ELSO 2025 NARRATIVE GUIDELINE ON PREGNANT AND PERIPARTUM EXTRACORPOREAL MEMBRANE OXYGENATION

Erika R. O'Neil,*† Ahmed Labib Shehatta,‡§ Cara Agerstrand,¶‖ Caroline Sampson,# Farah Siddiqui,** Priya Nair,††‡‡ Alexandra L. Schou,§§ Javier Kattan,¶¶ and Emily E. Naoum‖‖##

Reviewers: Marc Anders, Kollengode Ramanathan, and Matteo Di Nardo

***Disclaimer*: These guidelines on extracorporeal membrane oxygenation (ECMO) are intended for educational use to build the knowledge of physicians and other health professionals in assessing the conditions and managing the treatment of patients undergoing ECMO and describe what are believed to be useful and safe practices for ECMO. Guidelines aim to help clinicians make informed decisions about their patients. However, adherence to a guideline does not guarantee a successful outcome. Healthcare professionals must make their own treatment decisions about care on a case-by-case basis, after consultation with their patients, using their clinical judgment, knowledge, and expertise. These guidelines do not take the place of the physicians' and other health professionals' judgment in the diagnosis and treatment of ECMO patients. These guidelines are not intended to and should not be interpreted as setting a standard of care or being deemed inclusive of all proper methods of care, nor exclusive of other methods of care directed at obtaining the same results. The ultimate judgment must be made by the physician, other health professionals, and the patient/patient family, considering all the circumstances presented by the individual patient, and the known variability and biologic behavior of the clinical condition. These guidelines reflect the data at the time the guidelines were prepared. The results of subsequent studies or other information may lead to revisions of the recommendations in these guidelines. In no event will ELSO be liable for any decision made or action taken in reliance upon the information provided through these guidelines. *ASAIO Journal* 2025; XX:XX–XX**

Key Words: peripartum ECMO, ECMO in pregnancy, peripartum patients supported by ECMO

At the time of publication of this guideline, the leading causes of maternal death for pregnant and peripartum patients include hemorrhage, infection, eclampsia, thromboembolism, and cardiac disease.[1–3] Not only are these causes of death preventable, but they have also been successfully supported with extracorporeal membrane oxygenation (ECMO).[4–8] In fact, survival for peripartum patients supported on ECMO is higher than any other population supported on ECMO.[9] Physiologic changes, such as impaired right atrial venous return and hypercoagulability, however, make ECMO support in these patients complicated.[10–12] Specific guidance for the successful support of these patients using ECMO is lacking. The Extracorporeal Life Support Organization (ELSO), with subject matter experts, performed a literature search, screening 378 articles, fully reading 98 manuscripts, and narrowing the references down to 87 publications to guide ECMO use in pregnant and peripartum patients. A summary of our recommendations can be found in Table 1.

Indications

Extracorporeal membrane oxygenation indications during pregnancy and peripartum are most commonly the same as in other populations, however, there are pregnancy-specific indications. Published reports quote ECMO in refractory acute respiratory distress syndrome (ARDS) and respiratory failure as the most common indication for peripartum ECMO, seen in 50% of peripartum cases, followed by

From the *United States Air Force, Department of Pediatrics, Brooke Army Medical Center, San Antonio, Texas; †Uniformed Services University of Health Sciences, Bethesda, Maryland; ‡Medical Intensive Care Unit, Hamad General Hospital, Doha, Qatar; §Weill Cornell Medical College, Doha, Qatar; ¶Division of Pulmonary, Allergy & Critical Care Medicine, Columbia University Irving Medical Center New York City, New York, New York; ‖New York-Presbyterian Hospital, New York City, New York; #Anesthesia, Critical Care and Adult Extracorporeal Membrane Oxygenation (ECMO), University Hospitals of Leicester National Health Service (NHS) Trust, Glenfield Hospital, Leicester, UK; **Fetal and Maternal Medicine, University Hospitals of Leicester NHS Trust, Leicester Royal Infirmary, Leicester, UK; ††Intensive Care Unit, St Vincents Hospital, Sydney, Australia; ‡‡University of New South Wales, Sydney, Australia; §§Department of Anaesthesia and Intensive Care, Copenhagen University Hospital - Bispebjerg, Copenhagen, Denmark; ¶¶Department of Neonatology, Pontificia Universidad Católica de Chile School of Medicine, Santiago, Chile; ‖‖Department of Anesthesia, Critical Care and Pain Medicine, Massachusetts General Hospital, Boston, Massachusetts; and ##Harvard Medical School, Boston, Massachusetts.

Submitted for consideration July 2025; accepted for publication in revised form August 2025.

Disclosure: The authors have no conflicts of interest to report.

Correspondence: Erika R. O'Neil, United States Air Force, Department of Pediatrics, Brooke Army Medical Center, San Antonio, TX. Email: erika.oneil.md@gmail.com.

DOI: 10.1097/MAT.0000000000002556

Table 1. Summary of Recommendations

- Unique indications for pregnant and peripartum ECMO include peripartum cardiomyopathy, amniotic fluid embolism, and eclampsia syndromes
- Changes in physiology affect nearly every organ system and require consideration for hemodynamic, oxygenation, ventilation, and anticoagulation goals in peripartum patients requiring ECMO
- ECMO gas exchange goals in pregnancy are pH > 7.3, $PaCO_2$ 30–40 mm Hg, PaO_2 > 70 mm Hg
- ECMO flows may be higher due to increased cardiac output in pregnancy
- Pregnant and peripartum women may be cannulated using all configurations
- Heparin does not cross the placenta and is the most well-studied anticoagulant for ECMO in pregnant women
- Heparin for the circuit should be paused for any patient who is suspected to be in labor or bleeding
- Anesthesia techniques for vaginal and cesarean delivery on ECMO may be achieved with systemic medications as regional techniques are limited in the context of anticoagulation and acquired coagulopathy
- The use of intravenous analgesia and anesthesia for delivery is preferred over inhaled agents in ECMO patients with significant pulmonary pathology
- Rehabilitation and early mobilization of the pregnant and parturient on ECMO is recommended
- Extubation on ECMO can be considered on a case-by-case and when airway difficulty can be excluded
- There are no ECMO-related contraindications to breastfeeding
- Fetal monitoring for pregnant women on ECMO is recommended
- We recommend early routine and preemptive ethics consultations with multidisciplinary expertise and close communication with the patient (if awake) and close relatives

ECMO, extracorporeal membrane oxygenation.

cardiogenic shock in one-third and extracorporeal cardiopulmonary resuscitation (CPR) in about 18%.[4,9] Bacterial and viral pneumonia, such as H1N1 and severe acute respiratory syndrome **coronavirus 2 (**SARS-CoV-2), leading to ARDS are typical indications.[9,13,14] Pre-eclampsia and eclampsia, hemolysis, elevated liver enzymes, and low platelets (HELLP) syndrome are specific disorders of pregnancy and peripartum period and indications for venovenous (VV) ECMO.[4,9] Pulmonary embolism is a leading cause of maternal morbidity and mortality, and ECMO can provide cardiovascular rescue in such cases.[4] The relatively uncommon amniotic fluid embolism is associated with very high maternal mortality, and venoarterial (VA) ECMO has been used with variable degrees of success.[12] Peripartum cardiomyopathy or worsening of pre-pregnancy cardiac disease are indications for VA ECMO.[4,9,15] Indications for ECMO in obstetric patients are listed in Figure 1.[4,9,12]

Extracorporeal Cardiopulmonary Resuscitation

Extracorporeal cardiopulmonary resuscitation (ECPR), defined as the deployment of VA ECMO during chest compressions or if sustained return of spontaneous circulation (ROSC) cannot be achieved, should be strongly considered in pregnant and postpartum patients as etiologies of the arrest are most likely reversible and survival is high.[4,9] The decision to provide ECPR for these women is not hard, but the preparation is challenging as not all ECMO teams are sufficiently experienced to manage such rare scenarios (*ie*, multiple teams working on the same patient to manage bleeding while performing CPR and cannulating for ECMO). Thus, hospitals should integrate an ECMO team notification early into their maternal cardiac arrest alert system so that the team can expeditiously bring the cannulation equipment and ECMO circuit. In an experienced center, we recommend that patients be cannulated during or immediately after the resuscitative hysterotomy if pregnant and as soon as possible with ongoing CPR to achieve the best neurological outcomes possible.[16] Cardiac arrest response teams, ECMO teams, and obstetrics should familiarize themselves with each other's roles, procedures, and environments during ECPR and train together regularly to allow for a swift response, smooth cannulations, and good outcomes for these women. Simulation is a valuable tool in ECMO and should strongly be considered for pregnant and peripartum ECPR training.

Contraindications

No established absolute contraindications to ECMO in pregnancy or peripartum exist, and these are typically extrapolated from the wider non-obstetrical population.[17] Obstetric emergencies such as eclamptic seizures, HELLP syndrome, placenta previa, and uncontrolled coagulopathy and hemorrhage may be regarded as relative contraindications due to neurological damage or coagulopathy, but ECMO may also be considered after maternal optimization.

Physiologic Changes of Pregnancy Pertinent to ECMO

Many physiological changes occur during pregnancy that may impact ECMO management in these patients (Figure 2).

Pulmonary Changes

Throughout pregnancy, mechanical and biochemical changes occur to accommodate the growth of the fetus. The rise in serum progesterone, estrogen, and relaxin is responsible for many of the pulmonary changes that occur.[18,19] There is an increase in tidal volume, inspiratory capacity, minute ventilation, and diaphragmatic excursion over the course of pregnancy that is most pronounced in the third trimester.[18,19] These changes are accompanied by a decrease in functional residual capacity and residual volume, as well as reduced pulmonary resistance.[18,19] Oxygen consumption increases throughout pregnancy, with the highest demand occurring during labor.[18,19] The combination of increased oxygen demand, reduced functional residual capacity, upper airway edema, and airway friability contributes to a poor tolerance for hypoxia and difficult airway management.[18,19]

Gas exchange at the placenta occurs via the "Double Bohr Effect" and the "Double Haldane Effect."[20] Fetal oxygen

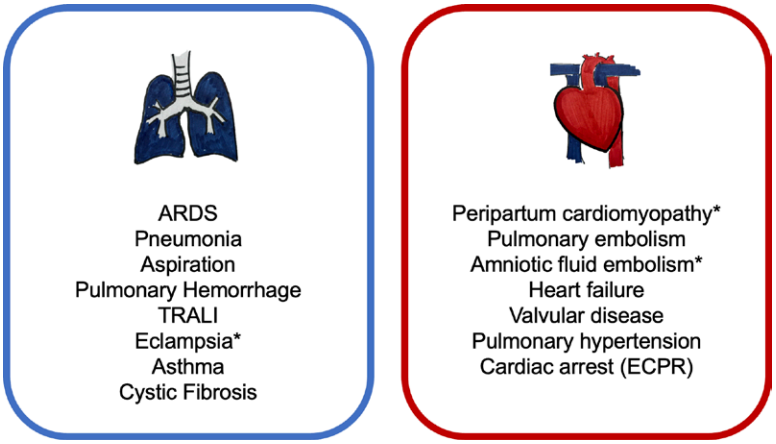


Figure 1. Indications for ECMO in pregnant and postpartum patients. ARDS, acute respiratory distress syndrome; ECMO, extracorporeal membrane oxygenation; ECPR, extracorporeal membrane oxygenation during cardiopulmonary resuscitation; TRALI, transfusion-related acute lung injury. *ECMO unique to the pregnant or peripartum patient.

delivery at the placenta is augmented when the maternal blood is more acidic from carbon dioxide accumulation. The acidity shifts the oxygen dissociation curve, allowing for the unloading of oxygen at the placenta (the Bohr effect).[20] Simultaneously, as fetal blood offloads carbon dioxide to the maternal circulation, it becomes relatively more alkaline, which facilitates increased oxygen uptake (the "Double Bohr Effect"). The delivery of maternal oxygen from the mother to fetus is further enhanced by fetal hemoglobin, which has a higher affinity to bind oxygen.

Carbon dioxide levels are higher in fetal blood when the blood is deoxygenated (the Haldane effect). As maternal blood transfers oxygen across the placenta, it can then accept more carbon dioxide as bicarbonate and carbaminohemoglobin. Simultaneously, as fetal blood takes up oxygen to form oxyhemoglobin, the affinity for carbon dioxide is reduced and, therefore, more easily transferred across the placenta to the mother (the "Double Haldane Effect").

The pulmonary changes of pregnancy result in a shift in arterial blood gas demonstrating a compensated respiratory alkalosis. The PaO_2 increases to 100–105 mm Hg (13.3–14.0 kPa) and normal $PaCO_2$ decreases to 28–32 mm Hg (3.7–4.2 kPa) while maintaining a normal pH to facilitate oxygen transfer across the placenta to the fetus and carbon dioxide unloading from the fetal system to the maternal.[18–21] Targeting the blood gas values of pregnancy is prudent while maintaining these patients on ECMO to support normal fetal oxygen delivery and acid-base status.

Cardiovascular Changes

Hemodynamic changes of pregnancy begin as early as the first trimester and include increased cardiac output (up to 50% increase from pre-pregnancy), increased heart rate, and decreased systemic vascular resistance.[22] This increase in cardiac output serves to support the fetus through the placenta which by term receives 700–900 ml/minute.[23] The need to meet the increased metabolic and oxygen delivery demands of pregnancy may impact these patients by requiring higher flows on ECMO to maintain systemic oxygenation and possibly needing larger cannulas. The peak increase in cardiac output immediately following delivery, rising to nearly 150% pre-pregnancy values, is due to the abrupt increase in venous return and loss of the low-resistance placental circulation.[24,25] This time frame is important to recognize as the highest risk period for patients with congestive heart failure, pulmonary

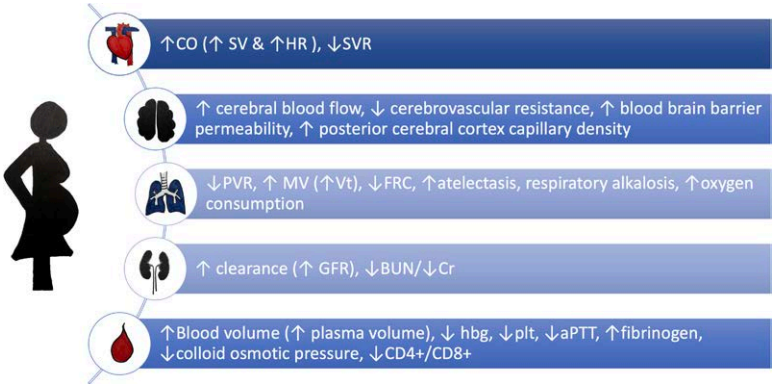


Figure 2. Physiologic changes in pregnant and postpartum patients. aPTT, activated partial thrombin time; BUN, blood urea nitrogen; CD, cluster of differentiation; CO, cardiac output; Cr, creatinine; FRC, functional residual capacity; GFR, glomerular filtration rate; hbg, hemoglobin; HR, heart rate; MV, minute ventilation; plt, platelets; PVR, pulmonary vascular resistance; SV, stroke volume; SVR, systemic vascular resistance.

emboli, amniotic fluid embolism, and other pathologies that may not tolerate the abrupt autotransfusion following delivery and may require urgent or emergent VA ECMO support.

As the gravid uterus grows, the risk of aortocaval compression rises, particularly after 20 weeks of gestation and in the supine position. By term, vena caval compression in the supine position can be associated with decreased venous return, stroke volume, and cardiac output.[26] For this reason, pregnant patients after 20 weeks may need to be positioned with a 15°–30° left lateral tilt to flow well on ECMO.

Neurologic Changes

Throughout pregnancy, there is an increase in cerebral blood flow, a decrease in cerebrovascular resistance, increased permeability of the blood-brain barrier, and an increased capillary density in the posterior cerebral cortex.[27] These changes, particularly in conjunction with hypertensive disorders of pregnancy, which are associated with endothelial dysfunction and impaired cerebral autoregulation, are important to consider when targeting blood pressures. Pregnant patients are at an increased risk of intracranial hemorrhage at lower systolic values and should receive anti-hypertensive medications for sustained pressures greater than or equal to 160/110 mm Hg, according to the American College of Obstetrics and Gynecology (ACOG).[28,29]

Renal Changes

Systemic vascular and renal dilatation results in an increase in glomerular filtration rate (GFR) by up to 50% by the end of the first trimester.[18,30] This increased GFR may impact dosing of anticoagulation or other medications while on ECMO. During pregnancy, the renal calyces, pelvis, and ureters dilate, resulting in physiologic hydronephrosis in up to 80% of women by mid-pregnancy.[31] There is also an increase in urine protein, albumin, and glucose excretion.[18] Sodium reabsorption increases in response to increased renin and aldosterone and helps to accommodate the increased plasma volume in the setting of vasodilation.[18,32]

Hematologic Changes

Pregnancy is associated with a disproportionate expansion of plasma blood volume compared to red blood cells which results in a physiologic anemia of pregnancy.[33] There is a reduction in the fibrinolytic system and an increased concentration of most coagulation factors (I, VII, VIII, IX, X) and von Willebrand Factor, as well as a decrease in protein S, all of which contribute to relative hypercoagulability during pregnancy.[33,34] Venous thromboembolism (VTE) risk is higher during pregnancy due to increased coagulation factors, increased resistance to anti-thrombotic factors, decreased fibrinolysis, venous stasis, and trauma.[35,36] Additionally, women who have undergone assisted reproductive therapies have a 2–3-fold higher risk of VTE, specifically in the upper extremities.[36] Total protein and osmotic pressure decrease throughout pregnancy and may be more pronounced in hypertensive disorders (preeclampsia, eclampsia, and HELLP syndrome) of pregnancy, which can increase the risk of pulmonary edema.[37,38]

Pregnancy Complications Affecting ECMO Management

Obstetric Hemorrhage

Postpartum hemorrhage remains the leading cause of maternal mortality and morbidity, accounting for approximately one-quarter of all maternal deaths worldwide.[1–3] Obstetric bleeding, defined as uterine bleeding, abdominal parietal hematoma, or hemoperitoneum, was reported in 33% of 24 peripartum patients supported with ECMO for severe ARDS.[38] Bleeding was significantly more common in patients commencing ECMO support post-delivery (46%) compared to those commencing ECMO support during pregnancy (18%).[39] In a retrospective review of peripartum patients requiring ECMO support for severe SARS-CoV-2, 36.4% of 22 patients who delivered whilst on ECMO suffered a postpartum hemorrhage.[14] Hemorrhage, however, was not associated with increased mortality and should not be considered a contraindication to ECMO in this population.[9]

Management of obstetric hemorrhage on ECMO should follow standard approaches further detailed by other international organizations, understanding that ECMO may safely continue without anticoagulation if needed.[40] Healthcare providers must anticipate and plan for major obstetric hemorrhage in all patients receiving ECMO support. Immediate interventions include uterotonic agents and uterine massage for atony, removal of retained conception products or tranexamic acid for coagulopathy, progressing to nonsurgical techniques such as intrauterine tamponade, followed by endovascular attempts of vessel embolization, and finally surgical techniques to include sutures, ligation, and hysterectomies.[40] The "4Ts" mnemonic (tone, trauma, tissue, tonics) may aid in the quick evaluation and management of postpartum hemorrhage.[40] An example of postpartum hemorrhage management can be found in Figure 3. As ECMO support is most likely provided in an intensive care unit (ICU) remote from labor suites, obstetric theaters, and interventional radiology suites, a plan must be in place to expeditiously transport or perform these interventions *in situ*. Similar to postpartum hemorrhage, menstrual bleeding can be significant for the patient on ECMO. An example of menstrual bleeding suppression can also be found in Figure 4.

Venous Thromboembolism

Pulmonary embolism remains a leading cause of maternal death in developed countries, and risks are highest in the immediate postpartum period.[3] A systematic review of extracorporeal life support in pregnancy (n = 358) showed that pulmonary embolism was the primary indication for ECMO support in 4.7%.[4] In a retrospective multicenter cohort study on 100 peripartum patients requiring ECMO support for severe SARS-CoV-2, VTE was the most common maternal morbidity reported in 39% of the patients.[14] Additionally, ECMO support is highly associated with VTE occurrence, most commonly at the site of cannulation following liberation from ECMO.[41] Extracorporeal membrane oxygenation providers need to maintain vigilance for VTE in pregnant and postpartum patients requiring ECMO, particularly those with severe SARS-CoV-2. Doppler ultrasound is recommended at ECMO cannulation

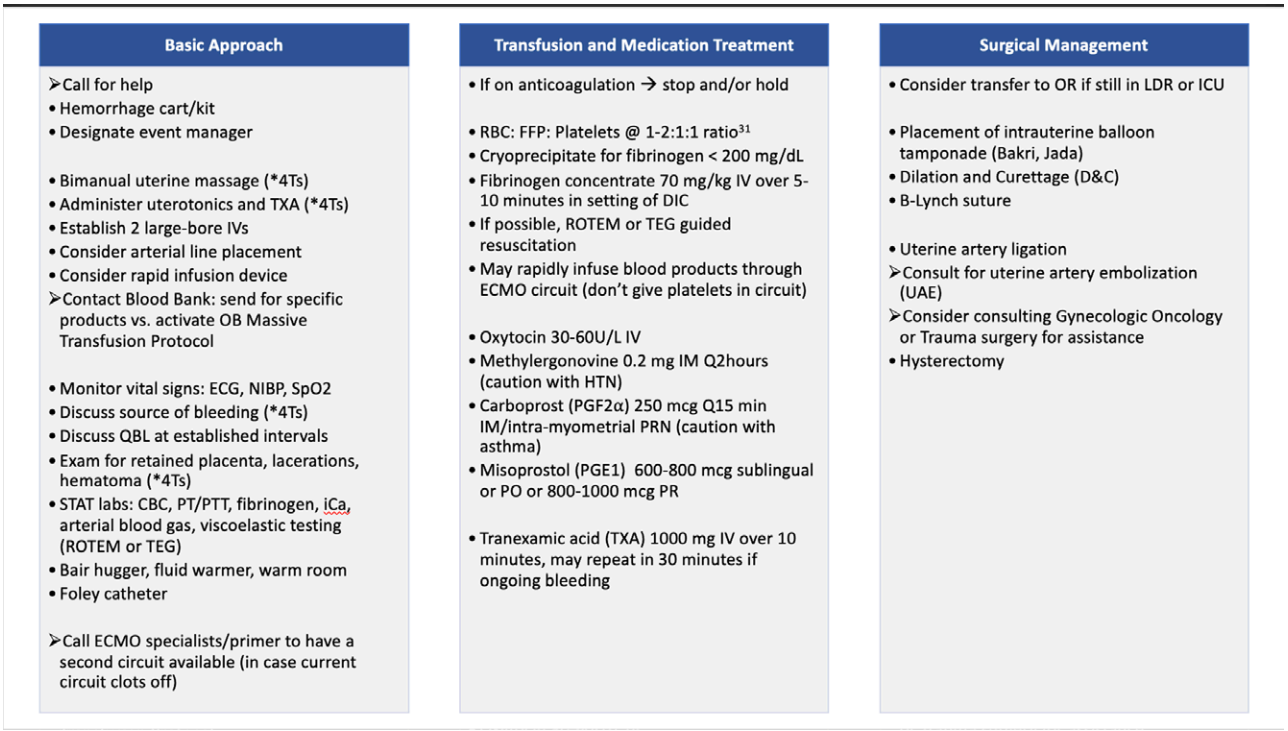


Figure 3. Example of postpartum hemorrhage management. Courtesy of Dr. Emily Naoum. CBC, complete blood count; DIC, disseminated intravascular coagulopathy; ECG, electrocardiogram; ECMO, extracorporeal membrane oxygenation; FFP, fresh frozen plasma; HTN, hypertension; iCa, ionized calcium; ICU, intensive care unit; IM, intramuscular; IV, intravenous; LDR, labor and delivery room; NIBP, noninvasive blood pressure; OB, obstetrics; OR, operating room; PGE, prostaglandin-E1; PRN, as needed; PT, prothrombin time; PTT, partial thromboplastin time; RBC, red blood cells; SpO_2, peripheral oxygen saturation; TXA, tranexamic acid. *"4Ts" mnemonic (tone, trauma, tissue, tonics) is helpful in the evaluation and management of postpartum hemorrhage.

sites in all patients following liberation from ECMO with continuation of anticoagulation until resolution of VTE.

Pre-Eclampsia

Pre-eclampsia, which is associated with endothelial dysfunction and activates an inflammatory process, may lead to ARDS necessitating ECMO support. Specific pre-eclampsia risks, including uncontrolled hypertension and renal or hepatic impairment, present additional maternal risks. Risks of intracranial hemorrhage with the development of pre-eclampsia may be higher with concomitant anticoagulation and ECMO-related coagulopathy. Extracorporeal membrane oxygenation providers must remain vigilant for signs and symptoms of pre-eclampsia with prompt consideration of delivery to reduce maternal morbidity and mortality.[42] Additionally, ECMO patients should be monitored for the progression to HELLP syndrome as the associated coagulopathy and liver dysfunction could impact anticoagulation on ECMO.

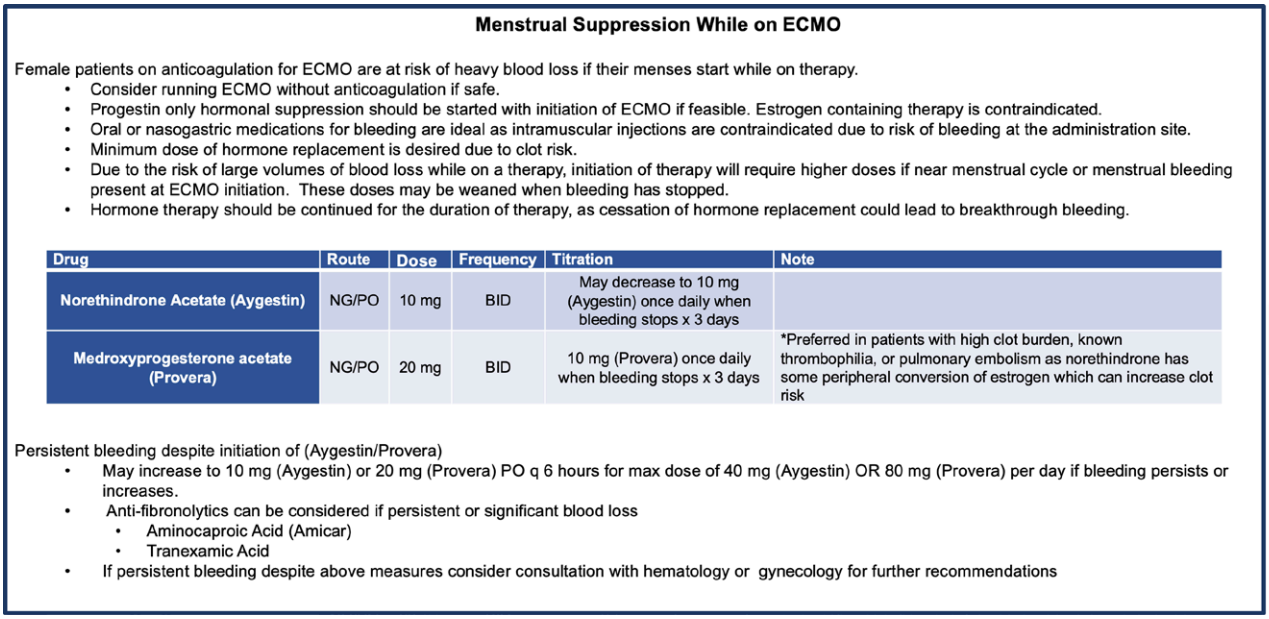
Cardiac Arrest

The causes of cardiac arrest in pregnant and postpartum patients, such as pulmonary embolism, amniotic fluid embolism, arrhythmias, or cardiomyopathy, are frequently reversible and can be supported with ECMO.[4,9] Advanced Cardiac Life Support (ACLS) algorithms should be followed to include alleviating aortocaval compression with manual uterine displacement to improve preload and performing a resuscitative hysterotomy by 5 minutes.[16] Although not yet part of the ACLS algorithm for pregnant patients, we strongly recommend early consideration of ECPR in this population.[16]

Cannulation

Pregnant and peripartum patients have been supported with all modes of ECMO (VV, VA, and venopulmonary [VP]) without reported complications during cannulation.[7,12,43–47] Pregnancy-related alterations in anatomic landmarks and physiologic changes may impact cannulation for ECMO. Pregnant and postpartum patients, however, can be cannulated via all configurations with some special considerations.

As pregnancy increases a woman's cardiac output, two-site cannulation or the use of a larger drainage cannula may be needed to maximize ECMO flows.[7] If cannulating the femoral vessels, consider tilting the patient to the left to relieve compression from the uterus on the inferior vena cava.[47] The internal jugular (IJ) vein overlies more of the carotid artery during pregnancy, which may impact dual lumen IJ cannulation in the pregnant woman.[43] As mentioned previously, VTE occur in pregnant patients due to alterations in the coagulation pathway and venous stasis related to the compression of the IVC as the uterus grows and extra caution should be taken to rule out VTEs, not only in the IVC but also upper extremity vessels, and to evaluate vessel patency before cannulation. Additionally, we recommend imaging with echocardiography and fluoroscopy be performed to confirm appropriate wire and then cannula placement. The risk of vessel or cardiac injury from



Menstrual Suppression While on ECMO

Female patients on anticoagulation for ECMO are at risk of heavy blood loss if their menses start while on therapy.

- Consider running ECMO without anticoagulation if safe.
- Progestin only hormonal suppression should be started with initiation of ECMO if feasible. Estrogen containing therapy is contraindicated.
- Oral or nasogastric medications for bleeding are ideal as intramuscular injections are contraindicated due to risk of bleeding at the administration site.
- Minimum dose of hormone replacement is desired due to clot risk.
- Due to the risk of large volumes of blood loss while on a therapy, initiation of therapy will require higher doses if near menstrual cycle or menstrual bleeding present at ECMO initiation. These doses may be weaned when bleeding has stopped.
- Hormone therapy should be continued for the duration of therapy, as cessation of hormone replacement could lead to breakthrough bleeding.

Drug	Route	Dose	Frequency	Titration	Note
Norethindrone Acetate (Aygestin)	NG/PO	10 mg	BID	May decrease to 10 mg (Aygestin) once daily when bleeding stops x 3 days	
Medroxyprogesterone acetate (Provera)	NG/PO	20 mg	BID	10 mg (Provera) once daily when bleeding stops x 3 days	*Preferred in patients with high clot burden, known thrombophilia, or pulmonary embolism as norethindrone has some peripheral conversion of estrogen which can increase clot risk

Persistent bleeding despite initiation of (Aygestin/Provera)

- May increase to 10 mg (Aygestin) or 20 mg (Provera) PO q 6 hours for max dose of 40 mg (Aygestin) OR 80 mg (Provera) per day if bleeding persists or increases.
- Anti-fibronolytics can be considered if persistent or significant blood loss
  - Aminocaproic Acid (Amicar)
  - Tranexamic Acid
- If persistent bleeding despite above measures consider consultation with hematology or gynecology for further recommendations

Figure 4. Example of menses suppression protocol courtesy of Dr. Krista Childress. BID, twice a day; ECMO, extracorporeal membrane oxygenation; mg, milligrams; NG, nasogastric; OG, orogastric; PO, orally; q, every.

improper cannulation is greater than the radiation exposure to the mother and fetus.

Medications

Anticoagulation

Due to its long history of use, unfractionated heparin (UFH) is the recommended anticoagulant for pregnant patients receiving ECMO support. Unfractionated heparin does not cross the placenta and is not present in breast milk.[48,49] There is limited evidence for the use or safety of parenteral direct thrombin inhibitors (argatroban and bivalirudin) during pregnancy. Thus, these agents are not recommended at this time unless extenuating circumstances precluding the use of UFH exist, such as severe allergy, heparin-induced thrombocytopenia (HIT), or heparin resistance.[48,49]

An approach to anticoagulation akin to the approach in nonpregnant patients supported with ECMO is recommended.[7,50] This includes a low-dose anticoagulation protocol with an activated partial thromboplastin time (aPTT) target of approximately 40–60 seconds or anti-Xa level of 0.2–0.4 units/ml unless indications for therapeutic levels of anticoagulation exist.[7,48,49] Of note, there is increased renal excretion and protein binding of heparin present during pregnancy, which necessitates the use of higher doses to maintain target levels of anticoagulation.[48]

There is no evidence to recommend the routine use of anticoagulation post-decannulation. Nevertheless, given the hypercoagulability in pregnancy, consider screening these patients for VTE with ultrasounds of the upper and lower extremities following decannulation, in addition to when clinical suspicion exists, and then using anticoagulation as appropriate.[7]

Other Medications

Medications with the most potential benefit for the pregnant patient and lowest morbidity to the fetus should be selected. When possible, fetotoxic medications should be avoided. Due to the complex pharmacokinetics of pregnancy and during ECMO, it is recommended to work in conjunction with obstetric or maternal-fetal medicine specialists as well as pharmacists to maximize treatment efficacy while minimizing risk.[50]

ECMO Goals

Physiologic changes in pregnancy may require slightly different ECMO goals compared to the nonpregnant patient (Figure 5). This guidance is based on subject matter expert opinion taking into account the pathophysiology of pregnancy and the current, but sparse ECMO literature that exists.

Oxygenation and Ventilation Goals

The aim should be to provide lung-protective ventilation to maximize the chance of early and maximal lung recovery from the underlying condition in the mother while satisfying the gas exchange requirements of both the mother and fetus.[51] As fetal lungs do not participate in gas exchange in utero, the placenta is the sole source of transfer of oxygen and carbon dioxide. Both are small molecules and, therefore, readily move by passive diffusion across a concentration gradient (approximately 30 mm Hg for oxygen and 10 mm Hg for carbon dioxide).

Fetal oxygen delivery is determined by uterine blood flow and its oxygen content, which in turn is determined by the oxygen content of uterine arterial blood (hemoglobin concentration and oxygen saturation) and uterine arterial blood flow, which is approximately 10% of maternal cardiac output (600–700 ml of oxygen/min) at full term (> 37 weeks' gestation).[7,23] Pregnant patients receiving ECMO should maintain a partial pressure of arterial oxygen (PaO_2) greater than or equal to 70 mm Hg and an oxygen saturation greater than or equal to 95% to ensure adequate fetal oxygenation.[52,53] If maternal hypoxemia occurs,

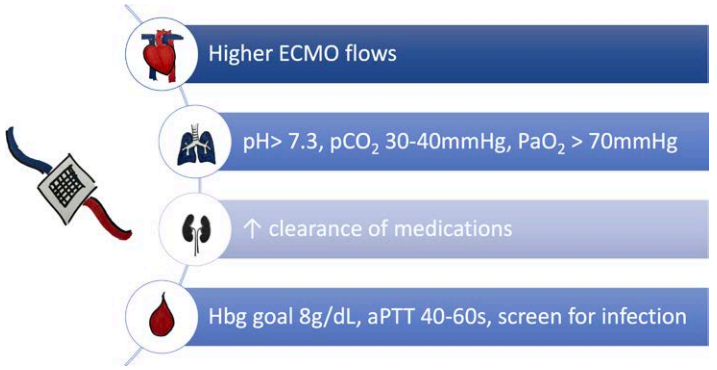


Figure 5. ECMO goals in pregnant and postpartum patients. aPTT, activated partial thrombin time; ECMO, extracorporeal membrane oxygenation; hbg, hemoglobin; PaO_2, partial pressure of oxygen; pH, potential of hydrogen; pCO_2, partial pressure of carbon dioxide.

the ECMO circuit should be preferentially used over the ventilator to augment systemic oxygenation. Positive end-expiratory pressure should be applied with caution given the potential for decreased preload and thus decreased cardiac output, leading to impairment in placental perfusion at elevated intrathoracic pressures.

As baseline $PaCO_2$ is 30–32 mm Hg during pregnancy, ECMO sweep should be titrated to maintain a mild respiratory alkalosis. Caution must be taken to avoid significant hypocapnia, which may result in fetal alkalosis, uterine artery constriction, and leftward shift of the fetal oxygen dissociation curve resulting in fetal hypoxia.[54,55] Severe hypercapnia with a $PaCO_2$ greater than 60 mm Hg should also be avoided, as rightward shift of the dissociation curve may limit oxygen binding to fetal hemoglobin.[52]

Hemodynamic Goals

Management of hemodynamics is similar to that for nonpregnant patients with the aim to achieve physiologic MAP targets (> 65 mm Hg) taking into consideration baseline blood pressure and monitoring markers of end-organ perfusion such as lactate, lactate clearance, urine output, renal and hepatic function. Standard vasopressors including norepinephrine, vasopressin, and dopamine may be used to support systemic blood pressures. Large fluctuations and drops in blood pressure can compromise placental circulation and should be avoided.[52] Hypertension during pregnancy predisposes to life-threatening complications such as intracranial hemorrhage, which can be compounded by anticoagulation on ECMO and requires pharmacologic control. Various organizations recommend different blood pressure targets and thus, we recommend targeting a systolic blood pressure goal of less than or equal to 160 mm Hg in the obstetrical ECMO patient to avoid intracranial hemorrhage and placental abruption.[56] There is no ECMO-specific guidance on how to control the obstetrical patient's hemodynamics. We recommend avoiding teratogenic medications if able such as renin-angiotensin system blockers.[29,56]

Left lateral tilt from the second trimester onward, which avoids uterine compression of the vena cava and optimizes venous return and ECMO flows, is recommended. As maternal cardiac output increases by the third trimester, higher ECMO flows may be needed compared to the nonpregnant patients to grant adequate fetal oxygenation, as reflected by a maternal SaO_2 greater than 90%.

Hematologic and Coagulation Goals

Given the physiologic anemia of pregnancy and lack of evidence to keep a higher transfusion threshold, we recommend a hemoglobin goal of 8 g/dl, consistent with ELSO guidance.[33,57,58] Obstetrical patients on ECMO are at risk of developing disseminated intravascular coagulopathy (DIC) from HELLP, retained products of conception, or infection; and should be monitored closely, although thresholds for transfusions are no different than other ECMO patients.[58] Anticoagulation goals are also similar to nonpregnant ECMO patients with aPTT goals of 40–60s.[7,58,59] With increased GFR in pregnancy, however, medication doses may need to be adjusted if renally cleared, such as with bivalirudin.

Infection Goals

The altered immune response predisposes pregnant women to infection. Although prophylactic antimicrobials are not recommended, we do endorse a very low threshold to screen for infection and to start empiric antimicrobials.

Rehabilitation and Mobilization

Prolonged ECMO runs may be anticipated with the initiation of ECMO in the antepartum period, rendering the patient more vulnerable to muscle weakness and requiring a protracted course of rehabilitation.[39] Early rehabilitation and mobilization of pregnant and post-partum patients supported with ECMO present the interdisciplinary clinical team with significant challenges due to the unique physiological changes of pregnancy, the need to simultaneously support and monitor both the fetus and the mother, and the underlying cardio-pulmonary pathology necessitating ECMO support. Early rehabilitation whilst on ECMO may decrease the clot potential on the patient and circuit by improving venous drainage and augmenting systemic antegrade blood flow.[60] The decision for tracheal extubation on ECMO to enhance rehabilitation and mobilization must be weighed carefully against the risk of airway management and difficult endotracheal intubation related to anatomical and physiological changes of pregnancy, such as airway edema, in

Table 2. Fetal Monitoring Recommendations in Viable Pregnancies on ECMO

Test	Evaluation	Use	Frequency
Handheld Doppler US	Fetal heart rate	16+ weeks gestation Fetal viability	1–2 × daily
CTG	Fetal heart rate	26+ weeks gestation Predicts acute fetal hypoxia or acidemia	Continuous
US	Fetal anatomy Fetal growth Placental disease Placental location Amniotic fluid levels	3D or 4D US to assess fetal anatomy, longer-term wellbeing and growth Umbilical artery Doppler US to assess placental perfusion	• With clinical changes • Every week for Dopplers • Every 2–3 weeks for growth assessments
BPP	Fetal heart rate Fetal movement Fetal growth Amniotic fluid levels	Combines CTG with a US to evaluate the wellbeing of the fetus	Weekly
Pelvic exams	Maternal bleeding Cervical dilation Ruptured membranes	Evaluates the need for delivery due to maternal hemorrhage, or premature labor or risk of infection such as chorioamnionitis	As indicated if patient is symptomatic or clinical signs of labor, rupture of membranes or bleeding
Maternal vital signs	Maternal bleeding Infection Heart failure	Evaluates the need for delivery due to maternal hemorrhage, infection such as chorioamnionitis, or low cardiac output	Continuous

BPP, biophysical profile; CTG, cardiotocography; ECMO, extracorporeal membrane oxygenation; US, ultrasound.

addition to the ability to maintain oxygenation and ventilation goals for the fetus if still pregnant.[17] Tracheostomy of pregnant patients while on ECMO has also been performed and may be an excellent option to lighten sedation and begin rehabilitation earlier.[10,39]

We suggest a balanced approach to early mobilization and rehabilitation during pregnancy, further detailed in the ELSO Mobility Guideline.[61] Referrals to the rehabilitation team should be done as soon as practically possible, ideally within 24 hours of ECMO initiation. Daily interdisciplinary review of patient progress, targets of each physiotherapeutic session, training, clear protocols, and engagement of patient and family are critical components of safe mobilization. Ideally, a protocol of the rehabilitation and mobilization continuum should be in place in each ECMO center.

Fetal Monitoring

Extrapolating from the little data on fetal monitoring in critically ill mothers and less in those on ECMO, Table 2 outlines the following suggestions for fetal monitoring in pregnant ECMO patients.[21,62] Fetal monitoring also benefits the mother as fetal distress is a reflection of the mother's instability. We recommend developing a personalized plan for your patient with the help of a multidisciplinary team to include critical care medicine, maternal-fetal medicine, neonatology, nursing, and the family.

Delivery

Analgesia/Anesthesia

The induction of labor for a vaginal delivery may present a need for labor analgesia in pregnant patients on ECMO support. Non-pharmacologic options for a healthy patient include acupuncture, acupressure, hypnosis, sterile water injections, transcutaneous electrical nerve stimulation, water immersion, continuous labor support, massage, and aromatherapy, however, the efficacy of these techniques has never been studied in ECMO patients.[63] Pharmacologic options include opioid medications for analgesia and inhaled nitrous oxide for sedation. Pregnant patients on ECMO support may already be receiving opioids for analgesia, and this may be continued or increased for additional labor analgesia with the understanding that placental transfer may result in fetal respiratory depression at delivery. Nitrous oxide may provide labor sedation but requires patient cooperation and self-administration during contractions, which is not feasible in an intubated or sedated patient.[64] Anecdotal case reports of neuraxial blockade performed while on ECMO are available in the literature; however, it carries the risk of complications such as hematoma, and hence, it is not routinely recommended.[39,65]

Anesthesia for cesarean delivery may be achieved with neuraxial or general anesthetic techniques.[39] For the same reasons outlined above, neuraxial anesthesia may be contraindicated. Furthermore, if the peripartum patient on ECMO is already intubated, the pragmatic approach is most often general anesthesia. The use of inhaled anesthetics in patients on VV or VA ECMO is complicated by unreliable drug delivery due to underlying lung pathology or blood flow diversion away from the lungs.[66] The recommended approach to general anesthesia is with intravenous agents that can be titrated to the appropriate depth of anesthesia required for cesarean delivery. The volume of distribution is larger in pregnant patients as well as those supported on ECMO, and there is the potential for drug sequestration in the circuit; therefore, dosing may need to be increased to achieve anesthetic depth.[65] Providers may consider the use of processed electroencephalography monitoring for depth of anesthesia as pregnant patients have an increased risk of awareness under anesthesia.[67,68] Dosing of these medications should be judicious to avoid rapid vasodilation and potential drops in the ECMO flow as well as to minimize fetal exposure to anesthetic agents.

Indication and Timing of Delivery

The timing of delivery in the critically ill parturient must be balanced against 1) the potential benefit to maternal status

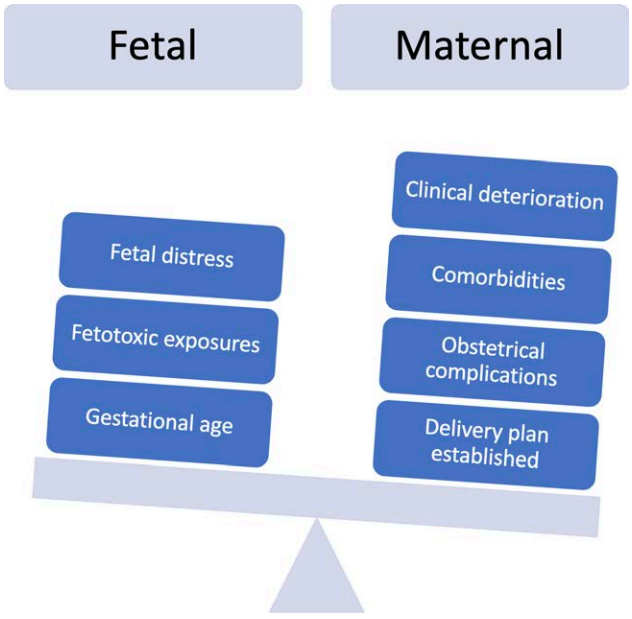


Figure 6. Balancing maternal and fetal considerations for delivery of the pregnant mother on ECMO. ECMO, extracorporeal membrane oxygenation.

and 2) the risk of prematurity (Figure 6).[35] However, once supported on ECMO, delivery of the fetus may not improve oxygenation, particularly in the second and early third trimesters.[39] Therefore, the timing of delivery should include an assessment of the burden of the fetoplacental unit on maternal oxygenation and fetal stability. It is highly recommended for early consultation with a specialist in high-risk maternal-fetal medicine to ensure adequate fetal support, identify signs of physiologic stress, and optimize the fetus for possible preterm (< 37 weeks' gestation) or emergency delivery.

The Society for Maternal and Fetal Medicine supports the use of ECMO in pregnant patients not only to save the life of the mother but also as a tool to help keep the pregnancy active as the mother recovers from severe hypoxemia, allowing the fetal lungs more time to mature.[69] The use of ECMO to enhance fetal perfusion can be considered past the point of maternal recovery; however, this must be weighed against the risk of ECMO-related complications. Given the paucity of data and the risk of ECMO-related complications, ELSO does not recommend prolonging ECMO use if the mother has fully recovered.

Although ideally, the pregnancy would be carried to full term (> 37 weeks of gestation), planning for prompt delivery while on ECMO is key to optimizing both maternal and fetal outcomes.[7,39] Consideration for delivery should be a cyclical activity as part of the daily review, considering the respiratory status and response to treatment, any comorbidities (*ie*, pulmonary hypertension, asthma, *etc*), the development of obstetric complications such as pre-eclampsia or chorioamnionitis, and the gestation of delivery.

Additionally, following obstetrical guidelines, we recommend giving antenatal steroids to pregnant patients supported on ECMO, which can reduce the risk of respiratory distress syndrome in the infant, and magnesium sulfate if given before the 32nd week of gestation, which reduces the risk of neurological disability.[70]

Mode of Delivery

There is no clear guidance regarding the mode of delivery, and any decision requires careful multidisciplinary team discussion with the views of the family and taking maternal factors into account to create individualized plans. Notwithstanding this, equipment for a vaginal birth, emergency cesarean delivery, and neonatal resuscitation must be available promptly on the unit, with the contact numbers for obstetricians, neonatologists, and midwives in the event of emergency birth or spontaneous labor.

Maternal factors such as pulmonary hypertension or peripartum cardiomyopathy may impact a safe vaginal delivery as the increase in pressure from labor may precipitate heart failure or cardiac arrest.[7,71] Additionally, during vaginal deliveries, the blood flow of ECMO can be unstable and reduced as contractions become more severe, resulting in a reduction in maternal oxygenation.[72] The second stage of labor can also be challenging in pregnant patients on ECMO if heavily sedated or anesthetized, as the patient will not be able to push with a contraction. In these circumstances, an assisted vaginal birth can be performed, however, it will require the patient to be positioned into lithotomy, which may not be possible with femoral cannulation.

Cesarean deliveries are the most common form of delivery on ECMO, possibly due to improved hemodynamic control, fewer interruptions in ECMO flow, and speed of the delivery.[7,39] Cesareans may be complicated by intraoperative or postoperative hemorrhage. Heparin may be discontinued for the duration of the cesarean delivery and the immediate postnatal period; however, this does risk clots within the ECMO circuit. Strict hemostasis during the cesarean delivery is essential. Using electrocautery to enter the uterus, the use of hemostatic sutures, and closing the peritoneum layers can be used to reduce intraoperative blood loss and the risk of postoperative bleeding complications. Prophylactic drains placed at the level of the rectus sheath and in the pelvis can help evaluate the amount of blood loss and reduce the risk of pelvic collections.

Regardless of the mode of delivery, the heparin should be paused for any patient who is suspected to be in labor or bleeding.[10] Extracorporeal membrane oxygenation centers should be prepared to perform an emergency cesarean delivery even if the plan is to attempt a vaginal delivery. In the event of fetal death or termination of pregnancy, aiming for a vaginal birth is reasonable. The usual protocols can be used with mifepristone and misoprostol with measures in place to reduce the chance of a major post-partum hemorrhage with uterine massage, uterotonics (Figure 3), and prompt management of a retained placenta or products.[40] If labor is induced, there can be a delay from the start of induction to the delivery of the infant. Even in the event of fetal death, this delay needs to be balanced with the possibility of maternal deterioration whilst awaiting delivery. Additionally, delaying the delivery of an infant who has died can increase the risk of DIC.

The multidisciplinary team should determine the place of delivery. There are benefits and risks to delivering in the labor suite, operating room, or ICU. If the ECMO patient is in the ICU, far from a labor suite or obstetrical operating room, preparations should be made in the ICU for immediate delivery in the event of an emergency (Table 3).[62]

At the initiation of ECMO or even before the cannulation of a pregnant patient, we recommend developing a

Table 3. Recommended Equipment Readily Available for an Emergent Cesarean Delivery While on ECMO

Emergency Cesarean Equipment	
Maternal Equipment	Neonatal Equipment
Uterotonic medications	Isolette or warmer
Tranexamic acid	Airway supplies (masks, laryngoscope, endotracheal tubes)
Cesarean pack	Suction device
Surgical table with sterile surgical instruments	T-piece resuscitator or flow-inflating bag
Hysterectomy packs	Oxygen blender and pulse oximeter
Balloon tamponade devices	Sterile bag
Drains	Blankets
Blood products	Umbilical cord clamps and scissors
Airway equipment	UAC/UVC equipment
Anesthetic medications	Cardiopulmonary resuscitation medications
Cardiopulmonary resuscitation medications	

ECMO, extracorporeal membrane oxygenation; UAC, umbilical arterial catheter; UVC, umbilical vein catheter.

multidisciplinary plan of delivery of the fetus in the safest way possible for the mother with a well-developed contingency plan for an emergency cesarean delivery.

Ethics

The urgent nature of ECMO exacerbates the complex ethical challenges of life support.[73] These are particularly aggravated in the pregnant woman with a potentially viable fetus. It is difficult to apply the basic ethical principle of autonomy and shared decision-making in ECMO initiation due to the urgency, risk of misunderstanding, patient's trust in expertise, and emotional distortion.[74] Consent from the patient in this setting may not be achievable. If the patient's wishes are not considered, viewing ECMO as futile may be inaccurate. Although stopping ECMO in the case of maternal nonrecoverability seems unethical, ECMO should not be withheld for this reason. Both options, withholding ECMO or withdrawing ECMO, are considered ethically equivalent.[75,76] The pregnant patient may have conflicting autonomous wishes that may benefit the fetus while risking her own life. The treating clinical team may therefore experience moral distress respecting the patient's wishes to act according to the principle of beneficence towards a fetus, yet going against the beneficence-based obligations to the woman.[77] Quality of life futility is not applicable in perinatal medicine as it is subjective for each individual.[78] When the fetus is regarded as a patient, it adds another fiduciary obligation of the clinicians to their obligations to maternal autonomy and beneficence: the obligation of beneficent action towards the fetus, who is particularly vulnerable because it has no autonomy of its own.[79]

We recommend the early routine implementation of preemptive ethics consultations with multidisciplinary expertise and close communication with the patient (if awake) and close relatives to address the ethical challenges that may present for the woman and fetus while on ECMO.

Maternal-Fetal Bonding

Skin-to-skin contact and breastfeeding are important for both maternal and neonatal health.[79] Little official guidance exists on breastfeeding and maternal-infant bonding during critical illness. Extracorporeal membrane oxygenation alone, however, does not prohibit skin-to-skin bonding nor breastfeeding, especially if the patient is awake and able to sit and participate in physiotherapy. Guidance from the Academy of Breastfeeding Medicine (ABM) can be extended to ECMO patients.[80] The ABM states that direct breastfeeding is preferred, and efforts to support lactation in hospitalized patients should be made.[80,81] Mothers on ECMO should have consultation with a lactation consultant, pumping equipment at the bedside, and the time the infant and mother spend together should be maximized. Important for mothers on ECMO, breastfeeding while on anticoagulation with heparin is safe according to the American Society of Hematology and the European Society of Cardiology.[49] There is no caution against breastfeeding while on intravenous direct-thrombin inhibitors, with case reports highlighting successes; however, both these societies recommend against breastfeeding while on oral direct-thrombin inhibitors. All maternal medications should be reviewed for infant safety during breastfeeding while on ECMO.

Weaning From ECMO

Weaning from ECMO in pregnant or peripartum patients is similar to that of other populations of ECMO. If the patient is pregnant, we recommend fetal monitoring during the trials off VV ECMO or while weaning VA ECMO to evaluate fetal distress. Please refer to the ELSO Guidelines on VV and VA ECMO for full weaning guidance.[82,83]

Follow-Up

Maternal

All peripartum patients requiring ECMO support need close follow-up, the specifics of which will depend on the underlying pathology necessitating ECMO, any complications from treatments or organ support received, maternal health status post-ECMO decannulation, and stage of pregnancy. Many patients will have delivered before or during ECMO support, but for those remaining pregnant after successful ECMO weaning, antenatal care will follow a high-risk pathway requiring close multidisciplinary working between obstetric, neonatal, and critical care teams.

In addition to disease-specific and obstetric antenatal and postnatal care, the peripartum ECMO patient should be seen in an ECMO or intensive care follow-up clinic at

3–6 months post-discharge from critical care. All intensive care survivors are at risk of post-intensive care syndrome (PICS), which encompasses new or worsening impairments in physical, cognitive, or mental health arising after critical illness and persisting beyond discharge from the acute care setting.[84]

Impairments can be profound and last for months or years. They have been shown to significantly impair quality of life, in addition to increasing risks of future healthcare utilization and, in the case of the peripartum ECMO patient, the ability to care for an infant.[84] Age, preexisting comorbidities, and frailty are risk factors for PICS.[85] The peripartum ECMO patient is likely to be younger with a better physiological baseline and health status than the overall ECMO patient cohort providing some protection against developing PICS symptoms, however, female sex is a risk factor for adverse mental health outcomes.[85] A population-based retrospective cohort study of greater than 4,000 participants matching ECMO survivors to non-ECMO critical care survivors showed a modestly increased risk of new mental health diagnoses or social problems in those requiring ECMO.[86] The psychological sequelae of critical illness can be just as disabling as the physical adverse effects, significantly hamper physical recovery and, in the case of postpartum patients, affect infant bonding. Pregnant and post-partum patients may be at particular risk especially if they have experienced a pregnancy loss or have other risk factors for postnatal depression. Long-term quality of life regarding physical and mental health is lower in patients who require obstetric intensive care admission.[87]

Critical care or ECMO follow-up clinics provide an opportunity to screen for specific PICS symptoms with referral to appropriate support services, such as rehabilitation programs, peer-support groups, and medical psychology services, when problems are identified.

Newborn Outcomes and Follow-Up

Although the body of literature on pregnant patients supported with ECMO is growing, few publications describe fetal outcomes.[4,6,39,71] Survival rates for fetuses of patients supported on ECMO are approximately 65–71%.[4,46,71] Fetal survival differed significantly, however, according to the timing of ECMO onset, with an 8% neonatal mortality rate when ECMO was initiated after delivery in contrast to a 45% stillbirth rate when onset before delivery.[39]

Furthermore, 36% of patients started on ECMO while pregnant experienced spontaneous in-ICU expulsions at viability, and preterm deliveries occurred at approximately 50%, of which nearly 30% required neonatal intensive care admission.[4,39] Moreover, the infants that were born alive to patients receiving ECMO had low Apgar scores (0–6), respiratory failure, and growth restriction.[10,46,71] Supporting mothers with ECMO while pregnant allowed for longer intrauterine time for fetal growth and resulted in no higher rates of NICU stay nor long-term disability compared with infants born at 34 weeks and before mothers were cannulated onto ECMO.[39]

Few studies evaluate the long-term outcomes of infants born to patients on ECMO. Two studies show no severe preterm morbidity in children born to patients on ECMO and reported normal neurological developmental abilities after a median follow-up of 60 months.[39,46] Analyses of the possible side effects of ECMO on fetal development are necessary, and data collected should include gestational age, mode of delivery, birth weight, need for neonatal intensive care, complications of preterm birth (*ie*, intraventricular hemorrhage, bronchopulmonary dysplasia, necrotizing enterocolitis, retinopathy, or cerebral palsy), infant health status, and neurological development at follow-up.[39]

References

1. US Center for Disease Control and Prevention. *Four in 5 Pregnancy-Related Deaths in the U.S. Are Preventable [Press release]*. September 19, 2022. https://archive.cdc.gov/#/details?url=https://www.cdc.gov/media/releases/2022/p0919-pregnancy-related-deaths.html. Accessed June 26, 2025.
2. World Health Organization. *Maternal Mortality [Press release]*. April 26, 2024. https://www.who.int/news-room/fact-sheets/detail/maternal-mortality#:~:text=The%20major%20complications%20that%20account,pre%2Declampsia%20and%20eclampsia)%3B. Accessed June 26, 2025.
3. Felker A, Patel R, Kotnis R, Kenyon S, Knight M, on behalf of MBRRACE-UK. *Saving Lives, Improving Mothers' Care Compiled Report - Lessons Learned to Inform Maternity Care From the UK and Ireland Confidential Enquiries Into Maternal Deaths and Morbidity 2020-22*. Oxford, National Perinatal Epidemiology Unit, University of Oxford, 2024.
4. Naoum EE, Chalupka A, Haft J, *et al*: Extracorporeal Life Support in pregnancy: A systematic review. *J Am Heart Assoc* 9: e016072, 2020.
5. Wong MJ, Bharadwaj S, Galey JL, Lankford AS, Galvagno S, Kodali BS: Extracorporeal membrane oxygenation for pregnant and postpartum patients. *Anesth Analg* 135: 277–289, 2022.
6. 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* 67: 132–136, 2021.
7. Agerstrand C, Abrams D, Biscotti M, *et al*: Extracorporeal membrane oxygenation for cardiopulmonary failure during pregnancy and postpartum. *Ann Thorac Surg* 102: 774–779, 2016.
8. Desai M, Osborn E, King C, *et al*: Extracorporeal life support for cardiogenic shock during pregnancy and postpartum: A single center experience. *Perfusion* 37: 493–498, 2022.
9. Ramanathan K, Tan CS, Rycus P, *et al*: Extracorporeal membrane oxygenation in pregnancy: An analysis of the Extracorporeal Life Support Organization Registry. *Crit Care Med* 48: 696–703, 2020.
10. Lankford AS, Chow JH, Jackson AM, *et al*: Clinical outcomes of pregnant and postpartum extracorporeal membrane oxygenation patients. *Anesth Analg* 132: 777–787, 2021.
11. Sebastian NA, Spence AR, Bouhadoun S, Abenhaim HA: Extracorporeal membrane oxygenation in pregnant and postpartum patients: A systematic review. *J Maternal-Fetal Neonatal Med* 35: 4663–4673, 2022.
12. Malfertheiner SF, Brodie D, Burrell A, *et al*: Extracorporeal membrane oxygenation during pregnancy and peripartal. An international retrospective multicenter study. *Perfusion* 38: 966–972, 2023.
13. 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* 205: 248–250, 2022.
14. Byrne JJ, Shamshirsaz AA, Cahill AG, *et al*: Outcomes following extracorporeal membrane oxygenation for severe COVID-19 in pregnancy or post-partum. *JAMA Netw Open* 6: e2314678, 2023.
15. Olson TL, O'Neil ER, Ramanathan K, Lorusso R, MacLaren G, Anders MM: Extracorporeal membrane oxygenation in peripartum cardiomyopathy: A review of the ELSO Registry. *Int J Cardiol* 311: 71–76, 2020.

16. Panchal AR, Bartos JA, Cabañas JG, *et al*; Adult Basic and Advanced Life Support Writing Group: Part 3: Adult Basic and Advanced Life Support: 2020 American Heart Association Guidelines for Cardiopulmonary Resuscitation and Emergency Cardiovascular Care. *Circulation* 142: S366–S468, 2020.
17. Agerstrand C, Naoum E, Ramanathan K, Siddiqui F, Nair P. Chapter 34: Pregnancy. In MacLaren G (ed), *Extracorporeal Life Support: The ELSO Red Book*, 6th ed. Ann Arbor, Michigan, ELSO, 2022, pp. 459–469.
18. Tan EK, Tan EL: Alterations in physiology and anatomy during pregnancy. *Best Pract Res Clin Obstet Gynaecol* 27: 791–802, 2013.
19. Hegewald MJ, Crapo RO: Respiratory physiology in pregnancy. *Clin Chest Med* 32: 1–13, 2011.
20. Griffiths SK, Campbell JP: Placental structure, function and drug transfer. *CEACCP* 15: 84–89, 2015.
21. Practice Bulletin ACOG: 211: Critical care in pregnancy. *Obstet Gynecol* 133: e303–e319, 2019.
22. Mehta LS, Warnes CA, Bradley E, *et al*; American Heart Association Council on Clinical Cardiology; Council on Arteriosclerosis, Thrombosis and Vascular Biology; Council on Cardiovascular and Stroke Nursing; and Stroke Council: Cardiovascular considerations in caring for pregnant patients: A scientific statement from the American Heart Association. *Circulation* 141: e884–e903, 2020.
23. Thaler I, Manor D, Itskovitz J, *et al*: Changes in uterine blood flow during human pregnancy. *Am J Obstet Gynecol* 162: 121–125, 1990.
24. Sanghavi M, Rutherford JD: Cardiovascular physiology of pregnancy. *Circulation* 130: 1003–1008, 2014.
25. Bhatt AB, DeFaria YD: Pregnancy and adult congenital heart disease. *Cardiol Clin* 33: 611–623, ix, 2015.
26. Clark SL, Cotton DB, Pivarnik JM, *et al*: Position change and central hemodynamic profile during normal third-trimester pregnancy and postpartum. *Am J Obstet Gynecol* 164: 883–887, 1991.
27. Cipolla MJ: The adaptation of the cerebral circulation to pregnancy: Mechanisms and consequences. *J Cereb Blood Flow Metab* 33: 465–478, 2013.
28. Miller EC, Leffert L: Stroke in pregnancy: A focused update. *Anesth Analg* 130: 1085–1096, 2020.
29. Committee on Obstetric Practice: Committee Opinion No. 692: Emergent therapy for acute-onset, severe hypertension during pregnancy and the postpartum period. *Obstet Gynecol* 129: e90–e95, 2017.
30. Dunlop W: Serial changes in renal hemodynamics during normal human pregnancy. *Br J Obstet Gynaecol* 88: 1–9, 1981.
31. Rasmussen PE, Nielsen FR: Hydronephrosis during pregnancy: A literature survey. *Eur J Obstet Gynecol Reprod Biol* 27: 249–259, 1988.
32. El Fathi W, van Ochten M, Rehman M, *et al*: Active plasma renin concentration throughout healthy and complicated pregnancy: A systematic review and meta-analysis. *Reprod Biol Endocrinol* 22: 29, 2024.
33. Rodger M, Sheppard D, Gándara E, Tinmouth A: Haematological problems in obstetrics. *Best Pract Res Clin Obstet Gynaecol* 29: 671–684, 2015.
34. Brenner B: Haemostatic changes in pregnancy. *Thromb Res* 114: 409–414, 2004.
35. Bremme KA: Haemostatic changes in pregnancy. *Best Pract Research Clin Haematol* 16: 153–168, 2003.
36. Nichols KM, Henkin S, Creager MA: Venous thromboembolism associated with pregnancy: JACC Focus Seminar. *J Am Coll Cardiol* 76: 2128–2141, 2020.
37. Oian P, Maltau JM: Calculated capillary hydrostatic pressure in normal pregnancy and preeclampsia. *Am J Obstet Gynecol* 157: 102–106, 1987.
38. Wu PY, Udani V, Chan L, Miller FC, Henneman CE: Colloid osmotic pressure: Variations in normal pregnancy. *J Perinat Med* 11: 193–199, 1983.
39. Aissi James S, Guervilly C, Lesouhaitier M, *et al*: Delivery decision in pregnant women rescued by ECMO for severe ARDS: A retrospective multicenter cohort study. *Crit Care* 26: 312, 2022.
40. Committee on Practice Bulletins-Obstetrics: Practice Bulletin No. 183: Postpartum hemorrhage. *Obstet Gynecol* 130: e168–e186, 2017.
41. Abruzzo A, Gorantla V, Thomas SE: Venous thromboembolic events in the setting of extracorporeal membrane oxygenation support in adults: A systematic review. *Thromb Res* 212: 58–71, 2022.
42. Richmond A, Siddiqui F, Sampson C, Charlton M: Extracorporeal membrane oxygenation (ECMO) in pregnant and postpartum women. *Obstetrician Gynecolog* 25: 255–262, 2023.
43. Siddiqui N, Goldszmidt E, Haque SU, Carvalho JC: Ultrasound simulation of internal jugular vein cannulation in pregnant and non-pregnant women. *Can J Anaesth* 57: 966–972, 2010.
44. Oliveros E, Collado FM, Poulin MF, Seder CW, March R, Kavinsky CJ: Percutaneous right ventricular assist device using the Tandem Heart Protek Duo: Real-world experience. *J Invasive Cardiol* 33: E407–E411, 2021.
45. El Banayosy AM, El Banayosy A, Smith JG, *et al*: Extracorporeal life support in pregnant and postpartum women with COVID-19-related acute respiratory distress syndrome. *Int J Artif Organs* 46: 289–294, 2023.
46. 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* 37: 648–654, 2011.
47. Ngatchou W, Ramadan ASE, Van Nooten G, Antoine M: Left tilt position for easy extracorporeal membrane oxygenation cannula insertion in late pregnancy patients. *Interact Cardiovasc Thorac Surg* 15: 285–287, 2012.
48. Andra J, Meredith B, Anjali K: ACOG Practice Bulletin No. 196: Thromboembolism in Pregnancy. *Obstet Gynecol* 132: e1–e17, 2018.
49. Bates SM, Rajasekhar A, Middeldorp S, *et al*: American Society of Hematology 2018 guidelines for management of venous thromboembolism: Venous thromboembolism in the context of pregnancy. *Blood Adv* 2: 3317–3359, 2018.
50. Shekar K, Fraser JF, Smith MT, Roberts JA: Pharmacokinetic changes in patients receiving extracorporeal membrane oxygenation. *J Crit Care* 27: 741.e9–741.e18, 2012.
51. Fan E, Gattinoni L, Combes A, *et al*: Venovenous extracorporeal membrane oxygenation for acute respiratory failure: A clinical review from an international group of experts. *Intensive Care Med* 42: 712–724, 2016.
52. Guntupalli KK, Karnad DR, Bandi V, Hall N, Belfort M: Critical illness in pregnancy: Part II: Common medical conditions complicating pregnancy and puerperium. *Chest* 148: 1333–1345, 2015.
53. Lapinsky SE: Acute respiratory failure in pregnancy. *Obstet Med* 8: 126–132, 2015.
54. Omo-Aghoja L: Maternal and fetal acid-base chemistry: A major determinant of perinatal outcome. *Ann Med Health Sci Res* 4: 8–17, 2014.
55. Levinson G, Shnider SM, DeLorimier AA, Steffenson JL: Effects of maternal hyperventilation on uterine blood flow and fetal oxygenation and acid-base status. *Anesthesiology* 40: 340–347, 1974.
56. Garovic VD, Dechend R, Easterling T, *et al*; American Heart Association Council on Hypertension; Council on the Kidney in Cardiovascular Disease, Kidney in Heart Disease Science Committee; Council on Arteriosclerosis, Thrombosis and Vascular Biology; Council on Lifestyle and Cardiometabolic Health; Council on Peripheral Vascular Disease; and Stroke Council: Hypertension in pregnancy: Diagnosis, blood pressure goals, and pharmacotherapy: A scientific statement from the American Heart Association. *Hypertension* 79: e21–e41, 2022.
57. Ramanathan K, Peek G, Martucci G, *et al*: Blood transfusion during extracorporeal membrane oxygenation: An ELSO position statement. *ASAIO J* 70: 719–720, 2024.
58. McMichael ABV, Ryerson LM, Ratano D, Fan E, Faraoni D, Annich GM: 2021 ELSO Adult and Pediatric Anticoagulation Guidelines. *ASAIO J* 68: 303–310, 2022.
59. Weiniger CF, Yakirevich-Amir N, Sela HY, Gural A, Ioscovich A, Einav S: Retrospective study to investigate fresh frozen plasma

and packed cell ratios when administered for women with postpartum hemorrhage, before and after introduction of a massive transfusion protocol. *Int J Obstet Anesth* 36: 34–41, 2018.
60. Polastri M, Swol J, Loforte A, Dell'Amore A: Extracorporeal membrane oxygenation and rehabilitation in patients with COVID-19: A scoping review. *Artif Organs* 46: 30–39, 2022.
61. Ramsey S, Shehatta AL, Ramanathan K, *et al*; Reviewers: Extracorporeal Life Support Organization 2024 Guideline for Early Rehabilitation or Mobilization of Adult Patients on Extracorporeal Membrane Oxygenation. *ASAIO J* 71: 187–199, 2025.
62. Levitus M, Shainker SA, Colvin M: COVID-19 in the critically ill pregnant patient. *Crit Care Clin* 38: 521–534, 2022.
63. Arendt KW, Tessmer-Tuck JA: Nonpharmacologic labor analgesia. *Clin Perinatol* 40: 351–371, 2013.
64. Likis FE, Andrews JC, Collins MR, *et al*: Nitrous oxide for the management of labor pain: A systematic review. *Anesth Analg* 118: 153–167, 2014.
65. Anim-Somuah M, Smyth RM, Cyna AM, Cuthbert A: Epidural versus non-epidural or no analgesia for pain management in labour. *Cochrane Database Syst Rev* 5: CD000331, 2018.
66. Mazzeffi MA, Rao VK, Dodd-O J, *et al*: Intraoperative management of adult patients on extracorporeal membrane oxygenation: An Expert Consensus Statement From the Society of Cardiovascular Anesthesiologists-Part II, intraoperative management and troubleshooting. *Anesth Analg* 133: 1478–1493, 2021.
67. Lewis SR, Pritchard MW, Fawcett LJ, Punjasawadwong Y: Bispectral index for improving intraoperative awareness and early postoperative recovery in adults. *Cochrane Database Syst Rev* 9: CD003843, 2019.
68. Robins K, Lyons G: Intraoperative awareness during general anesthesia for cesarean delivery. *Anesth Analg* 109: 886–890, 2009.
69. Society for Maternal-Fetal Medicine COVID-19 Task Force, Vaught J, Hallscott T. Society for Maternal-Fetal Medicine Management Considerations for Pregnant Patients With COVID-19 Developed With Guidance From Torre Halscott, MD, MS. 2021. https://s3.amazonaws.com/cdn.smfm.org/media/2734/SMFM_COVID_Management_of_COVID_pos_preg_patients_2-2-21_(final).pdf. Accessed June 26, 2025.
70. Stock SJ, Thomson AJ, Papworth S; the Royal College of Obstetricians and Gynaecologists: Antenatal corticosteroids to reduce neonatal morbidity and mortality. *BJOG* 129: e35–e60, 2022.
71. Zhang JJY, Ong JA, Syn NL, *et al*: Extracorporeal membrane oxygenation in pregnant and postpartum women: A systematic review and meta-regression analysis. *J Intensive Care Med* 36: 220–228, 2021.
72. Liu C, Sun W, Wang C, Liu F, Zhou M: Delivery during extracorporeal membrane oxygenation (ECMO) support of pregnant woman with severe respiratory distress syndrome caused by influenza: A case report and review of the literature. *J Matern Fetal Neonatal Med* 32: 2570–2574, 2019.
73. Courtwright AM, Robinson EM, Feins K, *et al*: Ethics Committee Consultation and extracorporeal membrane oxygenation. *Ann Am Thorac Soc* 13: 1553–1558, 2016.
74. Peetz AB, Sadovnikoff N, O'Connor MF: Is informed consent for extracorporeal life support even possible? *AMA J Ethics* 17: 236–242, 2015.
75. DeMartino ES, Braus NA, Sulmasy DP, *et al*: Decisions to withdraw extracorporeal membrane oxygenation support: Patient characteristics and ethical considerations. *Mayo Clin Proc* 94: 620–627, 2019.
76. Steinhorn DM: Termination of extracorporeal membrane oxygenation for cardiac support. *Artif Organs* 23: 1026–1030, 1999.
77. Chervenak FA, McCullough LB: The fetus as a patient: An essential concept for the ethics of perinatal medicine. *Am J Perinatol* 20: 399–404, 2003.
78. Chervenak FA, McCullough LB: Professional ethics and decision making in perinatology. *Semin Perinatol* 46: 151520, 2022.
79. Mann DG, Sutton CD: Ethics in the labor and delivery unit. *Anesthesiol Clin* 39: 839–849, 2021.
80. MacLaren G, Ramanathan KR, Sorokin V: Extubation to facilitate mother-baby bonding in refractory acute respiratory distress syndrome. *Intensive Care Med* 40: 1558–1559, 2014.
81. Bartick M, Hernández-Aguilar MT, Wight N, *et al*: ABM Clinical Protocol #35: Supporting breastfeeding during maternal or child hospitalization. *Breastfeed Med* 16: 664–674, 2021.
82. 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* 67: 601–610, 2021.
83. Richardson ASC, Tonna JE, Nanjayya V, *et al*: Extracorporeal cardiopulmonary resuscitation in adults. Interim Guideline Consensus Statement From the Extracorporeal Life Support Organization. *ASAIO J* 67: 221–228, 2021.
84. Hiser SL, Fatima A, Ali M, Needham DM: Post-intensive care syndrome (PICS): Recent updates. *J Intensive Care* 11: 23, 2023.
85. Lee M, Kang J, Jeong YJ: Risk factors for post-intensive care syndrome: A systematic review and meta-analysis. *Aust Crit Care* 33: 287–294, 2020.
86. Fernando SM, Scott M, Talarico R, *et al*: Association of extracorporeal membrane oxygenation with new mental health diagnoses in adult survivors of critical illness. *JAMA* 328: 1827–1836, 2022.
87. Ramlakhan KP, van der Zande JA, Roos-Hesselink JW, Franx A, Cornette J: Long-term quality of life after obstetric intensive care unit admission: A cross-sectional cohort study. *BJOG* 130: 813–822, 2023.