ECMO center serving a province and surrounding areas with a diverse population of more than 14 million. Second, the matching of two groups by propensity scores may have improved comparability between groups at the cost of statistical power. Third, the sample size related to the use of a convenience sample may have been insufficient to detect a significant difference in transport-related complications because of insufficient statistical power. Fourth, there was a lack of pre-ECMO data for transported patients; therefore, the ICU admission clinical indices formed the foundational data for the two groups, and patients with VA-ECMO lacked the duration from shock to ECMO initiation, but the severity of illness scores was used to match survival rate comparisons. Further experiences are needed to better characterize long-term follow-up beyond hospital discharge and the inability to report on longitudinal complications of these transports and draw insightful conclusions.

Conclusions

In this single-center, retrospective study, patients who underwent cannulation and retrieval by an ECMO transport team did not exhibit a higher risk than patients who received ECMO treatment at established ECMO centers in China. The majority of transported patients (72.1 %) survived beyond 28 days. Patients deemed suitable for ECMO without contraindications should be promptly referred to local ECMO centers. This conclusion provides valuable insights for guiding future ECMO transport strategies and techniques, thereby paving the way for the establishment of a regional ECMO center.

CRediT Authorship Contribution Statement

Lingjuan Liu: Writing – original draft, Software, Methodology, Formal analysis, Data curation. **Dingji Hu:** Supervision, Investigation, Conceptualization. **Tong Hao:** Project administration, Formal analysis, Conceptualization. **Shanshan Chen:** Methodology, Investigation, Data curation, Conceptualization. **Lei Chen:** Formal analysis, Data curation. **Yike Zhu:** Investigation, Data curation. **Chenhui Jin:** Formal analysis, Data curation. **Jing Wu:** Formal analysis, Data curation. **Haoya Fu:** Formal analysis, Data curation. **Haibo Qiu:** Supervision, Funding acquisition. **Yi Yang:** Supervision, Funding acquisition. **Songqiao Liu:** Writing – review & editing, Visualization, Supervision, Project administration, Funding acquisition, Conceptualization.

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Ethics Statement

The study was conducted in accordance with the Declaration of Helsinki and was approved by the Ethics Committee of Zhongda Hospital Affiliated to Southeast University approved this study (2022ZDSYLL177-P01). Informed consents were waived due to the retrospective observational study design requiring no intervention and posing no impact on the diagnosis and treatment of patients. STROBE recommendations were followed.

Conflict of Interest

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and publication of this article.

Data Availability

The data sets generated during and/or analyzed during the current study are available from the corresponding author upon reasonable request.

Supplementary Materials

Supplementary material associated with this article can be found in the online version at doi:10.1016/j.jointm.2024.04.003.

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