CLINICAL OBSTETRICS AND GYNECOLOGY
*Volume 66, Number 1, 151–162*


# *Extracorporeal Membrane Oxygenation During Pregnancy*

**LUIS D. PACHECO, MD,***
**and AMIR A. SHAMSHIRSAZ, MD†‡**

**Divisions of Maternal Fetal Medicine and Surgical Critical Care, Departments of Obstetrics, Gynecology, and Anesthesiology, University of Texas Medical Branch, Galveston; † Maternal Fetal Medicine/Surgical Critical Care, Division of Maternal Fetal Medicine, Department of Obstetrics and Gynecology; and ‡ Department of Surgery/Michael E. DeBakey, Texas Children's Hospital/Pavilion for Women, Baylor College of Medicine, Houston, Texas*

**Abstract:** In the last 2 decades, the use of venovenous (VV) and venoarterial (VA) extracorporeal membrane oxygenation (ECMO) during pregnancy and the postpartum period has increased, mirroring the increased utilization in nonpregnant individuals worldwide. VV ECMO provides respiratory support for patients with acute respiratory distress syndrome (ARDS) who fail conventional mechanical ventilation. With the COVID-19 pandemic, the use of VV ECMO has increased dramatically and data during pregnancy and the postpartum period are overall reassuring. In contrast, VA ECMO provides both respiratory and cardiovascular support. Data on the use of VA ECMO during pregnancy are extremely limited.

*Correspondence: Luis D. Pacheco, MD, Divisions of Maternal Fetal Medicine and Surgical Critical Care, Departments of Obstetrics, Gynecology, and Anesthesiology, University of Texas Medical Branch, Galveston, 301 University Boulevard. Galveston, TX. E-mail: ldpachec@utmb.edu*

*The authors declare that they have nothing to disclose.*

**Key words:** extracorporeal membrane oxygenation, pregnancy, acute respiratory distress syndrome

## *Introduction*

The use of extracorporeal membrane oxygenation (ECMO) has increased dramatically during the last 2 decades. This exponential increase in ECMO utilization has also expanded to the obstetrical field as baseline cardiorespiratory risk factors among childbearing age women continue to increase.[1–3] ECMO may be divided into 2 main modalities: venovenous (VV) and venoarterial (VA). VV ECMO provides respiratory support, whereas VA ECMO provides both respiratory and cardiovascular support.

The use of VV ECMO during pregnancy took off during the H1N1 influenzae pandemic.[4,5] In a systematic review and metanalysis of pregnant and postpartum patients with acute respiratory distress syndrome (ARDS) secondary to influenzae H1N1 who received VV ECMO, the reported maternal survival was 75% with a live birth rate of 70%.[6]

More recently, during the COVID-19 pandemic, the use of VV ECMO for refractory ARDS in pregnant and postpartum women became a relatively common intervention in developed nations.[7–9] As expected, outcomes in this otherwise young and healthy population are usually better compared with nonpregnant individuals with severe ARDS requiring ECMO support.[10–12]

The latter reflects that ECMO use during pregnancy is feasible and safe when performed in experienced centers and is usually associated with acceptable outcomes.

In this article, we will discuss the use of both modalities in pregnant and postpartum individuals. Our main goal is for readers to understand the basic clinical concepts of ECMO circuits and their most common indications and complications.

## *VV ECMO*

VV ECMO provides respiratory support by extracting deoxygenated blood from a central vein with subsequent return of fully oxygenated blood to the central venous system after oxygenation, and carbon dioxide ($CO_2$) removal is accomplished in the ECMO circuit by exposing blood to highly oxygenated air through a semipermeable membrane.[13] ARDS is the most common indication for VV ECMO during pregnancy and the postpartum period.[14,15] The commonly utilized treatment strategies for ARDS include lung protective mechanical ventilation, moderate to high positive end expiratory pressure (PEEP), conservative fluid management, paralysis via neuromuscular agents in cases of patient ventilator desynchrony, prone ventilation, and inhaled pulmonary vasodilator therapy.[16] Cases refractory to the latter interventions may be candidates for VV ECMO. Beyond its ability to rescue patients with very severe gas exchange abnormalities not responding to standard treatment, the ECMO to Rescue Lung Injury in Severe ARDS trial strongly suggested that the main benefit of ECMO is ameliorating iatrogenic ventilator-induced lung injury (VILI).[17] Once oxygenation and $CO_2$ removal improve after ECMO initiation, it is possible to lower ventilator settings utilizing lower tidal volumes with lower airway pressures, resulting in decreased VILI allowing the lung to heal from the primary insult (ultraprotective mechanical ventilation).[18] Table 1 depicts the common indications and contraindications for ECMO use during pregnancy.

### CANNULATION

Membrane oxygenators are "artificial organs" designed to replace the lungs' gas exchange capacity by supplying oxygen and removing $CO_2$ from blood.

Full-flow VV ECMO and bicaval dual-lumen jugular VV ECMO are common cannulation modalities for VV ECMO.[14] In full-flow VV ECMO, venous blood is drawn from the inferior vena cava through the femoral vein; after oxygenation in the circuit, blood is returned to the jugular vein or to the contralateral femoral vein.[13] This technique is at a higher risk of recirculation (some of the returned oxygenated blood may be drained back into the circuit before it enters the right heart). Bicaval double-lumen cannulas are placed into the right internal jugular vein. This single cannula has a distal and a proximal lumen that will drain blood from the inferior and superior vena cava into the extracorporeal circuit. Oxygenate blood is then returned through a second lumen (within the same cannula, located in the midportion of the catheter) with its opening close to the right atrium facing the tricuspid

***TABLE 1. Indications and Contraindications to Venovenous ECMO for Acute Respiratory Distress Syndrome (ARDS)***

| Indications[17] | Relative Contraindications | Absolute Contraindications |
|---|---|---|
| $PaO_2/FiO_2$ <50 mm Hg for >3 h | Invasive mechanical ventilation for >7–10 d | Moribund state with established multiple organ failure |
| Or | Contraindication to anticoagulation | Prolonged cardiac arrest |
| $PaO_2/FiO_2$ <80 mm Hg for >6 h<br>Or<br>PH <7.25 with $PaCO_2 \geq 60$ mm Hg for >6 h despite respiratory rate >35/min and plateau pressure $\geq 32$ cm $H_2O$ | Severe coagulopathy | Severe anoxic brain injury<br>Massive intracranial hemorrhage<br>Severe chronic respiratory failure with no possibility of lung transplantation<br>Metastatic malignancy or hematological disease with poor short-term prognosis |

ECMO indicates extracorporeal membrane oxygenation; $FiO_2$, fraction of inspired oxygen; $PaCO_2$, partial pressure of carbon dioxide; $PaO_2$, partial pressure of oxygen.

valve, from which blood flows into the right atrium and then into the right ventricle. One limitation of this technique is that ECMO blood flow rates are limited by the smaller-diameter cannula, and effectiveness is very dependent on optimal placement of the reinfusion port (the port with opening close to the right atrium).[14,19] More recently, the Protek Duo cannula is placed similarly to a pulmonary artery catheter and is floated into the pulmonary artery. The cannula drains blood from the right atrium and returns fully oxygenated blood directly into the pulmonary artery. More data are required on the use of the Protek Duo cannula for VV ECMO.

If the decision is made to obtain femoral access for VV ECMO during pregnancy, aortocaval compression by the gravid uterus might impede femoral guidewire advancement. Left uterine displacement by placing a cushion or a wedge under the right hip may be helpful.[20]

## OXYGENATION AND VENTILATION

Within the extracorporeal circuit, blood flows through an oxygenator and a heat exchanger that warms the blood before it returns to body. Fresh air (sweep gas) and oxygen are mixed in a blender before the exposure of this gas to the blood through a semipermeable membrane.[17]

Oxygenation is determined by the flow rate in the circuit. The oxygen content of blood is dependent on the hemoglobin level, the partial pressure of oxygen ($PaO_2$), the oxyhemoglobin dissociation curve, and to a lesser extent, the amount of dissolved oxygen. In most cases, the minimal ECMO blood flow required to provide full oxygenation is around 3 to 4L/min in most cases.[21]

Because of the physiological increase in both cardiac output and blood volume during pregnancy, higher initial flow rates may be required (4 to 6 L/min).[22,23] Importantly, higher flows, especially in the setting of femoral cannulation, may result in recirculation (reinfused oxygenated blood is withdrawn through the drainage cannula before it flows into the right heart). Similarly, higher flows increase the risk of hemolysis, thrombocytopenia, and decreased filling pressures in patients with hypovolemia.[24,25]

Although the arterial hemoglobin oxygen saturation ($SaO_2$) >80% has been considered acceptable in recent VV

ECMO landmark studies, this may not apply to pregnant patients and may affect fetal oxygenation.[22]

Although historically a flow to achieve a maternal $SaO_2$ above 95% has been recommended, this is rarely achievable in clinical practice.[24,26] A more realistic goal may be a $PaO_2$ above 60 mm Hg, which corresponds to a $SaO_2$ of at least 90%.[22]

At any given ECMO blood flow, $CO_2$ removal is more efficient than oxygenation, as $CO_2$ is more soluble than oxygen.[27,28] $CO_2$ removal is directly proportional to the sweep gas rate set by the operator.[21]

Pregnancy-induced hyperventilation results in a $PaCO_2$ of 28 to 32 mm Hg; the latter allows for a fetal to maternal $PaCO_2$ gradient favoring diffusion of $CO_2$ from fetal to maternal blood.[22,29–32] Severe ARDS usually leads to hypercarbia and ineffective ventilation.[33] Although this may be partially corrected with increases in sweep gas flow during ECMO, commonly, some degree of hypercarbia will remain despite full ECMO support. Increased maternal $PaCO_2$ results in $CO_2$ fetal accumulation with fetal respiratory acidosis and category 2 fetal monitoring tracings (delivery for the latter is rarely indicated). Ideally, we recommend avoiding maternal $PaCO_2$ values above 60 mm Hg, when possible.

Severe maternal acidosis with arterial PH <7.25 may be poorly tolerated by the fetus, resulting in non-reassuring electronic fetal monitoring patterns. Acid-base status is usually improved by treating the underlying cause (eg, sepsis, decreased cardiac output) and optimizing the ECMO settings (mainly increasing the sweep gas flow) as opposed to proceeding with immediate delivery unless a category 3 fetal monitoring pattern is present. Despite the limiting evidence, some propose temporary interventions to improve serum PH with the use of sodium bicarbonate or renal replacement therapy while addressing the main cause of the acidosis.[24,34]

## LUNG REST STRATEGIES

As previously stated, the main goal of VV ECMO is to guarantee gas exchange and oxygenation while minimizing the VILI, allowing time for the lungs to heal from the primary insult. Once oxygenation and $CO_2$ clearance are improved with ECMO, ultraprotective mechanical ventilation may be applied to decrease further the iatrogenic lung injury from high pressures and high oxygen concentrations. This is usually achieved by decreasing both the tidal volumes (to values as low as 100 to 300 mL to maintain plateau pressures well below 30 cm $H_2O$) and the inspired fraction of oxygen ($FiO_2$). The optimal tidal volume and $FiO_2$ to achieve ultraprotective ventilation are unknown; however, aiming for a plateau pressure below 30 cm $H_2O$ is reasonable.[35] Although it is common practice to lower the tidal volume, respiratory rate, and $FiO_2$, some degree of PEEP should be maintained to keep the lungs open and to avoid atelectasis. Commonly, a PEEP of 10 to 12 cm $H_2O$ is sufficient to avoid complete lung collapse. The use of PEEP, low tidal volumes to decrease plateau pressure, and lower respiratory rates improve survival.[36–38] Despite these suggestions, as previously discussed, the ideal ventilation parameters during VV ECMO are still largely unknown in both pregnant and nonpregnant patients.[39]

## FETAL CONSIDERATIONS DURING VV ECMO

Any maternal condition compromising respiratory function has the potential to affect the fetus. The fetal impact of most maternal critical illnesses will be directly proportional to the degree of hemodynamic instability and/or oxygenation/ventilation compromise of the mother.[40]

Importantly, the fetus may tolerate a certain degree of hypoxemia through numerous physiological adaptations such as a leftward shift of the fetal oxygen-hemoglobin dissociation curve, fetal

polycythemia, and redistribution of fetal blood flow to the vital organs.[41,42]

As uterine blood flow is poorly autoregulated and is highly dependent on uterine perfusion pressure, any condition limiting uterine perfusion (eg, aortocaval compression) will have a great impact on the fetoplacental blood flow.[43] As such, left lateral decubitus position using a cushion or a pillow under the right hip is recommended during all ECMO runs.[32,44–46]

Maternal hypoxemia, hypercarbia with respiratory acidosis, and/or hypovolemia may all result in non-reassuring fetal heart rate tracings. If hypoxemia is detected, increasing ECMO flow will improve the fetal status by improving the maternal oxygenation; similarly, increases in sweep flow will increase $CO_2$ clearance, improving abnormal fetal tracings secondary to maternal acidemia. In cases of hypovolemia, the replacement of volume or blood products as indicated will improve uteroplacental perfusion without the need of an urgent delivery.

Continuous fetal heart rate monitoring may be utilized in viable pregnancies.[47] Importantly, once patients are started on VV ECMO, and oxygenation and $CO_2$ clearance improve, the fetal status also tends to improve. The decision to deliver the fetus in patients with VV ECMO is a difficult one and no evidence-based guidelines are available to guide the management. Before 23 to 24 weeks (viability), delivery should only be considered as part of an advanced cardiac life support to improve the efficacy of cardiopulmonary resuscitation. In viable pregnancies, the administration of steroids should be undertaken, and continuous fetal monitoring may be instituted when a multidisciplinary team (led by the obstetrician/maternal fetal medicine) considers it reasonable. During VV ECMO, it is extremely unlikely that delivery will improve the respiratory status as gas exchange is mainly undertaken in the ECMO circuit. Emergent delivery may be indicated in cases of category 3 tracings not improved rapidly with hemodynamic optimization and ECMO flow/gas adjustments. Although some recommend delivery after 32 weeks in patients receiving VV ECMO, the latter is arbitrary and is not always indicated in stable patients in whom, despite being on VV ECMO, oxygenation is stable or improving. In cases where fetal growth restriction is present, delivery after the completion of steroids is suggested, as the fetal reserve to tolerate acute changes in oxygenation may be limited. If required for delivery, anticoagulation may be held for a few hours while on VV ECMO. In most cases, the route of delivery should be dictated by obstetrical indications.

## *VA ECMO*

In VA ECMO, both the venous and the arterial systems are cannulated. Blood is drained from the cannulated vein and oxygenated blood is returned through the cannulated artery. In general, cannulation may be central or peripheral. Central cannulation occurs mainly during heart surgery for patients who do not tolerate weaning from cardiopulmonary bypass. Cannulas are placed in the right atrium and the proximal aorta. Most obstetrical patients who require VA ECMO will not be undergoing heart surgery; as such, cannulation is peripheral (commonly utilizing the femoral vein and femoral artery).[45,48] The common indications of VA ECMO are listed in Table 2.

Briefly, blood is pulled from the venous system through the femoral vein and is delivered to the extracorporeal oxygenator, where it is exposed through a semipermeable membrane to oxygenated gas (sweep gas). The fraction of delivered oxygen is the concentration of oxygen the operator determines for the sweep gas; the latter is commonly set at 1.0 (100% oxygen). Like VV ECMO, $CO_2$

***TABLE 2. Common Indications for Venoarterial ECMO***

| |
|---|
| Inability to wean cardiopulmonary bypass during heart surgery |
| Profound persistent right ventricular failure (eg, secondary to pulmonary embolism, severe pulmonary hypertension, amniotic fluid embolism, and right ventricular myocardial infarction) |
| Profound persistent left ventricular failure (eg, secondary to myocarditis, peripartum cardiomyopathy, and myocardial infarction) |
| Need for prolonged cardiopulmonary resuscitation (at least 10 min), with a potentially reversible cause (eg, bupivacaine intoxication) |

ECMO indicates extracorporeal membrane oxygenation.

clearance depends on the flow of sweep gas (the higher the flow, the higher the clearance of $CO_2$), whereas the oxygenation is determined by the rate of blood flow through the circuit. After gas exchange is completed, the oxygenated blood is returned to the arterial circulation retrogradely through the cannula placed into the femoral artery; this flow into the arterial system provides hemodynamic support and determines the blood pressure. To prevent ischemia of the cannulated extremity, a small arterial cannula is commonly placed to divert oxygenated blood from the return arterial site into the artery distal to the cannulation site.[49] Despite this, it is of paramount importance to periodically evaluate the cannulated extremity for signs of hypoperfusion (eg, cold, clammy, cyanotic leg, weak distal pulses, pain out of proportion, and significant edema).[49]

The fact that oxygenated blood will flow in a retrograde manner through the arterial system will have significant consequences for left ventricular function by dramatically increasing the afterload.[50] As many patients requiring VA ECMO will have severe left ventricular dysfunction, increased afterload (from retrograde flow coming from the ECMO circuit) may worsen stroke volume with left ventricular inability to eject blood. Distension of the left ventricle will compress the free wall against the pericardium with coronary compression, decreased left ventricular perfusion, and subsequent inability of the ventricular tissue to recover normal function. Stasis of blood within the ventricular cavity will increase the risk of thrombosis and eventual catastrophic embolic events.[51]

Clinicians caring for patients on VA ECMO should ensure that the left ventricle is able to contract and generate a stroke volume. This may be accomplished by regular surveillance with transthoracic echocardiography and evaluation of the arterial line waveform. The latter will have some degree of pulsatile flow if the left ventricle is contracting; sudden loss of pulsatility in the arterial line tracing (especially in the setting of a recent increase in ECMO flow) should alert the clinician of excessive afterload and severe left ventricular dysfunction. Potential solutions to improve the ventricular performance include decreasing the ECMO blood flow and/or adding inotropes (eg, dobutamine and milrinone) to improve myocardial contractility. If the problem persists, unloading of the left ventricle may be accomplished with the placement of a percutaneous left ventricular assist device such as an Impella (drains blood from the left ventricular cavity directly to the aorta, bypassing the aortic valve).[51]

Another potentially serious complication of VA ECMO (with peripheral cannulation) is the Harlequin or North-South Syndrome.[52]

As explained previously, oxygenated blood returning to the femoral artery from the ECMO circuit will ascend to the chest retrogradely. At the same time, the left ventricle will have some degree of contractility and will also expel blood anterogradely. The anatomic point where both flows meet is known as the mixing point. In patients with coexistent lung disease, it is possible that the ejected

blood from the left ventricle may be poorly oxygenated and this flow (not the oxygenated blood coming from the ECMO circuit) will be preferentially perfusing the coronaries and the brain, with a potential for brain ischemia and stroke. Figure 1 depicts the Harlequin syndrome.

The ideal scenario is one where the ECMO flow is sufficient to "push the mixing point proximally" (toward the heart) so that the oxygenated blood perfuses the brain. The latter may be achieved by increasing the ECMO flow as long as it does not result in decreased left ventricular contractility, as previously discussed. If the latter is not an option, because of concerns of excessive afterload to the already severely compromised left ventricle, optimization of mechanical ventilation (eg, increased inspired oxygen fraction, appropriate use of PEEP, recruitment maneuvers) may improve the oxygenation of blood pumped by the left ventricle.

Because of the risk of Harlequin syndrome with peripheral cannulation, arterial lines in patients on VA ECMO should ideally be placed on the upper right extremity as opposed to the left side.[45] Arterial blood gases from the left upper extremity may reflect high oxygen concentrations from oxygenated blood returning from the ECMO circuit, whereas deoxygenated blood from the left ventricle will not be detected. On the contrary, as the takeoff of the right subclavian artery is closer to the heart, such deoxygenated blood, if present, will be identified on the right radial artery earlier.

Once started, blood flow (commonly between 3 and 6 L/min) will provide oxygenation and hemodynamic support, whereas the sweep gas flow deter mines the clearance of $CO_2$. When the patient starts improving hemodynamically, weaning of ECMO is accomplished by gradually decreasing the blood flow as long as the patient remains hemodynamically stable. Intrinsic heart performance is regularly evaluated with serial transthoracic echocardiography during the weaning process. Once patients tolerate low flows (1 to 1.5 L/min), decannulation will likely be successful.[53]

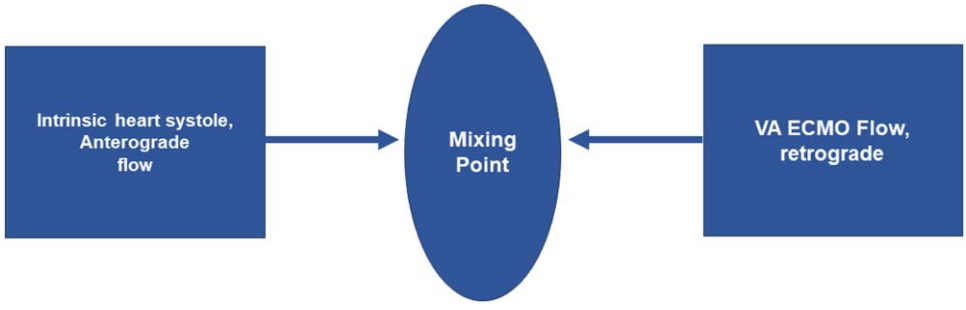


***FIGURE 1.*** Interaction between anterograde flow from the heart and retrograde flow from the extracorporeal membrane oxygenation (ECMO) circuit in venoarterial (VA) ECMO. The mixing point is the point where the blood ejected from the heart joins or mixes with the blood returning from the ECMO circuit. Increasing the ECMO blood flow will displace the mixing point proximally toward the left ventricular outflow allowing for better oxygenation of the brain and coronary arteries but at the price of increasing afterload to the left ventricle. Similarly, decreasing ECMO flow will decrease the afterload to the heart but will displace the mixing point distally risking brain hypoxemia especially in patients with lung disease [acute respiratory distress syndrome (ARDS)] in whom the blood ejected from the heart may be poorly oxygenated. full color online

## *Anticoagulation During ECMO (VV and VA)*

Blood interaction with extracorporeal circuits results in a prothrombotic state commonly requiring some form of anticoagulation. Although in some cases both VV and VA ECMO may be successfully used without anticoagulation in patients at high risk of bleeding for short periods, the use of anticoagulation is the standard of care.

Traditionally, unfractionated heparin (UFH) has been the agent of choice.[54] The advantages of UFH include ease of titration, short half-life (60 to 90 min), and availability of an antidote (protamine sulfate). Most centers will titrate UFH to an activated partial thromboplastin time (aPTT) of 40 to 60 seconds. Recently, the use of anti-Xa levels (in lieu of aPTT) for UFH titration has been shown to be more accurate in achieving therapeutic levels faster with less dose adjustments.[55] Similarly, the anti-Xa test is not affected by elevations of factor VIII and fibrinogen commonly seen in acute diseases and pregnancy. During ECMO runs, the goal anti-Xa is usually 0.2 to 0.4 U/mL. We recommend titrating UFH using anti-Xa levels in lieu of aPTT.

In nonpregnant individuals, the direct thrombin inhibitor bivalirudin results in less bleeding and circuit thrombosis compared with UFH and has become the anticoagulant of choice in many ECMO centers.[54] Safety data on bivalirudin during pregnancy is limited and we recommend the use of intravenous UFH as the anticoagulant of choice in pregnant women receiving any form of ECMO until more data are available for alternative agents such as bivalirudin or argatroban.

## *ECMO-Associated Complications (VV and VA)*

Despite the significant advances in technology, ECMO remains an invasive intervention with potentially life-threatening complications including mechanical injury during cannulation, circuit thrombosis, infection, coagulopathy and bleeding, hemolysis, and central nervous system injury.

Although a prothrombotic state is present during ECMO secondary to clotting activation during the blood-circuit interaction, an "ECMO-associated coagulopathy" may develop.[56] The latter is multifactorial and different mechanisms coexist, resulting in bleeding complications. First, the priming volume of the extracorporeal circuit results in hemodilution. Second, platelets aggregate and adsorb to the circuit resulting in thrombocytopenia and platelet dysfunction. Third, acquired Von Willebrand disease may develop within 1 day of ECMO initiation. Large Von Willebrand multimers (normally secreted as folded glycoproteins by the endothelium) are unfolded as they circulate through the extracorporeal circuit due to shear stress forces leaving their binding sites exposed to the metalloproteinase ADAMTS-13 resulting in cleavage with rapid degradation.[56] Large multimers are the most effective in binding to exposed collagen and platelets, as such, their deficiency increases the risk of hemorrhagic complications. Most ECMO centers will transfuse packed red cells to maintain hemoglobin above 7 to 8 g/dL and platelets if $<50{,}000/mm^3$.

Acute brain injury is the most devastating complication from ECMO and may include ischemic stroke, hemorrhagic stroke, and acute hypoxemic brain injury.[57] The rate of brain injury may be as high as 19% in VA ECMO and 11% in VV ECMO.[58] Although ischemic complications and anoxic injuries are typically more common in VA ECMO, the incidence of intracranial hemorrhage (5% to 10%) appears to be similar in both forms of cannulation.

Other complications seen in VA ECMO, such as Harlequin syndrome and

profound left ventricular failure induced by excessive afterload from the retrograde blood return from the ECMO circuit, have been previously described in this article. Table 3 summarizes common complications associated with ECMO.

## *VA ECMO During Pregnancy*

Data regarding VA ECMO use during pregnancy and the immediate postpartum are extremely limited. In a recently published series from a single academic center, only 1 case was VA ECMO.[59] Moore et al[44] reported 4 cases of VA ECMO during pregnancy in a review of the literature from 1991 to 2015. Similarly, in a systematic review of the literature between 1974 and 2019, only 145 cases were identified.[15] Importantly, many of these cases usually follow maternal cardiac arrest and perimortem cesarean delivery limiting even more available data to guide obstetrical management while on VA ECMO. We suggest that in viable pregnancies ($>24$ wk) requiring VA ECMO, clinicians consider continuous fetal monitoring, steroids for lung maturity, and early delivery in non-reassuring fetal tracings as the effects of long-term retrograde nonpulsatile flow on the fetus are largely unknown.[45] It is of paramount importance that patients are always on lateral decubitus, as uterine compression of the inferior vena cava and aorta may limit VA ECMO flow. Compression of cannulas by the gravid uterus is less of a concern in cases of VV ECMO, as most patients will have a single cannula in the right internal jugular vein.[45]

## *Conclusions*

The use of VV and VA ECMO during pregnancy and the postpartum period has increased mirroring the increased utilization in nonpregnant individuals. VV ECMO provides respiratory support for patients with ARDS who fail conventional mechanical ventilation. With the COVID-19 pandemic, the use of VV ECMO has increased worldwide, and data during the pregnancy and the postpartum period are overall reassuring. In contrast, VA ECMO provides both respiratory and hemodynamic support by returning fully oxygenated blood to the arterial system. Data during pregnancy are more limited; however, its use in refractory cases of severe right and/or left ventricular failure secondary to pulmonary embolism, amniotic fluid embolism, and peripartum cardiomyopathy continues to increase.

Overall, the management of ECMO in pregnant patients should be similar to nonpregnant individuals. Main differences include fetal and delivery timing

***TABLE 3. Common Complications With VV-/VA ECMO Support***

| Circuit Thrombosis | Prevent With Systemic Anticoagulation |
|---|---|
| Bleeding | Etiology is multifactorial, including anticoagulation, thrombocytopenia, acquired Von Willebrand disease |
| Infection | Prophylactic antibiotics commonly used in many ECMO centers despite the limited evidence |
| Hemolysis | Some degree of hemolysis may occur from the negative pressure generated by the pump. Excessive hemolysis maybe due to cannula malposition, hypovolemia, or high flow rates |
| Thrombocytopenia | May require transfusion of platelets if active bleeding or $<50{,}000/mm^3$ |
| Neurological complications | Include both ischemic and hemorrhagic strokes and anoxic brain injury. Overall, more common in VA ECMO. |

ARDS indicates adult respiratory distress syndrome; ECMO, extra corporeal membrane oxygenation; VA, venoarterial; VV, venovenous.

considerations, avoidance of alternative anticoagulant agents for which there is limited evidence during pregnancy, and lateral decubitus, especially for patients on VA ECMO who have femoral cannulas to avoid compression and flow limitations.

## *References*


1. Joseph KS, Lisonkova S, Muraca GM, et al. Factors underlying the temporal increase in maternal mortality in the United States. *Obstet Gynecol*. 2017;129:91–100.
2. Easter SR, Bateman BT, Sweeney VH, et al. A comorbidity-based screening tool to predict severe maternal morbidity at the time of delivery. *Am J Obstet Gynecol*. 2019;221:271.e271–271.e210.
3. Leonard SA, Main EK, Carmichael SL. The contribution of maternal characteristics and cesarean delivery to an increasing trend of severe maternal morbidity. *BMC Pregnancy Childbirth*. 2019;19:16.
4. Nair P, Davies AR, Beca J, et al. Extracorporeal membrane oxygenation for severe ARDS in pregnant and postpartum women during the 2009 H1N1 pandemic. *Intensive Care Med*. 2011;37:648–654.
5. Dubar G, Azria E, Tesnière A, et al. French experience of 2009 A/H1N1v influenza in pregnant women. *PLoS One*. 2010;5:e13112.
6. 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;127:241–247.
7. Zambrano LD, Ellington S, Strid P, et al. Update: characteristics of symptomatic women of reproductive age with laboratory-confirmed SARS-CoV-2 infection by pregnancy status - United States, January 22-October 3, 2020. *MMWR Morb Mortal Wkly Rep*. 2020;69:1641–1647.
8. London V, McLaren R Jr, Atallah F, et al. The relationship between status at presentation and outcomes among pregnant women with COVID-19. *Am J Perinatol*. 2020;37:991–994.
9. Dashraath P, Wong JLJ, Lim MXK, et al. Coronavirus disease 2019 (COVID-19) pandemic and pregnancy. *Am J Obstet Gynecol*. 2020;222:521–531.
10. 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;67:132–136.
11. Kayem G, Lecarpentier E, Deruelle P, et al. A snapshot of the Covid-19 pandemic among pregnant women in France. *J Gynecol Obstet Hum Reprod*. 2020;49:101826.
12. 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;205:248–250.
13. 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;67:601–610.
14. Combes A, Schmidt M, Hodgson CL, et al. Extracorporeal life support for adults with acute respiratory distress syndrome. *Intensive Care Med*. 2020;46:2464–2476.
15. Naoum EE, Chalupka A, Haft J, et al. Extracorporeal life support in pregnancy: a systematic review. *J Am Heart Assoc*. 2020;9:e016072.
16. Fielding-Singh V, Matthay MA, Calfee CS. Beyond low tidal volume ventilation: treatment adjuncts for severe respiratory failure in acute respiratory distress syndrome. *Crit Care Med*. 2018;46:1820–1831.
17. Combes A, Hajage D, Capellier G, et al. Extracorporeal membrane oxygenation for severe acute respiratory distress syndrome. *N Engl J Med*. 2018;378:1965–1975.
18. MacLaren G, Combes A, Bartlett RH. Contemporary extracorporeal membrane oxygenation for adult respiratory failure: life support in the new era. *Intensive Care Med*. 2012;38:210–220.
19. Schmidt M, Pham T, Arcadipane A, et al. Mechanical ventilation management during extracorporeal membrane oxygenation for acute respiratory distress syndrome. An International Multicenter Prospective Cohort. *Am J Respir Crit Care Med*. 2019;200:1002–1012.
20. Ngatchou W, Ramadan AS, Van Nooten G, et al. Left tilt position for easy extracorporeal membrane oxygenation cannula insertion in late pregnancy patients. *Interact Cardiovasc Thorac Surg*. 2012;15:285–287.
21. Schmidt M, Tachon G, Devilliers C, et al. Blood oxygenation and decarboxylation determinants during venovenous ECMO for respiratory failure in adults. *Intensive Care Med*. 2013;39:838–846.
22. Bobrowski RA. Pulmonary physiology in pregnancy. *Clin Obstet Gynecol*. 2010;53:285–300.
23. Guntupalli KK, Hall N, Karnad DR, et al. Critical illness in pregnancy: part I: an approach

to a pregnant patient in the ICU and common obstetric disorders. *Chest*. 2015;148:1093–1104.
24. Wong MJ, Bharadwaj S, Galey JL, et al. Extracorporeal membrane oxygenation for pregnant and postpartum patients. *Anesth Analg*. 2022. doi:10.1213/ane.0000000000005861
25. Nunes LB, Mendes PV, Hirota AS, et al. Severe hypoxemia during veno-venous extracorporeal membrane oxygenation: exploring the limits of extracorporeal respiratory support. *Clinics (Sao Paulo)*. 2014;69:173–178.
26. Lankford AS, Chow JH, Jackson AM, et al. Clinical outcomes of pregnant and postpartum extracorporeal membrane oxygenation patients. *Anesth Analg*. 2021;132:777–787.
27. Brodie D, Slutsky AS, Combes A. Extracorporeal life support for adults with respiratory failure and related indications: a review. *JAMA*. 2019;322: 557–568.
28. Boyle AJ, Sklar MC, McNamee JJ, et al. Extracorporeal carbon dioxide removal for lowering the risk of mechanical ventilation: research questions and clinical potential for the future. *Lancet Respir Med*. 2018;6:874–884.
29. Hegewald MJ, Crapo RO. Respiratory physiology in pregnancy. *Clin Chest Med*. 2011;32:1–13.
30. Lapinsky SE, Posadas-Calleja JG, McCullagh I. Clinical review: ventilatory strategies for obstetric, brain-injured and obese patients. *Crit Care*. 2009;13:206.
31. Ivankovic AD, Elam JO, Huffman J. Effect of maternal hypercarbia on the newborn infant. *Am J Obstet Gynecol*. 1970;107:939–946.
32. Zieleskiewicz L, Chantry A, Duclos G, et al. Intensive care and pregnancy: epidemiology and general principles of management of obstetrics ICU patients during pregnancy. *Anaesth Crit Care Pain Med*. 2016;35(suppl 1):S51–S57.
33. Bandi VD, Munnur U, Matthay MA. Acute lung injury and acute respiratory distress syndrome in pregnancy. *Crit Care Clin*. 2004;20:577–607.
34. Deatrick KB, Mazzeffi MA, Galvagno SM Jr, et al. Breathing life back into the kidney-continuous renal replacement therapy and veno-venous extracorporeal membrane oxygenation. *Asaio j*. 2021;67:208–212.
35. Shekar K, Brodie D. Should patients with acute respiratory distress syndrome on venovenous extracorporeal membrane oxygenation have ventilatory support reduced to the lowest tolerable settings? No. *Crit Care Med*. 2019;47:1147–1149.
36. Araos J, Alegria L, Garcia P, et al. Near-apneic ventilation decreases lung injury and fibroproliferation in an acute respiratory distress syndrome model with extracorporeal membrane oxygenation. *Am J Respir Crit Care Med*. 2019;199:603–612.
37. Wang R, Sun B, Li X, et al. Mechanical ventilation strategy guided by transpulmonary pressure in severe acute respiratory distress syndrome treated with venovenous extracorporeal membrane oxygenation. *Crit Care Med*. 2020;48:1280–1288.
38. Gattinoni L, Tonetti T, Cressoni M, et al. Ventilator-related causes of lung injury: the mechanical power. *Intensive Care Med*. 2016;42:1567–1575.
39. Jenks CL, Tweed J, Gigli KH, et al. An international survey on ventilator practices among extracorporeal membrane oxygenation centers. *Asaio j*. 2017;63:787–792.
40. Behrman RE, Lees MH, Peterson EN, et al. Distribution of the circulation in the normal and asphyxiated fetal primate. *Am J Obstet Gynecol*. 1970;108:956–969.
41. Acharya G, Sitras V. Oxygen uptake of the human fetus at term. *Acta Obstet Gynecol Scand*. 2009;88:104–109.
42. Cousins L. Fetal oxygenation, assessment of fetal well-being, and obstetric management of the pregnant patient with asthma. *J Allergy Clin Immunol*. 1999;103:S343–S349.
43. Venuto RC, Cox JW, Stein JH, et al. The effect of changes in perfusion pressure on uteroplacental blood flow in the pregnant rabbit. *J Clin Invest*. 1976;57:938–944.
44. Moore SA, Dietl CA, Coleman DM. Extracorporeal life support during pregnancy. *J Thorac Cardiovasc Surg*. 2016;151:1154–1160.
45. Pacheco LD, Saade GR, Hankins GDV. Extracorporeal membrane oxygenation (ECMO) during pregnancy and postpartum. *Semin Perinatol*. 2018;42:21–25.
46. Carlier L, Devroe S, Budts W, et al. Cardiac interventions in pregnancy and peripartum - a narrative review of the literature. *J Cardiothorac Vasc Anesth*. 2020;34:3409–3419.
47. Muench MV, Canterino JC. Trauma in pregnancy. *Obstet Gynecol Clin North Am*. 2007;34: 555–583; xiii.
48. Bohman JK, Ratzlaff RA, DeMartino ES, et al. Approach to adult extracorporeal membrane oxygenation patient selection. *Crit Care Med*. 2020;48:618–622.
49. Bonicolini E, Martucci G, Simons J, et al. Limb ischemia in peripheral veno-arterial extracorporeal membrane oxygenation: a narrative review of incidence, prevention, monitoring, and treatment. *Crit Care*. 2019;23:266.
50. Donker DW, Brodie D, Henriques JPS, et al. Left ventricular unloading during veno-arterial ECMO: a simulation study. *ASAIO Journal*. 2019;65:11–20.
51. Rob D, Belohlavek J. The mechanical support of cardiogenic shock. *Curr Opin Crit Care*. 2021;27: 440–446.
52. Pasrija C, Bedeir K, Jeudy J, et al. Harlequin syndrome during venoarterial extracorporeal membrane oxygenation. *Radiol Cardiothorac Imag*. 2019;1:e190031.

53. Ortuno S, Delmas C, Diehl JL, et al. Weaning from venoarterial extra corporeal membrane oxygenation: which strategy to use. *Ann Cardiothorac Surg*. 2019;8:E1–E8.
54. Seelhammer TG, Bohman JK, Schulte PJ, et al. Comparison of bivalirudin versus heparin for maintenance systemic anticoagulation during adult and pediatric extracorporeal membrane oxygenation. *Crit Care Med*. 2021;49:1481–1492.
55. Whitman-Purves E, Coons JC, Miller T, et al. Performance of anti-factor Xa versus activated partial thromboplastin time for heparin monitoring using multiple nomograms. *Clin Appl Thromb Hemost*. 2018;24:310–316.
56. Granja T, Hohenstein K, Schussel P, et al. Multimodal characterization of the coagulopathy associated with extracorporeal membrane oxygenation. *Crit Care Med*. 2020;48:e400–e408.
57. Cho SM, Geocadin RG, Caturegli G, et al. Understanding characteristics of acute brain injury in adult extracorporeal membrane oxygenation: an autopsy study. *Crit Care Med*. 2020;48: e532–e536.
58. Shoskes A, Migdady I, Rice C, et al. Brain injury is more common in venoarterial extracorporeal membrane oxygenation than venovenous extracorporeal membrane oxygenation: a systematic review and meta-analysis. *Crit Care Med*. 2020;48:1799–1808.
59. Webster CM, Smith KA, Manuck TA. Extracorporeal membrane oxygenation in pregnant and postpartum women: a ten-year case series. *Am J Obstet Gynecol MFM*. 2020;2:100108.