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Extracorporeal life support in pregnant and postpartum women with COVID-19-related acute respiratory distress syndrome

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Abstract

Objective: Extracorporeal membrane oxygenation (ECMO) is an intervention used for patients with acute respiratory distress syndrome (ARDS) from COVID-19 who have failed conventional ventilatory strategies. Very few studies have given insight into the outcomes of pregnant and postpartum patients requiring ECMO support.

Methods: Single center, retrospective, observational study of female pregnant and postpartum patients suffering COVID-19 ARDS and requiring ECMO.

Results: Eight SARS-CoV-2 positive patients were identified. The average age was 31 ± 4 years, with Body Mass Indices (BMI) and SOFA scores ranging between 32–49 and 8–11, respectively. Two patients were pregnant at the time of ECMO initiation, two were peripartum, and four were postpartum. Five patients (63%) had bleeding, and one patient had a hysterectomy. Seven patients (88%) were supported by V-V ECMO and one with V-A ECMO. Patients had between one and three circuit exchanges due to oxygenator failure or clots in the circuit. All patients were in ICU between 7 and 74 days, with hospital length of stay between 8 and 81 days. All patients were weaned off ECMO and were successfully discharged from the hospital. All newborns were born via cesarean section, and all survived to discharge.

Conclusion: Our study shows a 100% neonatal and maternal survival rate demonstrating that ECMO in this patient population is safe. These patients should be transferred to experienced high-volume ECMO centers with the ability to perform emergent cesarean sections. ECMO should be considered a life-saving therapy for pregnant women with severe COVID-19 with an overall excellent maternal and neonatal survival rate.

Keywords

Cesarean section, ECLS, ECMO, ECPR, veno-pulmonary, pregnancy, ProtekDuo

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Introduction

The coronavirus SARS-CoV-2 resulted in the recent pandemic of the Coronavirus Disease of 2019 (COVID-19) and was associated with more than five million deaths worldwide.[1] This disease, capable of affecting many different organs, mainly caused acute respiratory failure that often-required endotracheal intubation and mechanical ventilation. In many cases, the limits of invasive ventilation were reached quickly and the use of extracorporeal membrane oxygenation (ECMO) became necessary. ECMO is an intervention that allows for either cardiac-, respiratory-, or combined cardiorespiratory support for patients who cannot be managed with conventional treatment strategies.[2]

Mechanical ventilation of peripartum patients is often complicated by high intra-abdominal pressure and the fact that prone positioning is highly complicated, thus lateral positioning is the preferred alternative. As a result of increased intra-abdominal pressure, higher ventilation pressure is needed to achieve adequate tidal volumes in late pregnancy, which interferes with reaching target plateau pressures. In addition, maternal and fetal physiology requires to maintain a maternal partial pressure of oxygen (PaO_2) greater than 70 mmHg and a partial pressure of carbon dioxide ($PaCO_2$) of less than 60–70 mmHg.[3,4]

During the last H1N1 pandemic, pregnant and postpartum patients who received ECMO for acute respiratory distress syndrome (ARDS) secondary to H1N1 infection showed a pooled estimate of survival of 74.6%, with neonatal outcomes demonstrating a live birth rate of 70%.[5,6] Now, a decade later, we present our single center experience, results, and outcomes of pregnant and peripartum patients suffering from ARDS secondary to COVID-19 infection during the most recent SARS-CoV-2 pandemic.

Methods

We present a single center, retrospective, observational study of female pregnant and postpartum patients who required ECMO for COVID-19 related ARDS in the time period between April 1, 2020 and August 31, 2022. After Institutional Review Board (IRB # 18-005) approval was obtained, the institutional ECMO database was screened, and all patient's data was obtained. Inclusion criteria were according to Murray Score of 3.25 or higher. As previously described, the ECMO circuit utilized consisted was either the Cardiohelp System (Getinge) with a non-modified HLS Set Advanced 7.0, or the CentriMag (Abbott) pump with Maquet Quadrox oxygenator and custom Terumo amphiphilic, biopassive coating – poly-2-methoxy-ethyl acrylate (PMEA) referred to as Xcoating™ circuit. Our standardized anticoagulation regimen includes bolus administration of 50–100 units/kg of unfractionated heparin at the time of ECMO cannulation, followed by heparin infusion to maintain an aPTT of 30–60 s, and a daily anti-factor Xa measurement correlating to a level of 0.2–0.5 IU/mL. The circuitry was kept simple without pigtails, bridge, or other connectors all of which are not heparin coated and may promote coagulative effects. The requirement therefore for anticoagulation in these patients is minimal from the circuit perspective, with the requirement for anticoagulation dependent on individual patient factors. In COVID-19 patients this was prophylactically kept at around 50–60 s to introduce another layer of safety. With approximately 150 ECMO runs per year, we have gained considerable experience with anticoagulation regimens for our circuit. Bearing institutional differences on circuitry in mind, each provider should adjust the anticoagulation strategy to their specific protocols.

Patients were ventilated in a pressure control mode. The so called "rest settings' as recommended by the Extracorporeal Life Support Organization (ELSO) were applied. Positive end-expiratory pressure (PEEP) was set at 10 cmH_2O. Peak inspiratory pressure (PIP) was aimed for a maximum of 30 cmH_2O to keep the plateau pressure (PPlat) less than 30 cmH_2O. Respiration rate (RR) was adjusted with an aim of 10 per minute, and FiO_2 was weaned as tolerated with an aim for 0.3.[7]

Data was reviewed for patients' demographics, present illness, and comorbidities, ECMO cannulation, settings and duration, and complications, as well as ICU and hospital length of stay.

Continuous variables were presented as mean ± standard deviation (SD), categorical variables were expressed as number (%).

Results

Eight female pregnant and postpartum patients with a polymerase chain reaction (PCR) test, confirmed positive for SARS-CoV-2 infection supported with ECMO were identified. The average age was 31 ± 4 years (range 22–35) with BMIs in the range of 32–49.2 (35.7 ± 5.4). Of this cohort, two patients were pregnant at the time of ECMO initiation, two peripartum, and four were postpartum.

Of this patient group, only one patient was vaccinated, and all patients but one had liver function tests (AST, ALT, and total bilirubin) within normal limits before ECMO. Anticoagulation was discontinued in five patients (63%) due to bleeding. One patient had continuous bleeding since her cesarean section for 10 days. An interventional radiology procedure, embolizing the uterine arty was not successful and a hysterectomy became necessary. Her anticoagulation was stopped throughout. One patient had acute kidney injury (AKI) during ECMO; however, none required renal replacement therapy. No patient had a history of asthma or other respiratory disease. SOFA scores ranged between 8 and 11. Six out of 8 (75%) patients were Caucasian and 1 (12.5%) each Hispanic or

Table 1. Patient demographics and pre-ECMO characteristics of COVID-19 patients.

Patient	1	2	3	4	5	6	7	8	All patients ($n=8$) (%)
Age (years)	22	38	35	33	31	29	29	34	30.9 ± 4.4
Race	C	C	C	C	AA	H	C	C	C = 6 (75) AA = 1 (12.5) H = 1 (12.5)
BMI (kg/m^2)	35.8	49.2	34.2	37	40	32	33	32.2	35.7 ± 5.4
Gestational age at time of delivery (weeks)	–	25	29	26	27	32	32	37	29.7 ± 3.9
COVID-19 symptoms onset (days)	16	12	21	13	12	27	11	4	14.5 ± 6.5
Days from symptoms onset to intubation	16	6	19	9	6	20	8	4	11 ± 5.9
Days from intubation to ECMO cannulation	1	3	2	1	6	6	2	1	2.8 ± 2
DM	N	Y	N	N	Y	N	Y	N	3 (37.5%)
Gestational DM	–	–	N	N	Y	Y	Y	N	3 (37.5%)
HTN	Y	N	N	N	Y	N	Y	N	3 (37.5%)
WBCs ($\times 10^3/\mu L$)	7.8	9.9	14.9	14.6	37.6	–	18	9.1	15.7 ± 8.5
Platelets ($\times 10^3/\mu L$)	286	303	193	218	276	106	294	225	212.7 ± 74.9
ALT (unit/L)	9	17	21	29	65	1012	14	12	123 ± 297
AST (unit/L)	27	29	42	32	77	169	20	17	46.9 ± 43.7
Total Bilirubin (mg/dL)	0.5	1.2	1.2	1.2	0.3	–	0.7	0.4	1 ± 0.6
Creatinine (mg/dL)	1.24	0.58	0.80	0.61	0.69	0.52	0.65	0.66	0.7 ± 0.2
BUN (mg/dL)	17	15	10	9	22	–	15	6	12 ± 5.2
Lactate (mg/dL)	0.85	1.12	0.81	1.33	1.7	–	1.53	–	1.1 ± 0.4
Arterial pH	7.32	7.42	7.29	7.41	7.35	7.21	7.4	–	7.4 ± 0.1
CO_2 (mmHg)	59	40	45	34	33	63	49	–	47.2 ± 9.8
P/F ratio	63	72	84	68	47	124	76	–	74.4 ± 20
PEEP	12	15	12	15	14	–	8	–	12.7 ± 2.4
HCO_3	30	26	22	21	38	–	30	–	30 ± 6.3
Oxygen saturation (%)	88	94	95	94	79	–	95	–	91.6 ± 5.2
SOFA	–	9	9	11	9	9	8	–	9.4 ± 1
Treatment received									
Convalescent plasma	N	Y	Y	N	N	N	N	N	2 (25)
Antiviral	N	Y	Y	Y	Y	Y	N	N	5 (62.5)
Antibiotics	Y	N	N	Y	Y	N	N	Y	4 (50)
Glucocorticoids	N	Y	Y	Y	Y	Y	Y	N	6 (75)

ECMO: extracorporeal membrane oxygenation; COVID-19: coronavirus disease 2019; C: Caucasian; AA: African American; H: Hispanic; BMI: Body Mass Index; DM: diabetes mellitus; HTN: hypertension; WBC: white blood cells; ALT: alanine aminotransferase; AST: aspartate aminotransferase; BUN: blood urea nitrogen; PEEP: positive end-expiratory pressure; SOFA: sequential organ failure assessment; Y: yes; N: no; P/F: PaO_2/FiO_2-ratio; –: unknown or not measured.
The data are presented as mean ± SD or number (%).

African American. Table 1 displays individual patients' demographics, comorbidities, time from endotracheal intubation to ECMO cannulation, and pre-ECMO laboratory, as well as arterial blood gas values. ECMO configuration and the total days on ECMO support are displayed in Table 2. Specific data on treatment received while on ECMO, days on the ventilator, ICU, and hospital length of stay, as well as survival rate and complications, are presented in Table 3. Three patients (38%) were cannulated by our team at an outside facility and were transported to our hospital on ECMO support, with no transport-related complications encountered. Seven patients (88%) were supported by V-V ECMO, of which one was reconfigured to venopulmonary (V-P) ECMO using the ProtekDuo cannula. The ProtekDuo is a relatively new single site, double lumen cannula that may be used as right ventricular assist device (RVAD) or for V-P ECMO. Details on its use and configurations were described elsewhere in detail.[8–10] One patient was cannulated for venoarterial (V-A) ECMO under extracorporeal cardiopulmonary resuscitation (ECPR) after undergoing emergent cesarean section that was complicated by cardiac arrest. The cardiac arrest was secondary to bilateral main pulmonary artery embolism and the patient underwent catheter embolectomy on post-operative day 1. Fortunately, she had a quick recovery and required only a short ECMO run, and ICU stay. All other patients had uncomplicated cesarean sections. One patient had pneumothorax before ECMO. Two patients had history of inflammatory/autoimmune disease; one with vasculitis and polyarteritis, and another patient with a history of Sjogren's syndrome. One with history of chronic lymphocytic leukemia.

Table 2. ECMO configuration and days on support.

Patient	1	2	3	4	5	6	7	8	All Patients ($n = 8$)
Time of ECMO initiation	3 mo post-partum	Before delivery	Peri-partum	Before delivery	2 days post-partum	16 days post-partum	2 days post-partum	Peri-partum	Before delivery = 2(25%), peri-partum = 2(25%), post-partum = 4(50%)
ECMO configuration	V-V	V-V	V-V	V-V	V-V	V-V, V-P	V-V	V-A	V-V = 7 V-P = 1 V-A = 1
Drainage cannula size and location	23 Fr	23 Fr	23 Fr	23 Fr	25 Fr	25 Fr	30 Fr	25 Fr	
	RFV	RFV	RFV	RFV	RFV	RFV	Crescent	RFV	
Return cannula size and location	23 Fr	23 Fr	23 Fr	23 Fr	23 Fr	23 Fr RIJV	30 Fr Crescent	17 Fr RFA	
	RIJV	RIJV	RIJV	RIJV	RIJV	/RIJV PA	RIJV	5 Fr RFA DPC	
ECMO days	11	30	5	34	20	66	10	4	20.7 ± 18.4

ECMO: extracorporeal membrane oxygenation; V-V: Veno-venous; V-A: Veno-arterial; V-P: Veno-pulmonary; Fr: French; RFV: right femoral vein; RFA: right femoral artery; DPC: distal perfusion cannula

Of the eight patients – two were placed on ECMO during their pregnancy at 25 and 26 weeks of gestation, and two were cannulated immediately after delivery (peri-partum) at 29 and 37 weeks. The remaining four patients had ECMO support initiated post-delivery; two patients were within 2 days of delivery with 27 and 32 weeks of gestation, one patient on day 16 with 32 weeks gestation, and the last patient was placed on ECMO 3 months post-delivery with no available gestational age in our records. There were no obstetric challenges noted at the time of ECMO cannulation. Three patients had at least one and up to three circuit exchanges, due to oxygenator failure or clots in the circuit. All patients were resident in the ICU between 7 and 74 days with a total hospital stay of between 8 and 81 days. All patients were weaned off ECMO and were successfully discharged from the hospital. All newborns were born via cesarean section and all survived to discharge.

Discussion

Mechanical ventilation may worsen ARDS by the risk of ventilator-induced lung injury (VILI). Since the ARDSnet trial in the year 2000, small tidal volumes with limits to the maximum plateau pressure have been successfully used.[11] In addition, neuromuscular blockade and prone positioning has been shown to be beneficial.[12] Although prone positioning is recommended in late pregnancy, it is difficult to achieve and therefore lateral positioning is often preferred. We had eight patients that could not be managed with conventional ventilation strategies and required ECMO support.

A systematic review and meta-analysis from the previous H1N1 pandemic resulted in five observational studies including a total of 39 women. The overall ECMO survival rate was 75%, with the neonatal survival rate greater than 70%. None of the studies compared ECMO patients with a control group, therefore the question if ECMO improved maternal and neonatal survival remains unclear. However, historical mortality rates within this patient population with ARDS of any cause has been reported to be as high as 40%.[5]

The available data on pregnant and peripartum patients suffering from COVID-19 is very limited. Two case reports have described successful ECMO management,[13,14] and a case series of three patients from Italy has demonstrated maternal survival of 67%.[15]

Recently, Barrantes et al.[16] presented a case series of nine pregnant or peripartum women with COVID-19 ARDS managed with V-V ECMO. The results of this study are interesting because they are, on the one hand very comparable to our study, but also demonstrate significant differences. The study reports an excellent survival rate of nine out of nine women, and outcome, as well as distribution of patients (of which five were postpartum, two were cannulated at delivery, two were pregnant at the time of

Table 3. Treatment and outcomes of COVID-19 patients and newborns.

Patient	1	2	3	4	5	6	7	8	All patients ($n=8$) (%)
Medications received during ECMO support:									
Antiviral	N	N	N	N	N	N	N	N	0 (0)
Antibiotics	N	Y	Y	Y	Y	Y	Y	Y	7 (87.5)
Glucocorticoids	Y	Y	Y	Y	Y	Y	Y	N	7 (87.5)
Tracheostomy	N	N	N	Y	Y	Y	N	N	3 (37.5)
Total tracheostomy days	0	0	0	28	9	11	0	0	8 ± 8.5
Total days on ventilator	7	36	8	24	16	18	9	4	15 ± 10
Off anticoagulation >24 h	N	Y	N	Y	Y	Y	Y	N	5 (62.5)
Total days in ICU	15	47	11	54	25	74	15	7	31 ± 22.8
Total hospital days	24	76	14	57	25	81	19	8	38 ± 27.1
Weaned (Y/N)	Y	Y	Y	Y	Y	Y	Y	Y	8 (100)
Survived to discharge	Y	Y	Y	Y	Y	Y	Y	Y	8 (100)
Newborn survival	Y	Y	Y	Y	Y	Y	Y	Y	8 (100)
Newborn hospital discharge	Y	Y	Y	Y	Y	Y	Y	Y	8 (100)

ICU: intensive care unit; Y: yes; N: no.
The data are presented as mean $\pm$ SD or number (%).

ECMO management, and one was in early pregnancy and delivered 106 days after ECMO decannulation) are in line with our findings. Conversely to our study is the newborn survival rate which is difficult to interpret. One did not survive; no data was available for another and a third was described as pending. Also, very different from our study is that all nine patients were a collection from six different centers with different management strategies. The authors applied three different cannulation techniques including three patients each. All patients were started on heparin, with three subsequently changed to Bivalirudin. Some centers monitored anticoagulation with PTT and others with Anti Xa. Overall, it is felt to be an inhomogeneous study population for which interpretation seems difficult since, given a total of five centers were involved, a maximum of two patients was the greatest possible contribution to the study from each center. However, the presentation of the data is essential to provide growing evidence that ECMO is a very useful tool in the management of these patients.

In another report from a group in Kuwait, Mohammed Bamasood et al.[17] report on 10 peripartum patients who required ECMO (two V-VA, eight V-V). Five out of 10 patients were postpartum and the other five were still pregnant. Of the latter group, three underwent cesarean section whilst on ECMO, one continued her pregnancy after decannulation from ECMO and delivered at 37 weeks' gestation, and one aborted the pregnancy whilst on ECMO and deceased after decannulation from septic shock. In total they could show a 90% maternal survival rate and had 8 out of 10 neonates that could be discharged home. Overall, their results are comparable with the studies of Barrantes and our group and show very good survival rates of both maternal and neonates.

Shih et al.[18] reported on five pregnant and five postpartum women requiring ECMO for COVID-19 ARDS. One patient had an ischemic stroke, one had a presumed hemorrhagic stroke, and nine developed bleeding while on ECMO support. This appears to be a very high complication rate when compared to the other studies. Of the five pregnant women, two patients had intrauterine fetal demise and three underwent delivery for maternal hemodynamic instability. Unfortunately, the authors experienced two inpatient mortalities, six patients survived to discharge, and two patients were still admitted at the time their paper was published. In addition to the two intrauterine fetal demises, two infant deaths occurred. When considering the data, only discharged patients may be considered survivors. Out of these, only six mothers and four infants survived. Mortality and significant bleeding events in ECMO patients may be related. Khalil et al.[19] described disseminated intravascular coagulation (DIC) with overt bleeding in a patient who had cesarean section while on ECMO support. This was managed by an ECMO circuit exchange that resulted in a dramatic improvement of her coagulation profile. This should trigger future research into the relationship between coagulation and outcomes of cesarean sections in patients supported by ECMO.

In an editorial of O'Neil et al.,[20] the authors discussed the results of the ELSO registry and demonstrated that 1180 adult female patients were supported with V-V ECMO for COVID-19, of whom 100 were pregnant or peripartum patients. These 100 cases were reported out of 213 ELSO ECMO centers. In our study, we report eight cases from one center, representing 8% of cases in this patient population. Based on our experience with 100% survival of patients and neonates, we are in full agreement with the ELSO authors to fully recommend ECMO as a

useful modality in pregnant and peripartum patients suffering from COVID-19 ARDS.

Conclusion

Our study shows a 100% neonatal and maternal survival rate demonstrating that ECMO in this patient's population, suffering from ARDS secondary to COVID-19, is safe. These patients should be transferred to experienced high volume ECMO centers with the ability to perform emergent cesarean sections. ECMO should be considered a life-saving therapy for pregnant women with severe COVID-19 with an overall excellent maternal and neonate survival rate.

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References

1. WHO. WHO Coronavirus (COVID-19) dashboard, https://covid19.who.int/?mapFilter=deaths (2023, accessed 11 November 2022).
2. El Banayosy AM, El Banayosy A, Brewer JM, et al. The ProtekDuo for percutaneous V-P and V-VP ECMO in patients with COVID-19 ARDS. *Int J Artif Organs*. 2022; 45(12): 1006–1012.
3. Bandi VD, Munnur U and Matthay MA. Acute lung injury and acute respiratory distress syndrome in pregnancy. *Crit Care Clin* 2004; 20(4): 577–607.
4. Cole DE, Taylor TL, McCullough DM, et al. Acute respiratory distress syndrome in pregnancy. *Crit Care Med* 2005; 33(10 Suppl): S269–S278.
5. Saad AF, Rahman M, Maybauer DM, et al. Extracorporeal membrane oxygenation in pregnant and postpartum women with H1N1-related acute respiratory distress syndrome: a systematic review and meta-analysis. *Obstet Gynecol* 2016; 127(2): 241–247.
6. Agerstrand C, Saad A and Maybauer MO. *ECMO in pregnancy and the peripartum patient*. Maybauer, MO: Oxford University Press, 2022.
7. Tonna JE, Abrams D, Brodie D, et al. Management of adult patients supported with venovenous extracorporeal membrane oxygenation (VV ECMO): guideline from the extracorporeal life support organization (ELSO). *ASAIO J* 2021; 67(6): 601–610.
8. Brewer JM, Capoccia M, Maybauer DM, et al. The ProtekDuo dual-lumen cannula for temporary acute mechanical circulatory support in right heart failure: a systematic review. *Perfusion*. Epub ahead of print 3 January 2023. DOI: 10.1177/02676591221149859.
9. Maybauer MO, Capoccia M, Maybauer DM, et al. The ProtekDuo in ECMO configuration for ARDS secondary to COVID-19: a systematic review. *Int J Artif Organs* 2023; 46(2): 93–98.
10. Maybauer MO, Koerner MM, Swol J, et al. The novel ProtekDuo ventricular assist device: configurations, technical aspects, and present evidence. *Perfusion*. Epub ahead of print 26 May 2022. DOI: 10.1177/02676591221090607.
11. Acute Respiratory Distress Syndrome Network, Brower RG, Matthay MA, et al. Ventilation with lower tidal volumes as compared with traditional tidal volumes for acute lung injury and the acute respiratory distress syndrome. *N Engl J Med* 2000; 342(18): 1301–1308.
12. Ferguson ND, Fan E, Camporota L, et al. The Berlin definition of ARDS: an expanded rationale, justification, and supplementary material. *Intensive Care Med* 2012; 38(10): 1573–1582.
13. Hou L, Li M, Guo K, et al. First successful treatment of a COVID-19 pregnant woman with severe ARDS by combining early mechanical ventilation and ECMO. *Heart Lung* 2021; 50(1): 33–36.
14. Fiore A, Piscitelli M, Adodo DK, et al. Successful use of extracorporeal membrane oxygenation postpartum as rescue therapy in a woman with COVID-19. *J Cardiothorac Vasc Anesth* 2021; 35(7): 2140–2143.
15. Clemenza S, Zullino S, Vacca C, et al. Perinatal outcomes of pregnant women with severe COVID-19 requiring extracorporeal membrane oxygenation (ECMO): a case series and literature review. *Arch Gynecol Obstet* 2022; 305(5): 1135–1142.
16. Barrantes JH, Ortoleva J, O'Neil ER, et al. Successful treatment of pregnant and postpartum women with severe COVID-19 associated acute respiratory distress syndrome with extracorporeal membrane oxygenation. *ASAIO J* 2021; 67(2): 132–136.
17. Mohammed Bamasood O, Shamsah M, Alfoudri H, et al. Extracorporeal membrane oxygenation in pregnant women with COVID-19. *ASAIO J* 2022; 68(4): 471–477.
18. Shih E, DiMaio JM, Squiers JJ, et al. Treatment of acute respiratory distress syndrome from COVID-19 with extracorporeal membrane oxygenation in obstetrical patients. *Am J Obstet Gynecol MFM* 2022; 4(2): 100537.
19. Khalil M, Butt A, Kseibi E, et al. COVID-19-related acute respiratory distress syndrome in a pregnant woman supported on ECMO: the juxtaposition of bleeding in a hypercoagulable state. *Membranes (Basel)* 2021; 11(7): 544.
20. O'Neil ER, Lin H, Shamshirsaz AA, et al. Pregnant and peripartum women with COVID-19 have high survival with extracorporeal membrane oxygenation: an extracorporeal life support organization registry analysis. *Am J Respir Crit Care Med* 2022; 205(2): 248–250.