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Transportation of patients with severe respiratory failure on ECMO support. Four-year experience of a single ECMO center

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Abstract

Background: Acute respiratory distress syndrome (ARDS) is associated with high mortality despite advances in the field of critical care, including growing implementation of veno-venous extracorporeal membrane oxygenation (V-V ECMO) support. The primary aim of this study was to present complications during transport on V-V ECMO support from regional hospitals to a tertiary center. The secondary goal was to identify initial laboratory and demographic data differentiating survivors and non-survivors.

Methods: This was a retrospective, single-center, case-series study. We extracted data from the hospital's ECMO database from March 2016 to June 2019. Patients' diagnosis at admission, baseline demographics, the Sequential Organ Failure Assessment (SOFA) and the Respiratory ECMO Survival Prediction (RESP) scoring systems, laboratory parameters at admission, duration of ECMO therapy and mechanical ventilation time, and the patient survival rate until the ICU discharge were analyzed.

Results: We assessed 31 patients retrieved from regional intensive care units. All analyzed transports on V-V ECMO were performed by an ambulance and median distance and transport time were 100 kilometers and 70 minutes, respectively. Minor complications during the transport were reported in 10 cases (32.25%). The mean V-V ECMO support time was 6.56 days and survival rate until the patient discharge was 64.51%. We found higher body mass index (33.5 vs. 26.5, $P = 0.00251$) and lower serum lactate level (1.25 vs. 1.6, $P = 0.0058$) at V-V ECMO initiation to correlate with higher survival rates.

Conclusions: The transport of patients on V-V ECMO support appears to be safe and feasible. Further studies are needed to identify the specific clinical conditions which might affect the final outcomes.

Key words: extracorporeal membrane oxygenation (ECMO), transport, safety, respiratory failure, acute.

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Acute respiratory distress syndrome (ARDS) is diagnosed in approximately 5% of mechanically ventilated patients in intensive care units (ICUs) [1]. Severe ARDS may dynamically deteriorate respiratory failure. The mortality in patients with ARDS is still very high, and reaches 40% of mechanically ventilated individuals [2]. For many severely ill patients, the last chance therapy to improve the outcome is implementation of veno-venous extracorporeal membrane oxygenation (V-V ECMO) [3, 4]. The main aim of ECMO therapy implementation is to support exchange of blood gases by removal of carbon dioxide and provision of oxygen directly to the patients' bloodstream [5]. Undergoing V-V ECMO therapy may be associated with a number of complications, some of which potentially fatal. Two main sources of adverse events are thrombotic and hemorrhagic complications [6]. In order to prevent complications, units that conduct extracorporeal oxygenation require adequate expertise and constant training. Moreover, the experience of the medical team increases patient survival rate [7, 8]. Therefore, V-V ECMO-dedicated centers have been introduced in many countries [9]. Additionally, many patients suffering from severe ARDS, who may require ECMO, are distributed in regional ICUs. Thus, a dedicated experienced retrieval team is required in order to implement ECMO therapy and transfer the patient safely to the ECMO center [10]. Transport of a patient with severe ARDS on ECMO remains challenging and many adverse events have been reported [6, 7].

TABLE 1. Extracorporeal membrane oxygenation inclusion criteria according to Extracorporeal Life Support Organization and Polish National Consultant in the field of Anaesthesiology and Intensive Therapy [11, 12]

Extracorporeal Life Support Organization (ELSO)	Polish National Consultant in the field of Anaesthesiology and Intensive Therapy
Hypoxic respiratory failure due to any cause (primary or secondary) extracorporeal life support should be considered when the risk of mortality is 50% or greater, and is indicated when the risk of mortality is 80% or greater. 50% mortality risk is associated with a $PaO_2/FiO_2 < 150$ on $FiO_2 > 90\%$ and/or Murray score 2–3 (1), AOI score 60 (2), or APSS score 3 80% mortality risk is associated with a $PaO_2/FiO_2 < 100$ on $FiO_2 > 90\%$ and/or Murray score 3–4 (1), AOI > 80 (2), APSS 8 (3) despite optimal care for 6 hours or less	Major criteria: $PaO_2/FiO_2 < 80$ mm Hg when is PEEP ≥ 10 cm H_2O despite optimal therapy for more than 2 hours
CO_2 retention on mechanical ventilation despite high plateau pressure (> 30 cm H_2O)	The auxiliary criteria: 1. pH < 7.2; $PaCO_2 > 80$ mm Hg 2. Static compliance < 0.5 mL kg^{-1} cm H_2O 3. PIP > 40 cm H_2O when TV ≤ 6 mL kg^{-1} 4. Oxygenation index (OI) > 60 for 30 min or > 35 for 6 h [OI = (MAP × FiO_2 × 100)/PaO_2] 5. Chest X-ray: profound shadows in at least 2 quadrants
Severe air leak syndromes	
Need for intubation in a patient on lung transplant list	
Immediate cardiac or respiratory collapse (PE, blocked airway, unresponsive to optimal care)	

AOI – Age-Adjusted Oxygenation Index, APSS – Acute Physiology of Stroke Score, PEEP – positive end-expiratory pressure, PIP – peak inspiratory pressure, TV – tidal volume, MAP – mean pressure in airway

Few articles can be found regarding Polish experience with ECMO in the literature. The most important initiative is the program "Extracorporeal Membrane Oxygenation for Greater Poland" [10]. It shows an important role of medical simulation in skills testing and creating new, necessary algorithms and non-existing procedures [11]. However, this program is still in progress.

The goal of our study was to assess the safety and feasibility in patients transported on ECMO into our retrieval ECMO center.

METHODS

Population included

This was a retrospective, single-center, case-series study. We extracted data from the hospital's ECMO database from March 2016 to June 2019, including 38 cases (average number of patients treated per annum is approximately 15 cases). Our center is mainly focused on treating patients with severe respiratory failure and we perform only V-V ECMO support due to lack of a cardiosurgical unit. Only patients who were retrieved to our hospital from regional ICUs were analyzed (31 out of 38 cases – 81.6%).

TABLE 2. Extracorporeal Life Support Organization exclusion criteria [19]

There is no absolute contraindication to extracorporeal membrane oxygenation therapy
Mechanical ventilation at high settings ($FiO_2 > 0.9$, plateau pressure > 30) for 7 days or more. Many centers do not consider time on ventilation a contraindication.
Major pharmacologic immunosuppression (absolute neutrophil count < 0.4 G L^{-1})
Central nervous system hemorrhage that is recent or expanding
Nonrecoverable comorbidity such as major central nervous system damage or terminal malignancy
Age: no specific age contraindication but consider increasing risk with increasing age

Ethical approval for this study (permit number KE-0254/37/2018) was provided by the Medical University of Lublin Ethics Committee.

Analyzed parameters

We recorded patients' diagnosis at admission, baseline demographics, the Sequential Organ Failure Assessment (SOFA) and the Respiratory ECMO Survival Prediction (RESP) scoring systems, laboratory parameters at admission, duration of ECMO therapy and mechanical ventilation time, and the patient survival rate until the ICU discharge.

Goals

The primary aim of our study was to present complications during transport of patients on V-V ECMO from regional hospitals. Our secondary goal was to compare initial laboratory and demographic data in survivors and non-survivors of ECMO therapy.

Patient qualification

The decision to initiate ECMO support was performed by two intensivists according to Extracorporeal Life Support Organization (ELSO) guidelines [12] and recommendations of the Polish National Consultant in the field of Anaesthesiology and Intensive Therapy[13] (Tables 1 and 2).

During a telephone interview the inclusion and exclusion criteria were considered. The decision to implement the therapy was determined up to 24 hours. All vital equipment was collected and checked according to our center checklist presented below (Table 3).

Implementation

For cannulation, single lumen cannulae were used (Maquet 15–25 Fr). At the bedside, ultrasound (USG) guided percutaneous cannulation was performed. We preferred the femoral vein as the collecting line, and the internal jugular or the opposite femoral vein as a returning cannula. Apart from one case, V-V ECMO support was implemented before the transfer to our center. The cannulation sites and gauges are presented in Table 4.

Transport

The transport team included a specialist in anesthesia and intensive care, a resident in training and two paramedics. During the transport, all patients, apart from one, were both mechanically ventilated and oxygenated by an ECMO machine. We monitored vital signs: blood oxygen saturation (SpO_2), electrocardiography (ECG), respiratory rate (RR) and invasive blood pressure (IBP). In every case, sedatives and neuromuscular blocking agents were used. Circulation was supported with catecholamine infusion as required.

Ventilation during ECMO support

Mechanical ventilation during ECMO was adjusted to 10–15 cm H_2O value of positive end-expiratory pressure (PEEP) and fraction of inspired oxygen (FiO_2) was set to 0.6. A PEEP trial (to find optimal settings) and measurement of static and dynamic compliance were performed at least twice daily. If required, muscle relaxation was continued for 48 hours. Anticoagulation management included the use of low molecular weight heparin only.

RESULTS

We assessed 38 patients from the hospital's ECMO database for eligibility. Thirty-one patients (81.5%) met the inclusion criteria. Patient characteristics, admission diagnosis, RESP and SOFA scores, some laboratory parameters, and ECMO and mechanical ventilation time are presented in Table 5.

The ECMO retrieval team has not encountered any significant problems in the referring hospitals, besides one case of an unsuccessful cannulation attempt – the patient was transported to our center without ECMO support, using a standard ventilator with FiO_2 of 1.0 (Table 7).

The median distance and ECMO transport time were 100 km and 70 min, respectively. All transports were made by an ambulance. The ambulance was rented from an ambulance service company, ready to use in up to two hours from a call. An important part of the ambulance equipment was an electric generator. All other necessary devices were prepared before the transport and checked according to a specific checklist (Table 3).

TABLE 3. Equipment check-list applied in our center

	Yes
ECMO machine	
Power cord for ECMO machine	
Transport ventilator with PEEP valve	
Two infusion pumps	
Transport monitor with capnography module	
Ultrasound apparatus with linear and abdominal/cardiac probe and Doppler	
Sterile ultrasound probe covers	
Sterile ultrasound gel	
Return cannulas (length up to 25 cm) in sizes 15–19F	
Drainage cannulas (length up to 60 cm) in sizes 21–27F	
Vascular introducer sets	
Two ECMO circuits	
Vascular clamps	
Scissors and scalpels	
Four sterile drapes	
Surgical suture kit (size 0)	
Two syringes (capacity min. 50 mL)	
Transducer for invasive blood pressure measurement	

ECMO – extracorporeal membrane oxygenation, PEEP – positive end-expiratory pressure

TABLE 4. Cannulae characteristics

Factor	All patients	Survivors	Non-survivors
Cannulation site of collecting cannula			
RFV	27	18	9
LFV	3	1	2
RIJV	1	1	0
Cannulation site of return cannula			
RIJV	27	16	9
LFV	4	4	2
Size of collecting cannula			
25F	27	18	9
23F	1	0	1
21F	3	2	1

RFV – right femoral vein, LFV – left femoral vein, RIJV – right internal jugular vein, F – scale used to measure size of catheter

The survival rate until the patient discharge was 64.51% (20 patients). The median RESP score and SOFA score at the admission were 3 and 11 points. The predicted survival rate according to these scoring systems were 65% and 60%, respectively.

We identified 10 (32.25%) complications during the transport, as shown in Table 7, but no major complications occurred. In one case, ECMO was not initi-

TABLE 5. Baseline characteristics of patients transported on veno-venous extracorporeal membrane oxygenation. Data obtained prior to initiation of therapy

Patient characteristics	All patients ($n = 31$)	Survivors ($n = 20$)	Non-survivors ($n = 11$)	*P*-value
Age (years)	50 (42–60.5)	46.5 (39.5–55)	56 (47–63.5)	0.37
Female/Male (*n*)	9/22	4/16	5/6	0.415
Body mass (kg)	100 (80–123.5)	115 (90–130)	80 (68–105)	0.0516
Height (cm)	176 (165–180)	180 (170–183.5)	165 (165–177)	0.3152
BMI (kg m^{-2})	32.55 (26.73–40.75)	33.5 (29.72–45.5)	26.5 (25.00–39.5)	0.0251
SOFA	11 (9.25–13)	11 (9.5–13)	11 (9–13)	0.7235
RESP score	3 (0–5)	4 (0.5–5.5)	0 (0–4)	0.3393
Oxygenation index (PaO_2/FiO_2)	73.5 (60.0–81.8)	74 (58.4–80.5)	73 (68.9–85.0)	0.5807
pCO_2 (mm Hg)	51.6 (43.8–70.2)	49.8 (44.275–67.575)	58.1 (41.95–77.5)	0.9578
Lactate (mmoL L^{-1})	1.365 (1.2–1.6)	1.25 (1.1–1.3225)	1.6 (1.4–1.95)	0.0058
pH	7.33 (7.186–7.46)	7.31 (7.19–7.44)	7.32 (7.2075–7.465)	0.763
Duration of invasive ventilation prior V-V ECMO (days)	2.5 (1–4)	2 (1–4)	4 (2–5.75)	0.078
PCT (mmoL L^{-1})	1.53 (0.55–24.18)	4.96 (0.35–24.18)	1.475 (0.69–32.03)	0.815

Data are presented as the median (interquartile 25–75) or the percentage (%)
BMI – body mass index, V-V ECMO – veno-venous extracorporeal membrane oxygenation, PCT – procalcitonin

ated at the site due to prolonged cannulation. None of these complications affected patient mortality.

The mean length of mechanical ventilation before ECMO implementation was 2.5 days (Table 5), while the mean ECMO support time was 6.56 days (Table 7).

We found that higher body mass index (BMI) (33.5 vs. 26.5; $P = 0.00251$) and lower serum lactate level (1.25 vs. 1.6; $P = 0.0058$) on the day of ECMO implementation were a positive predictors of survival until ICU discharge (Table 5).

DISCUSSION

The findings presented in our study showed that the transport of patients on ECMO was relatively safe. None of the minor complications during the transportation affected the patient mortality (Table 7). According to the available data a standard ambulance, without sophisticated equipment, is adequate for this purpose [13]. Higher patient BMI and lower serum lactate level on the admission day significantly decreased patient mortality. We found an association between higher BMI, lower admission serum lactate level and increased survival rate in our population of V-V ECMO patients (Table 5).

Our results regarding the transportation are consistent with the body of literature – transport of patients on V-V ECMO is a relatively safe procedure. Nevertheless, inter-hospital transport of critically ill patients is a big challenge with possible adverse events. The incidence of severe complications during transport of high-risk patient without ECMO is 30% [15, 16]. In the literature, the number of adverse events during ECMO transport varies widely, from 0% up to 42% [17–19]. In most cases, complications occurring during the transport had no adverse effect on patient outcome [7]. The complications could be divided according to 4-grade severity risk categories by Fletcher-Sandersjöö *et al*. [7]. Alternatively, these complications can be categorized as related to equipment, human error, patient, transport vehicle, or environment. Foregoing data suggest that transport of patients on ECMO to specialized ECMO centers is safe and effective [7, 20, 21]. Importantly, specialized retrieval teams are the main reason for reduction of life-threatening

TABLE 6. Primary etiology of severe respiratory failure in patients transported on veno-venous extracorporeal membrane oxygenation

Diagnosis	All patients	Survivors	Non-survivors	*P*-value
Viral pneumonia	16/31 (51.6)	11/16 (68.75)	5/16 (31.25)	0.35
Bacterial pneumonia	13/31 (41.9)	5/13 (38.4)	8/13 (61.5)	0.73
Trauma	2/31 (6.5)	0/2 (0)	2/2 (100)	0.47
Acute pancreatitis	1/31 (3.23)	1/1 (100)	0/1 (0)	1.0
Pulmonary aspergillosis	1/31 (3.23)	0/1 (0)	1/1 (100)	1.0

Data are presented as number (%).

TABLE 7. Characteristics of ground transport and complications on veno-venous extracorporeal membrane oxygenation

Referring hospital	
Primary	26/31 (8%)
Secondary	4/31 (12.9%)
Tertiary	1/31 (3.2%)
Transport distance (km) – all patients	100 (64–120)
Transport distance (km) – survivors	85 (56.5–101.5)
Transport distance (km) – non-survivors	134 (92.5–212.5)
Transport time (min) – all patients	70 (40–100)
Transport time (min) – survivors	65 (30–75)
Transport time (min) – non-survivors	90 (65–195)
Cannulation site	
Femoral/jugular veins	27/31
Femoral/femoral veins	4/31
ECMO blood flow	4.75 (4.2–4.7475)
ECMO sweep gas flow (L min^{-1})	3.5 (2.25–4)
Duration of ECMO therapy (days)	6.56 (1.5–13)
ECMO-related complications	10/31 (32.25%)
Arterial oxygen desaturation (SpO_2 < 90%)	4/31 (12.9%)
Bleeding at cannulation site	1/31 (3.2%)
Bubble detection on the blood return line	2/31 (6.4%)
Cannula migration during transport	1/31 (3.2%)
ECMO circuit disconnection from ECMO machine	1/31 (3.2%)
Unsuccessful cannulation attempt (no ECMO support during transport)	1/31(3.2%)

Data are presented as number (%).
ECMO – extracorporeal membrane oxygenation

complications due to adequate training and equipment [9, 12, 14].

ELSO highlighted that the best outcome is achieved when V-V ECMO is instituted as quickly as possible [12]. Nonetheless, our study shows no difference in mortality between patients who were mechanically ventilated for 2 or 4 days ($P = 0.078$) (Table 5).

According to the literature, lactate level is shown to be a useful prognostic tool in the population of V-V ECMO patients [22]. Bonizzoli *et al*. observed a statistically significant difference in the initial lactate level between survivors and non-survivors (2.68 mmol/L vs. 4.95 mmol/L; $P = 0.002$), which corresponded to our results (1.25 mmol/L vs. 1.6 mmol/L; $P = 0.0058$ respectively). Our observation regarding a significant difference in BMI between the group of survivors and non-survivors (33.5 vs. 26.5; $P = 0.025$) is supported by the data from the mentioned study (26.7 vs. 24.6; $P = 0.004$ respectively) (Table 5).

Unexpectedly, we found out that patients with the median BMI 26.5 kg m^{-2} have a higher mortality rate in comparison to individuals with median BMI 33.5 kg m^{-2} ($P = 0.0251$) (Table 5). The efficacy of V-V ECMO treatment in obese patients with severe ARDS has already been shown [23]. Nonetheless, there is still a lack of data which support the thesis that a higher BMI can improve outcome in patients on V-V ECMO.

LIMITATIONS

Our study has multiple limitations. Due to the retrospective design of the study not all data were obtainable. There was a lack of data on the number of patients rejected from ECMO and no implementation of monitoring protocols during the transport. Finally, the relatively small number of patients included in the study may limit the overall generalisability of the study findings.

CONCLUSIONS

Retrieval of patients on ECMO support is safe and feasible in the presence of a trained team. Efforts must be made to recognize the need of extracorporeal respiratory support at an early stage and to prompt activation of the ECMO team.

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