



# Outcomes of Urgent Interhospital Transportation for Extracorporeal Membrane Oxygenation Patients

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## ARTICLE INFO

**Received** July 6, 2022  
**Revised** September 28, 2022  
**Accepted** October 2, 2022

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**Background:** Extracorporeal membrane oxygenation (ECMO) can be used in patients with refractory cardiogenic shock or respiratory failure. In South Korea, the need for transporting ECMO patients is increasing. Nonetheless, information on urgent transportation and its outcomes is scant.

**Methods:** In this retrospective review of 5 years of experience in ECMO transportation at a single center, the clinical outcomes of transported patients were compared with those of in-hospital patients. The effects of transportation and the relationship between insertion-departure time and survival were also analyzed.

**Results:** There were 323 cases of in-hospital ECMO (in-hospital group) and 29 cases transferred to Hallym University Sacred Heart Hospital without adverse events (mobile group). The median transportation time was 95 minutes (interquartile range [IQR], 36.5–119.5 minutes), whereas the median transportation distance was 115 km (IQR, 15–115 km). Transportation itself was not an independent risk factor for 28-day mortality (odds ratio [OR], 0.818; IQR, 0.381–1.755;  $p=0.605$ ), long-term mortality (OR, 1.099; IQR, 0.680–1.777;  $p=0.700$ ), and failure of ECMO weaning (OR, 1.003; IQR, 0.467–2.152;  $p=0.995$ ) or survival to discharge (OR, 0.732; IQR, 0.337–1.586;  $p=0.429$ ). After adjustment for covariates, no significant difference in the ECMO insertion-departure time was found between the survival and mortality groups ( $p=0.435$ ).

**Conclusion:** The outcomes of urgent transportation, with active involvement of the ECMO center before ECMO insertion and adherence to the transport protocol, were comparable to those of in-hospital ECMO patients.

**Keywords:** Extracorporeal membrane oxygenation, Patient transfer, Cardiogenic shock, Respiratory insufficiency

## Introduction

Extracorporeal membrane oxygenation (ECMO) can be employed as a life-saving procedure in patients with refractory cardiogenic shock or respiratory failure [1]. Its application has considerably increased as its indications have broadened. Nonetheless, the number of specialized centers that can efficiently provide ECMO remains inadequate because ECMO management requires skilled experts and resources. Due to these limitations, transportation to specialized centers is necessary in certain situations.

Bartlett et al. [2] first described ECMO transportation in 1977. Since then, more centers have provided transporta-

tion for ECMO [3]. In South Korea, the number of ECMO transportation cases has increased since 2004; however, few studies have investigated ECMO transportation in South Korea [4-6]. The coronavirus disease 2019 outbreak in South Korea has recently increased the demand for ECMO transportation, further aggravating the burden of the lack of specialized ECMO centers. In order to provide efficient ECMO care, it is recommended that patients be transferred to a high-volume center if possible [7]. In some hospitals that are not ready for ECMO management, short-term care for patients on ECMO can become a burden. Therefore, appropriately selected patients should be transported to a specialized center as soon as possible for effi-



cient ECMO treatment [8]. Globally, several centers have reported positive clinical outcomes, implying that the interhospital transportation of ECMO patients is reasonable [3,9]. Nevertheless, no studies have investigated the timing of transportation after ECMO insertion.

In this study, we hypothesized that the urgent transportation of patients on ECMO (i.e., transporting patients as soon as possible after ECMO insertion without waiting for stabilization, within 48 hours from ECMO insertion) from affiliated hospitals to specialized ECMO centers is clinically reasonable. We reviewed our interhospital ECMO transportation experience and the compared clinical characteristics and survival outcomes of mobile (i.e., transported) ECMO patients with in-hospital ECMO patients. In addition, we reviewed the correlation between the time taken from ECMO insertion to transportation and survival.

## Methods

### Patients

The study was approved by the institutional review board of Hallym University Sacred Heart Hospital (IRB no., 2022-03-018-001). The requirement for obtaining informed consent from patients was waived because of the retrospective nature of this study. Overall, 386 patients were treated with ECMO at Hallym University Sacred Heart Hospital between January 2017 and December 2021. We excluded 34 cases: 4 cases that were transferred by other medical teams without conforming to the protocol, 6 cases that were transferred to other hospitals before the completion of treatment, 2 cases because of refusal of further treatment by the patient's family against medical advice, and 22 cases with incomplete medical records. In total, 352 patients were included in this study. The patients were divided into 2 groups: 29 patients who were transported to our center from another center by our transportation team (mobile group) and 323 patients who were started on ECMO at our center (in-hospital group). Patients' characteristics and clinical outcomes after transportation were retrospectively reviewed based on their medical records. The primary outcome was 28-day survival and the secondary outcome was ECMO weaning time depending on whether transportation was performed. Long-term survival and morbidity were also analyzed.

### Transportation protocol

As a specialized ECMO center among the 5 affiliated

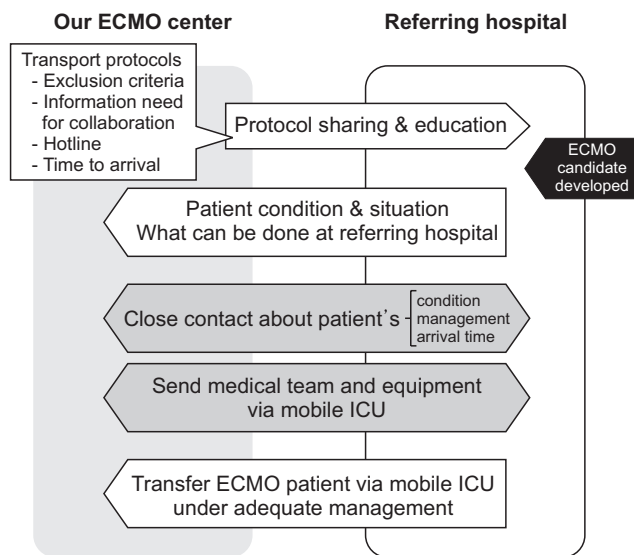
hospitals of the Hallym University Medical Center and as a tertiary general hospital, the Hallym University Medical Center has been requested to accept ECMO patients. In 2017, we developed our own mobile ECMO team, established our own ECMO transport protocol, and started transporting patients from referring hospitals.

Urgent transportation refers to transporting ECMO patients as soon as possible (within 48 hours from ECMO insertion). The most important factor in urgent transportation is to transfer the patient as soon as possible after he or she is stabilized after ECMO insertion at the referring hospital. Our urgent transport protocol emphasizes prompt communication between clinicians from each hospital and active intervention from the ECMO center to the referring hospital before ECMO insertion.

The protocol provided to the referring hospital included the following information: absolute exclusion criteria, including poor life expectancy (old age, malignant tumor, end-stage peripheral-organ disease, etc.), severe neurologic impairment, and systemic bleeding; the time required for our team's arrival; what information should be shared with us, including the patient's status (vital signs, medical history, lab results, and general information); and a hotline number that can be used to contact us at any time for any ECMO-related purpose.

ECMO transportation was initiated after consultation with the referring hospital's medical team. After a request was received, our ECMO team's physician discussed the patient's status, including the reasonableness of ECMO indication and the type of ECMO, with the referring hospital's physician and then decided whether transportation was appropriate. In addition, it was decided whether cannulation should be performed by the referring hospital's medical team or by our ECMO team upon arrival. The former was referred to as "secondary transportation," whereas the latter was regarded as "primary transportation" based on the Extracorporeal Life Support Organization (ELSO) guidelines [10].

When it was confirmed that a patient was confirmed would be transported, we set the transfer time and initiated the transport protocol. Our mobile ECMO team prepared the ECMO machine, including all necessary equipment, and departed to the referring hospital as soon as possible (Fig. 1). Usually, we prefer using permanent life support (PLS) (Quadrox; Cardiomedic, Munro, Argentina) and Cardiohelp (Getinge, Gothenburg, Sweden) as oxygenators. The PLS (Quadrox) was the preferred ECMO pump system because the frame in the ambulance bed for fixation of the ECMO system and oxygenator is suitable for



**Fig. 1.** Detailed description of our transportation protocol. ECMO, extracorporeal membrane oxygenation; ICU, intensive care unit.

PLS and Cardiohelp. If the referring hospital’s patient used the PLS system, the device was simply changed. However, if the patient was on an emergency bypass system (CAP-IOX; Terumo, Tokyo, Japan), the circuit was changed for stable fixation to the frame in ambulatory circumstances. The circuit change was performed by our mobile ECMO team.

We prepared a sufficient amount of intravenous fluids, including crystalloids and colloids, as well as blood for transfusion (particularly packed red blood cells) for volume loss, which might occur when changing the ECMO circuit. Intravenous medicines, including inotropes and sedative fluids, were prepared with an infusion pump. The ambulance for ECMO transport also possesses a portable ventilator; oxygen gas; an aseptic surgical set for several procedures; and a monitor to continuously assess oximetry, electrocardiography, non-invasive blood pressure, and invasive line pressure (e.g., an arterial line or central venous pressure line).

The 5 hospitals affiliated with the Hallym University Medical Center are located in Seoul as well as the Gyeonggi and Gangwon Provinces. The hospital with the greatest distance from Hallym University Sacred Heart Hospital in Pyeongchon, Gyeonggi Province is located in Chuncheon, Gangwon Province, 115 km away. Hence, ambulance transportation was chosen as the primary mode of transportation between hospitals as recommended by the ELSO guidelines for distances of up to 400 km [10]. Helicopter transportation was not considered owing to a lack of

equipment and facilities. We used our hospital’s ambulance, named the “Mobile ICU,” which specializes in transporting critically ill patients. Our transportation team comprised 2 cardiothoracic surgeons, 1 clinical perfusionist with nursing experience, 1 nurse, and 1 ambulance driver.

### Statistical analysis

All data were based on records from the affiliated hospitals of the Hallym University Medical Center. Continuous variables are presented as median (interquartile range [IQR]) or mean (standard deviation [SD]), and the Wilcoxon rank-sum test was used to analyze the differences between the in-hospital and mobile groups. Categorical variables are expressed as sample number (%), and the associations with transportation (in-hospital group versus mobile group) were analyzed using the chi-square test or the Fisher exact test.

The association between risk factors and short-term outcomes (i.e., ECMO weaning, 28-day survival, and survival to discharge) was examined using the chi-square test or Fisher exact test. For the analysis of the independent effect of risk factors on death or complications, multivariable binary logistic regression analysis that included variables with p-values <0.2 in the univariable analysis was performed. Long-term survival was evaluated by Kaplan-Meier survival analysis. The Cox proportional-hazard model was used to identify differences in long-term survival between the in-hospital and mobile groups.

For the mobile group data, analysis of covariance (ANCOVA) was used to determine whether the ECMO insertion–departure time was equivalent between the surviving and deceased groups while statistically controlling for covariates such as body mass index (BMI), ECMO flow, initial ECMO type, and length of hospital stay (in days). All statistical analyses were performed using R ver. 4.1.2 (R Foundation for Statistical Computing, Vienna, Austria), IBM SPSS Statistics ver. 27.0 (IBM Corp., Armonk, NY, USA), and T&F ver. 4.0 (YooJin BioSoft, Goyang, Korea).

## Results

### Demographics

The ECMO team of the Hallym University Sacred Heart Hospital completed ECMO management in 352 patients between January 2017 and December 2021. A total of 323 patients were not transported (in-hospital group) and 29

patients were transported (mobile group) to our institution. The median follow-up duration was 27.5 days (IQR, 7–199.75 days). The median patient age was 58 years (IQR, 49–68 years) in the in-hospital group and 58 years (IQR, 47–63.5 years) in the mobile group ( $p=0.372$ ). The initial ECMO type was classified as venoarterial (VA) and venovenous (VV), and venoarterial–venous cases were considered as VA. In both groups, VA ECMO was performed more frequently than VV ECMO, accounting for 77.7% ( $n=251$ ) and 72.4% ( $n=21$ ) of patients in the in-hospital and mobile groups, respectively. To compare baseline severity between the in-hospital and mobile groups, the Survival After Veno-Arterial ECMO (SAVE) risk score, which was introduced by Schmidt et al. [11], and the Respiratory ECMO Survival Prediction (RESP) risk score, which was introduced by Schmidt et al. [12], were used for the VA ECMO group and the VV ECMO group, respectively. The mean $\pm$ SD SAVE score was  $3.86\pm 0.846$  and  $3.81\pm 0.750$  ( $p=0.798$ ) in the in-hospital and mobile groups, respectively. The mean $\pm$ SD RESP score was  $2.51\pm 0.908$  and  $3.00\pm 1.095$  ( $p=0.752$ ) in the in-hospital and mobile groups, respectively. The most common indication for ECMO was cardiogenic shock without cardiac arrest and acute respiratory failure in the in-hospital and mobile groups, respectively.

In both groups, cardiac arrest was the second most common indication for ECMO. The next most common indications included septic shock, trauma, post-cardiotomy status, pulmonary embolism, other ECMO-assisted surgery, and bridge to transplantation. The baseline characteristics of both groups are detailed in Table 1.

## Transportation results

All transports were conducted via an ambulance. The median transportation time was 95 minutes (IQR, 36.5–119.5 minutes), and the median transportation distance was 115 km (IQR, 15–115 km). No adverse events, including death or mechanical failure, occurred. Three patients were cannulated by our team (i.e., primary transportation), whereas 26 patients were cannulated by the referring hospital's medical team (i.e., secondary transportation). The median insertion–departure time, defined as the time from ECMO insertion to transfer departure, was 165 minutes (IQR, 94.75–307.5 minutes) (Table 2).

**Table 1.** Baseline characteristics of patients in the in-hospital and mobile groups

Characteristic	In-hospital (n=323)	Mobile (n=29)	p-value
Sex (male)	235 (72.8)	23 (79.3)	0.586
Age (yr)	58 (49–68)	58 (47–63.5)	0.372
Body mass index (kg/m <sup>2</sup> )	23.99 (22.04–26.26)	23.88 (20.67–26.12)	0.357
Hypertension	142 (44)	10 (34.5)	0.429
Diabetes mellitus	92 (28.5)	7 (24.1)	0.777
Coronary artery disease	27 (8.4)	1 (3.4)	0.716
Cerebrovascular accident	18 (5.6)	2 (6.9)	0.675
Chronic kidney disease	17 (5.3)	1 (3.4)	1.000
Initial ECMO type (VA)	250 (77.4)	21 (72.4)	0.541
Reasons for ECMO			0.553
Cardiogenic shock without cardiac arrest	107 (33.2)	7 (24.1)	
Cardiac arrest	99 (30.7)	9 (31)	
Acute respiratory failure	74 (23)	10 (34.5)	
Septic shock	25 (7.8)	1 (3.4)	
Trauma	3 (0.9)	0 (0)	
Post-cardiotomy	4 (1.2)	0 (0)	
Pulmonary embolism	5 (1.6)	1 (3.4)	
Others	5 (1.5)	1 (3.4)	
Cannulation on CPR (extracorporeal CPR)	87 (26.9)	7 (24.1)	0.744
SAVE score (VA cases)	$3.86\pm 0.846$	$3.81\pm 0.750$	0.798
RESP score (VV cases)	$2.51\pm 0.908$	$3.00\pm 1.095$	0.752

Values are presented as number (%) for categorical variables and median (interquartile range) or mean $\pm$ standard deviation for continuous variables. ECMO, extracorporeal membrane oxygenation; VA, venoarterial; CPR, cardiopulmonary resuscitation; SAVE, Survival After Veno-Arterial Extracorporeal Membrane Oxygenation; RESP, Respiratory Extracorporeal Membrane Oxygenation Survival Prediction; VV, venovenous.

### Comparison of outcomes between the in-hospital and mobile groups

The median ECMO duration was significantly different between the 2 groups (13 days [IQR, 7–23 days] in the in-hospital group versus 9 days [IQR, 6–13 days] in the mobile group;  $p=0.026$ ). A significant difference was also found in the median duration of the intensive care unit (ICU) stay (23 days versus 15 days) and hospital stay (31 days versus 16 days) ( $p<0.001$ ). The median initial ECMO flow was 3.5 L/min (IQR, 3.1–4 L/min) in the in-hospital group and 3.2 L/min (IQR, 2.7–4 L/min) in the mobile group ( $p=0.032$ ).

Overall, 145 (44.9%) and 13 (44.8%) patients were weaned from ECMO in the in-hospital and mobile groups, respectively. We found that 162 (50.2%) and 16 (55.2%) patients

survived for 28 days in the in-hospital and mobile groups, respectively. The number of patients who survived to discharge was 110 (34.1%) and 12 (41.4%) in the in-hospital and mobile groups, respectively. There were no significant differences between the 2 groups with respect to the number of patients weaned from ECMO, 28-day survival, and survival to discharge ( $p=0.995$ ,  $p=0.605$ , and  $p=0.427$ , respectively). There were no significant differences in the majority of complications, including acute kidney injury, leg ischemia, gastrointestinal bleeding, cannulation-site bleeding, and pneumonia, between the 2 groups. The detailed outcomes of both groups are summarized in Table 3.

### Effects of transportation and risk factors on outcomes

Binary logistic regression analysis was performed to delineate risk factors affecting 28-day survival. An additional analysis of risk factors for ECMO weaning and survival to discharge was performed.

In the univariable analysis, VA ECMO and extracorporeal cardiopulmonary resuscitation (ECPR) were significantly associated with a higher risk of 28-day mortality (odds ratio [OR], 3.173; IQR, 1.851–5.441;  $p<0.001$  and OR, 2.372; IQR, 1.453–3.871;  $p=0.001$ , respectively). The  $p$ -values for female sex and hypertension were under 0.200. After multivariable binary logistic regression analysis including the variables with  $p$ -value under 0.200, VA ECMO and ECPR were still found to be significant risk factors for 28-

**Table 2.** Transportation characteristics

Variable	Value
Transportation time (min)	95 (36.5–119.5)
Transportation distance (km)	115 (15–115)
Insertion–departure time (min)	165 (94.75–307.5)
Complications during transportation	0
Transportation type	
Primary	3 (10.3)
Secondary	26 (89.7)

Values are presented as median (interquartile range) or mean±standard deviation for continuous variables and number (%) for categorical variables.

**Table 3.** Clinical outcomes

Variable	In-hospital (n=323)	Mobile (n=29)	p-value
ICU stay (day)	23 (10–41)	15 (6.5–17)	<0.001
Hospital stay (day)	31 (15–53)	16 (6.5–24.5)	<0.001
ECMO duration (day)	13 (7–23)	9 (6–13)	0.026
Complications			
Acute kidney injury	154 (47.7)	15 (51.7)	0.823
Hyperbilirubinemia	88 (27.2)	7 (24.1)	0.887
Leg ischemia	25 (7.7)	4 (13.8)	0.281
Gastrointestinal bleeding	31 (9.6)	1 (3.4)	0.496
Intracranial hemorrhage	13 (4)	2 (6.9)	0.355
Pneumonia	190 (58.8)	17 (58.6)	1.000
Positive blood culture	139 (43)	9 (31)	0.290
Cannulation-site bleeding	8 (2.5)	2 (6.9)	0.195
Outcomes of ECMO weaning and survival			
ECMO weaning	145 (44.9)	13 (44.8)	0.995
28-Day survival	162 (50.2)	16 (55.2)	0.605
Survival to discharge	110 (34.1)	12 (41.4)	0.427

Values are presented as median (interquartile range) or mean±standard deviation for continuous variables and number (%) for categorical variables. ICU, intensive care unit; ECMO, extracorporeal membrane oxygenation.



day mortality (OR, 2.553; IQR, 1.446–4.508;  $p=0.001$  and OR, 1.785; IQR, 1.059–3.007;  $p=0.030$ , respectively) (Table 4).

The same method was applied to the additional analysis of risk factors for ECMO weaning failure and survival to discharge.

ECPR was significantly associated with ECMO weaning failure (OR, 1.633; IQR, 1.004–2.656;  $p=0.048$ ). The  $p$ -values for hypertension, diabetes mellitus, cerebrovascular accident, and VA ECMO were under 0.200 ( $p=0.143$ ,  $p=0.186$ ,  $p=8.169$ , and  $p=0.152$ , respectively). After these variables were included in the multivariable binary logistic regression analysis, ECPR was no longer a significant risk factor for ECMO weaning failure (OR, 1.464; IQR, 0.871–2.461;  $p=0.150$ ).

For survival to discharge, age was a risk factor (OR, 1.024; IQR, 1.009–1.039;  $p=0.002$ ), and ECPR was the only variable with a  $p$ -value under 0.200 (OR, 1.550; IQR, 0.924–2.601;  $p=0.097$ ). In multivariable binary logistic regression analysis, age was still found to be a significant risk factor (OR, 1.026; IQR, 1.010–1.042;  $p=0.001$ ). In the analyses, mobile transportation did not influence ECMO weaning, 28-day survival, and survival to discharge.

Kaplan-Meier survival analysis was conducted to analyze long-term survival, and a Cox proportional-hazard model was used to compare long-term survival between the mobile and in-hospital groups. No significant difference was found between the groups (Kaplan-Meier log-rank test:  $p=0.758$ ; Cox-proportional hazard model: OR, 1.099; IQR, 0.680–1.777;  $p=0.700$ ) (Fig. 2).

### Relationship between the insertion–departure time and outcome

In order to determine the correlation between the time from ECMO insertion to the start of transfer and survival, patients in the mobile group were divided into surviving and deceased groups, and a subgroup analysis was performed. Seven patients without records of their transfer time were excluded. The shortest recorded insertion–departure time, defined as the time interval between ECMO insertion and starting transport, was 32 minutes.

ANCOVA was performed while statistically controlling for covariates such as BMI, ECMO flow, initial ECMO type, and hospital days. With respect to 28-day survival, there was no significant difference in the insertion–depar-

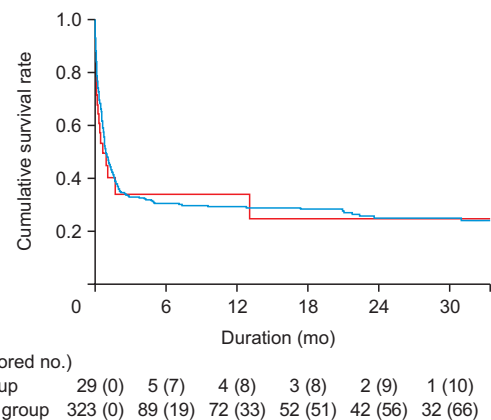


Fig. 2. Kaplan-Meier survival graph with numbers at risk.

Table 4. Effects of risk factors on 28-day mortality

Predictor	Univariable analysis		Multivariable analysis	
	OR (95% CI)	p-value	OR (95% CI)	p-value
ECMO transport	0.818 (0.381–1.755)	0.605		
Sex (female)	1.464 (0.910–2.354)	0.116	1.447 (0.884–2.367)	0.141
Age	1.004 (0.989–1.018)	0.627		
Body mass index (kg/m <sup>2</sup> )	0.979 (0.929–1.031)	0.414		
Hypertension	0.752 (0.493–1.148)	0.187	0.815 (0.524–1.266)	0.362
Diabetes mellitus	0.848 (0.532–1.35)	0.486		
Coronary artery disease	0.877 (0.405–1.903)	0.741		
Cerebrovascular disease	0.828 (0.334–2.051)	0.684		
Chronic kidney disease	1.649 (0.624–4.355)	0.313		
COPD	0.509 (0.046–5.661)	0.582		
Asthma	0.607 (0.143–2.580)	0.499		
Initial ECMO type (VA)	3.173 (1.851–5.441)	<0.001	2.553 (1.446–4.508)	0.001
ECPR	2.372 (1.453–3.871)	0.001	1.785 (1.059–3.007)	0.030

OR, odds ratio; CI, confidence interval; ECMO, extracorporeal membrane oxygenation; COPD, chronic obstructive pulmonary disease; VA, venoarterial; ECPR, extracorporeal cardiopulmonary resuscitation.

**Table 5.** Relationship between the insertion–departure time and 28-day survival

Insertion to departure interval time	Outcome				
	No. (%)	Median (interquartile range)	p-value	Least-square mean±standard error	Adjusted p-value
28-Day survival	12 (54.5)	117 (78.25–195.75)	0.107	344.453±204.383	0.872
28-Day mortality	10 (45.5)	190.5 (144.25–798.25)		272.709±298.127	

ture time between the surviving and deceased groups ( $p=0.107$ ). When controlling for covariates, there were also no significant differences between the 2 groups in terms of 28-day survival ( $p=0.872$ ). The detailed results are presented in Table 5.

## Discussion

Some studies have compared ECMO transportation outcomes with in-hospital ECMO outcomes [7,11]. As in previous studies, a comparison between transported and in-hospital patients will aid in understanding the characteristics of transportation and in achieving better clinical outcomes. The need for transporting patients under ECMO support is increasing with the development of smaller ECMO equipment, guidelines published by ELSO, better outcomes at high-volume centers, and expanding indications for ECMO [1,10,13]. However, to the best of our knowledge, no studies on the timing of transportation have been conducted. Therefore, we report our outcomes of transporting patients under ECMO support and the relationship between transport timing and 28-day survival.

The baseline characteristics, including sex, age, BMI, underlying disease, and reasons for ECMO, did not significantly differ between the in-hospital and mobile groups. The SAVE and RESP risk scores were also not significantly different. The similar profiles between the in-hospital and mobile groups result from usage of the same treatment strategy at our hospital and the referring hospitals. The strategy for ECMO patients was derived from sufficient consultation with the referring hospital's medical team before patients developed the need for ECMO.

The transportation distance was almost 115 km, as the most frequent referring hospital was located in Chuncheon. However, due to traffic conditions, the transporting times were highly diverse (median, 95 minutes; IQR, 36.5–119.5 minutes).

Hong et al. [6] reported the outcomes of transporting ECMO patients. The weaning success rate was 75% in the transported group and 72.3% in the in-house group ( $p=0.715$ ). The rate of survival to discharge was 70.5% and

56.6% in the transported and in-house groups ( $p=0.096$ ), respectively. Dalia et al. [14] also reported similar results. The survival to ECMO therapy rate was 60.8% in the transported group and 56.7% in the in-house group ( $p=0.58$ ). The survival to discharge rate was 47.1% and 38.1% in the transported and in-house groups, respectively. These reports suggest no differences in the ECMO weaning rate and short-term survival between the mobile group and in-hospital group (transported group and in-house group in the previous article). Our study demonstrated similar results for the ECMO weaning rate (45.2% versus 44.8%,  $p=1.000$ ), 28-day survival rate (50.2% versus 55.2%,  $p=0.746$ ), and survival to discharge rate (34.1% versus 41.4%,  $p=0.427$ ). These comparable results of the mobile group to the in-hospital group seem to have been achieved as a result of close collaboration and preparation of transportation equipment prior to the transfer. Our transportation results indicated a lower rate of survival to discharge (41.4%) than that reported previously by Bryner et al. [3] (62%), Hong et al. [6] (70.5%), and Fletcher-Sandersjö et al. [15] (76%). This may be explained by the high proportion of VA ECMO (72%, 21/29) compared to VV ECMO (29%, 8/29). The reported VA ECMO rates were 52% (114/211) by Bryner et al. [3], 65% (28/44) by Hong et al. [6], and 55% (493/908) by Fletcher-Sandersjö et al. [15]. Similarly, Dalia et al. [14] also reported a lower rate of survival to discharge (47.1%) in an analysis of patients who underwent VA ECMO.

Although the findings did not reach statistical significance, the higher proportion of VA ECMO type, cardiogenic shock cases, and septic shock cases could be a reason for the longer treatment duration of the in-hospital group (ECMO duration, ICU stay, and hospital stay). The ELSO registry [16] and Myers et al. [17] also reported relatively poor outcomes in cardiac-related and septic shock patients.

Regarding morbidity, the 2 groups showed no significant differences with respect to ECMO-related complications, including acute kidney injury, cannulation-site bleeding, leg ischemia, and gastrointestinal bleeding. Hong et al. [6] reported that the incidence of leg ischemia was significantly higher in the mobile group than in the in-hospital group

(25% versus 8.1%,  $p=0.017$ ); however, our results were not in agreement with the findings of their study (13.8% versus 7.7%,  $p=0.281$ ). Detailed consultations and close contact before and during cannulation may reduce leg and vascular complications in transported patients.

In our binary logistic regression analysis of risk for short-term outcomes, transportation was not a risk factor. VA ECMO was an independent risk factor for 28-day mortality and failure to survive until discharge. ECPR was found to be an independent risk factor for 28-day mortality, and age was an independent risk factor for failure to survive until discharge. We could not delineate risk factors for ECMO weaning.

No significant difference in long-term survival was found between the mobile and in-hospital groups. Although we performed transportation extremely early if deemed necessary, transportation did not affect survival. Furthermore, the complication rates were not significantly different between the 2 groups. We consider that these favorable outcomes resulted from prompt communication between the ECMO center and the referring hospital.

The durations of ICU and hospital stay (in days) and the duration of ECMO use (in days) were significantly longer in the in-hospital group than in the mobile group. This may have been caused by the long waiting time for lung or heart transplantation after ECMO insertion in the in-hospital group.

A previous study reported that transporting patients under ECMO support was highly risky [18]. Therefore, transporting patients after ECMO insertion is a distressing predicament for clinicians. Usually, when ECMO is performed, patients are often unstable immediately after ECMO initiation. Transporting patients in this condition can prove dangerous.

However, Barbaro et al. [19] reported that ECLS centers with more than 30 annual adult ECLS cases had significantly lower ECMO mortality than units with fewer than 6 cases per year. In other words, it is dangerous to treat high-risk ECMO patients in a hospital unprepared for ECMO management.

In summary, if the transportation risk is avoided, the continuation of treatment at an unprepared center is also risky. When ECMO treatment is undertaken at an unprepared hospital rather than at a specialized ECMO center, there may be difficulties not only with ECMO insertion but also with ECMO management thereafter.

Therefore, our center decided to implement active counseling prior to the initiation of ECMO treatment, and the patients were transferred at an early stage. In our experi-

ence, active participation before the insertion of ECMO prevents several simple but severe problems, such as ECMO application despite contraindications, inadequate cannula size, inappropriate ECMO type, cannulation at an unsuitable access site, and mortality due to inadequate medical management including ventilator care, volume management, and medication. Our mobile team actively supports patient medical care by consulting the attending physician even before initiating ECMO support.

The referring hospital's efforts are also important, as well as those of the high-volume center. Active collaboration, such as participation in educational programs, accepting the transport protocol, rapid response to the situation, and following advice from the high-volume center, enables organized transportation.

This study has some limitations. This was a retrospective, non-randomized study with inherent limitations, including selection bias. Some transported patients had a very short follow-up duration because they were followed up at the referring hospital after discharge. The small number of transported patients included in this study was also a statistical limitation in detecting true differences. Moreover, for the ECMO insertion–departure time, the records of 22 patients were analyzed, and some degree of record loss could not be avoided. The interpretation of data on ECMO duration, ICU stay, and hospital stay in the comparison between the mobile and in-hospital groups should be approached with caution. Some patients were weaned from ECMO and discharged with a short follow-up time; however, early mortality cases also had a short ECMO duration and hospital stay. It is important to take this error into account when interpreting the results of this study. A large, prospective, multicenter study is clearly needed to confirm our findings and achieve greater statistical power.

In conclusion, outcomes of urgent transportation, with active involvement from the ECMO center before ECMO insertion and preparation of a transport protocol, were comparable to those of in-hospital ECMO patients. The intervention and transport system, through the urgent transport protocol, allows patients to be transferred from hospitals that are unable to provide optimal ECMO management to a hospital that can do so. To establish a safe and urgent ECMO transport system, it is necessary to establish a collaborative system between specialized ECMO centers and referring hospitals before initiating ECMO.



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### Conflict of interest

No potential conflict of interest relevant to this article was reported.

### Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

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