COVID-19: Extracorporeal membrane oxygenation (ECMO)

Authors: Michael G Fitzsimons, MD, Jerome Crowley, MD, MPH
Section Editors: Michael F O'Connor, MD, FCCM, Jonathan B Mark, MD
Deputy Editors: Nancy A Nussmeier, MD, FAHA, Geraldine Finlay, MD

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INTRODUCTION

The pneumonia associated with novel coronavirus disease 2019 (COVID-19 or nCoV-2) can lead to respiratory failure with profound hypoxemia requiring endotracheal intubation and mechanical ventilation. Patients that do not respond to optimal conventional mechanical ventilation may be candidates for management with extracorporeal membrane oxygenation (ECMO) in institutions with appropriate resources (equipment and personnel).

This topic will address anesthetic, surgical, and critical care considerations during initiation and management of ECMO in patients with COVID-19 respiratory failure. General concepts regarding use of ECMO in other settings are discussed in other topics. (See "Extracorporeal membrane oxygenation (ECMO) in adults" and "Intraoperative problems after cardiopulmonary bypass", section on 'Extracorporeal membrane oxygenation'.)

Ventilation management and other critical care issues in COVID-19 patients who develop severe respiratory failure are also discussed in other topics. (See "COVID-19: Management of the intubated adult" and "COVID-19: Intensive care ventilation with anesthesia machines".)

PLANNING FOR ECMO USE DURING THE COVID-19 PANDEMIC

Resource considerations — Institutions without a well-established ECMO program should **not** attempt to initiate a new program during a pandemic [1-3]. ECMO is a resource-intensive therapy requiring a multidisciplinary team of experienced medical professionals with training and expertise in initiation, maintenance, and discontinuation of ECMO in critically ill patients [1-

10]. Competent planning, resource allocation, and infection control are necessary to assure that ECMO is appropriately used during the COVID-19 pandemic. In institutions already near capacity due to hospitalization of a large number of COVID-19 patients requiring mechanical ventilation, use of ECMO for even a limited number of cases may overwhelm the institution [1,2,4,10].

Preparations — Preparation for geographic patient surges during the current COVID-19 pandemic have focused on four components: personnel, equipment, facilities, and support systems [1,11-15].

- **Personnel** – Availability of a multidisciplinary team that includes clinicians in several specialties (eg, surgeons, intensivists, anesthesiologists) as well as nurses, physician assistants, nurse practitioners, respiratory therapists, and/or perfusionist technologists who have previously worked together managing ECMO patients is critically important. All team members require education regarding anesthetic, surgical, and critical care management of COVID-19 patients, including the need to use appropriate personal protective equipment (PPE) [1]. (See "COVID-19: Anesthetic concerns, including airway management and infection control" and "COVID-19: Management of the intubated adult" and "COVID-19: Infection control for persons with SARS-CoV-2 infection", section on 'Infection control in the health care setting'.)

- **Equipment** – Inventory of available durable and disposable supplies and equipment for initiation and maintenance of ECMO therapy should be determined, with plans for replacement if inventory becomes rapidly depleted during a regional pandemic surge of critically ill patients. Such planning should include routine ECMO maintenance and potential need for emergency exchange of the ECMO oxygenator due to problems with clotting, or for conversion of venovenous (VV) ECMO to venoarterial (VA) ECMO. (See 'Maintenance of anticoagulation' below and 'Conversion to venoarterial ECMO' below.)

  Planning for decontamination of ECMO equipment after use is also necessary. Programs able to offer ECMO for COVID-19 patients should also be able to manage availability of this support for other indications (eg, cardiogenic shock from myocardial infarction, heart transplants, lung transplants, severe acute respiratory distress syndrome [ARDS] from non-COVID-19 disease).

- **Facilities** – Placement of COVID-19 patients on ECMO support in a single intensive care unit (ICU) location within a facility consolidates expertise of personnel with experience in ECMO, and reduces exposure of additional medical personnel to infection risk.

- **Support systems** – ECMO for COVID-19 patients is best provided in institutions with extensive relevant experience that includes:
  - Assessment of appropriate and safe transfers of critically ill patients from other institutions for ECMO support
  - Management of resource-intensive daily care for patients receiving ECMO (see 'Management of ECMO' below)
  - Care of COVID-19 patients with severe ARDS

INDICATIONS AND CONTRAINDICATIONS

Indications — Indications for ECMO in patients with acute respiratory distress syndrome (ARDS) due to COVID-19 are similar to indications for its use for other causes [16,17]. We advocate that ECMO be reserved as a last resort after failure of other strategies including lung protective ventilation, prone positioning, high positive end-expiratory pressure (PEEP), recruitment maneuvers, neuromuscular blocking agents (NMBAs), and pulmonary vasodilators [1,3,4,10,18,19]. (See "COVID-19: Management of the intubated adult", section on 'Ventilator management of acute respiratory distress syndrome'.)

Data regarding use of ECMO in patients with respiratory failure due to COVID-19 are mostly observational series [1,3,5,15,19-22]. Reports from retrospective studies have suggested variable use, ranging from 1 to 25 percent, an observation that may reflect varying availability of ECMO equipment and experienced personnel [21,23]. ECMO has been employed during other pandemics, notably the outbreaks of Middle East respiratory syndrome coronavirus (MERS-CoV) in 2012, and Influenza A (H1N1) in 2009 [24-28]. Reports from these pandemics indicated that ECMO can improve oxygenation and ventilation, as well as reduce mortality in younger infected patients with very severe lung dysfunction. Discussion of evidence supporting use of ECMO in patients with ARDS due to various other causes is available in a separate topic. (See "Extracorporeal membrane oxygenation (ECMO) in adults", section on 'Indications'.)

There are two types of ECMO, venovenous (VV) and venoarterial (VA) (figure 1 and figure 2) [6]. COVID-19 patients who are potentially suited to each type are discussed in the sections below [1].

Venovenous (VV) ECMO — During VV ECMO, blood is removed from the venous system, passed through an oxygenator, and then returned back to the venous system where it passes through the lungs (figure 1). VV ECMO is an option in COVID-19 for eligible adults with ARDS. Candidates are refractory to conventional ventilator management, with an arterial oxygen tension/fraction of inspired oxygen tension (PaO_2/FiO_2) ratio <150 on a high F_iO_2 >90 percent and with optimized PEEP. (See "Ventilator management strategies for adults with acute respiratory distress syndrome" and "Extracorporeal membrane oxygenation (ECMO) in adults", section on 'Technique'.)

In some instances, a patient who requires VV ECMO and who has right ventricular dysfunction may receive a dual lumen ECMO catheter that is actually a percutaneous right ventricular assist device (RVAD) [29], rather than initiating VA ECMO. (See 'Techniques for vascular cannulation' below and 'Venoarterial (VA) ECMO' below.)

Venoarterial (VA) ECMO — During VA ECMO, blood is removed from the venous system and returned to the arterial system (figure 2), thereby providing both cardiac and pulmonary support [30]. Use of VA ECMO is reserved for selected COVID-19 patients with severe respiratory failure accompanied by severe heart failure, RV dysfunction, excessive shunting through the lungs (eg, due to pulmonary emboli), persistent malignant arrhythmias, acute myocardial infarction, or acute myocarditis [1,17]. (See "COVID-19: Evaluation and management of cardiac disease in adults" and "COVID-19: Myocardial infarction and other coronary artery disease issues" and "COVID-19: Hypercoagulability" and "Extracorporeal membrane oxygenation (ECMO) in adults", section on 'Technique'.)

Contraindications — ECMO in COVID-19 patients is contraindicated in patients with severe comorbidities incompatible with recovery [1]. Examples include multiorgan failure, advanced malignancy, severe neurologic injury, cardiac arrest for a prolonged period, or central nervous system hemorrhage that is recent or expanding.

Relative contraindications for COVID-19 patients, particularly in centers with significant resource constraints, may include [1,3,10,14,15,31]:

- Advanced age (particularly if significant frailty or other comorbidities are present; usually age >70, although age may vary based on predicted reversibility of the underlying pathophysiology)
- Morbid obesity defined as body mass index >40 kg/m^2
- Severe immunocompromised status
- Advanced chronic systolic heart failure
- Extracorporeal cardiopulmonary resuscitation after cardiac arrest that does not rapidly resolve with standard advanced cardiac life support (see "Therapies of uncertain benefit in basic and advanced cardiac life support", section on 'Extracorporeal oxygenation') [32]

Acute kidney injury is not a contraindication to ECMO [3]. In fact, many patients with COVID-19 have acute kidney injury when ECMO is initiated, and may require ongoing renal replacement therapy during ECMO support. Ideally, ECMO can be initiated for a COVID-19 patient when duration of mechanical ventilation has been less than seven to ten days, although there is no clear cutoff [3,14].

Patients with minor or no comorbidities are prioritized when resources are limited [1,3]. When capacity of a hospital system is overwhelmed during a pandemic surge, limitations of institutional or regional resources may contraindicate use of ECMO [1]. (See 'Resource considerations' above.)

INITIATION OF ECMO

Precautions for vascular cannulation — For patients with novel COVID-19, the cannulae for ECMO are placed at the bedside in the intensive care unit (ICU) when feasible, thereby avoiding the need for patient transport to a procedural suite with fluoroscopy equipment [1]. This differs from typical management for non-COVID-19 patients. Avoiding transport of patients for catheter placement minimizes the number of health care personnel who are exposed to infection risk, and avoids disconnection from the ICU ventilator that can result in alveolar derecruitment and cardiopulmonary instability [33]. Although use of a negative pressure room is ideal for any invasive procedure performed in a COVID-19 patient, this may not be feasible if patient movement would be necessary. (See "COVID-19: Anesthetic concerns, including airway management and infection control", section on 'Infection control during patient transport'.)

The airway should be secured by endotracheal intubation prior to vascular cannulation for ECMO [1]. The Centers for Disease Control and Prevention (CDC) and other organizations state that surgeons, anesthesiologists, and other clinicians participating in cannulation and initiation of ECMO should ideally wear personal protective equipment (PPE) optimal for contact, droplet, and airborne precautions (including N95 or higher respirator, or powered air-purifying respirator [PAPR]) [15]. However, if N95 respirators and PAPRs are not available or are in short supply, and the patient's airway has been secured, then use of a surgical mask is an acceptable alternative. Further details are discussed elsewhere. (See "COVID-19: Anesthetic concerns, including airway management and infection control", section on 'Infection control for anesthesia'.)

Notably, insertion of ECMO cannulae may be challenging in COVID-19 patients who develop rapid deterioration [34]. Institution of emergency ECMO requires two separate teams, with one managing sudden clinical changes, while another team accomplishes vascular cannulation and establishes ECMO.

Techniques for vascular cannulation — There are three types of cannulation strategies that may be used for venovenous (VV) ECMO (listed in order of preference) for COVID-19 patients (table 1 and table 2):

- The preferred approach for VV ECMO in a COVID-19 patient involves drainage from an inflow cannula that is placed in the femoral vein and threaded up into inferior vena cava until it is 1 to 2 cm below the cavoatrial junction, with return of oxygenated blood via an outflow cannula inserted into an internal jugular (IJ) vein (preferably the right IJ) and positioned near the superior cavoatrial junction (image 1) [13,15,17]. Ideally, these cannulae can provide blood flows up to 7 L/minute [35].

  The cannulae may be placed via a percutaneous or open technique. Fluoroscopy is not necessary for confirmation of cannula position, as this may be accomplished with chest radiography (CXR) (image 2). While either transthoracic echocardiography or transesophageal echocardiography (TEE) may also be used to ensure optimal cannulae placement (image 3), TEE examination is avoided if possible for COVID-19 patients since this is an aerosol-generating procedure. Risk is reduced after endotracheal intubation, and appropriate protection of the echocardiographer and ultrasound equipment [36-41]. (See "Overview of perioperative uses of ultrasound", section on 'Ultrasound use during the COVID-19 pandemic'.)

- Another approach for establishing VV ECMO is insertion of a bicaval dual lumen single catheter [42]. The single catheter can be inserted percutaneously through the IJ vein, with the two drainage ports positioned in the superior and inferior vena cavae [43]. Blood is withdrawn from these drainage ports, passed through the oxygenator, and then returned via a single port that positioned near the tricuspid valve. Such catheters allow patient mobility within the ICU (eg, sitting up while intubated).

  Although initial placement of a dual-port cannula is generally accomplished using fluoroscopy, placement and subsequent repositioning efforts may be accomplished using TEE alone [44-48]. However, cannula placement with TEE assistance is not ideal for a COVID-19 patient because the procedure is time-consuming and frequent readjustments may be necessary, exposing the echocardiographer to infection risk. When placement with TEE is attempted, PPE and airborne precautions appropriate for high-risk procedures are necessary [37-39]. (See "COVID-19: Anesthetic concerns, including airway management and infection control", section on 'PPE for care of patients who undergo aerosol-generating procedures'.)

- One commercially available dual lumen atriopulmonary catheter single catheter is actually a percutaneous right ventricular assist device (RVAD) that can be used with an oxygenator to provide ECMO support [15,29,49]. This particular dual lumen atriopulmonary cannula must be inserted through the right IJ vein under fluoroscopy. Blood is drained from the right atrium, passed through an oxygenator then returned to the patient just beyond the pulmonary valve in the pulmonary artery (image 4 and image 5 and image 6 and image 7 and image 8) [29]. Since fluoroscopy must be used to position this dual lumen cannula, patient transport to the fluoroscopy suite or hybrid operating room is required, which entails additional risks and the necessary infection control precautions. (See "COVID-19: Anesthetic concerns, including airway management and infection control", section on 'Infection control during patient transport'.)

MANAGEMENT OF ECMO

Management of venovenous ECMO — Goals for maintaining oxygenation and ventilation during venovenous (VV) ECMO are the same for patients with respiratory failure due to novel COVID-19 as for non-COVID-19 patients.

In the absence of any significant gas exchange in the lungs, which can occur with severe acute respiratory distress syndrome (ARDS), the VV ECMO flow must be at least 60 to 70 percent of the cardiac output in order to provide adequate arterial oxyhemoglobin saturation (ie, >88 percent). This can best be accomplished by:

- Maintaining adequate ECMO flow similar to normal cardiac output (ie, 4 to 8 L/minute). If ECMO flow is limited by drainage, consider adding a second femoral drainage cannula. If the patient exhibits hyperdynamic cardiac function, an esmolol infusion may be appropriate to reduce native cardiac output. However, this strategy may not be feasible in patients with distributive shock (eg, due to sepsis).

- Ensuring that recirculation is minimized. In a well-functioning VV ECMO circuit, deoxygenated blood is drained from the patient (usually in the inferior vena cava), passed through the oxygenator for gas exchange, returned to the superior vena cava, and then pumped systemically by the heart. If undesirable recirculation is occurring, a proportion of oxygenated blood is drained back into the ECMO circuit rather than being pumped systemically (such that blood is actually travelling directly from the return cannula to the drainage cannula). In this case, increasing ECMO pump flow will have minimal effect on systemic oxygenation [50]. If recirculation is suspected, cannulae position should be checked with a radiograph; readjustments may be necessary. The goal is to maintain at least 8 cm of separation between the cannulae ports [51].

- Maintaining oxygenation. If ECMO is not adequate for oxygenation, then efforts to ensure optimal native lung contribution typically include adjustments in mechanical ventilatory parameters, although this may induce lung injury. Other interventions such as inhaled pulmonary vasodilators or prone positioning may also be employed in selected patients. (See "Ventilator management strategies for adults with acute respiratory distress syndrome", section on 'Refractory patients'.)

The following additional issues are notable for COVID-19 patients [1]:

- COVID-19 patients may require more sedation than some other critically ill patients [52-54]. Higher sedation requirements in COVID-19 patients may be due to their younger age, higher respiratory drive, increased clearance caused by other medications, and a particularly intense inflammatory response [52,54]. As with other mechanically ventilated patients with ARDS, sedation should be titrated to individual patient needs. However, it may be particularly difficult to wean moderate to heavy sedation during ECMO support of a COVID-19 patient due to development of severe agitation, which can result in dislodgement of ECMO cannulae, shifts in venous return affecting ECMO flows, or ventilator dyssynchrony [52,53]. (See "COVID-19: Management of the intubated adult", section on 'Sedation and analgesia'.)

- Tracheostomy is often considered after initiation of ECMO in non-COVID-19 patients with respiratory failure to improve patient comfort and allow lightening of sedation. However, tracheostomy may be reasonably deferred in COVID-19 patients since it is an aerosol-generating procedure, and sedation requirements may be high even after tracheostomy [1,52,55].

  Appropriate use of personal protective equipment (PPE) is critically important during tracheostomy in a COVID-19 patient [55,56] (see "COVID-19: Anesthetic concerns, including airway management and infection control", section on 'PPE for care of patients who undergo aerosol-generating procedures'). Ideally, the tracheostomy is performed in the intensive care unit (ICU) rather than the operating room, thereby eliminating patient transport to another hospital location. An open rather than a percutaneous approach reduces the need for airway manipulation and bronchoscopy; however, close attention to avoidance of ventilation is necessary while the trachea is open [55,56]. Muscle relaxants are used to reduce the risk of coughing. (See "COVID-19: Management of the intubated adult", section on 'Tracheostomy'.)

- Prone ventilation of COVID-19 patients with respiratory failure is known to be advantageous during the period of mechanical ventilation before initiation of ECMO. Although prone positioning is not usually attempted during ECMO support due to risk of cannulae displacement, it may be used in selected patients, particularly if ECMO weaning is necessary due to bleeding or cannulation site infection. (See "COVID-19: Management of the intubated adult", section on 'LTVV in the prone position'.)

Conversion to venoarterial ECMO — Although relatively rare, conversion of VV ECMO to venoarterial (VA) ECMO may be appropriate in selected COVID-19 patients [1,15]. Development of cardiopulmonary failure with inadequate tissue perfusion or shock manifest by hypotension and low cardiac output may occur in some patients on VV ECMO support despite adequate intravascular volume, and use of standard and novel vasopressors to treat vasoplegia [57]. This may be due to right ventricular dysfunction due to severe ARDS or pulmonary emboli [58-60], or persistent malignant arrhythmias or cardiogenic shock due to acute myocardial infarction or myocarditis [30,61].

For VA ECMO, a femoral-femoral configuration is typically used (with drainage from a femoral vein and return to a femoral artery) [1]. Due to the large size of the arterial cannula that is inserted percutaneously into a femoral artery to initiate VA ECMO, lower limb ischemia complications are common [30]. Prophylactic ipsilateral placement of a distal perfusion catheter antegrade into the superficial femoral artery and continuous monitoring for limb ischemia (eg, using near-infrared spectroscopy monitoring of tissue on the calves) are strategies used to reduce complications of limb ischemia [62].

Adequacy of anticoagulation is even more critical during VA ECMO compared with VV ECMO therapy since arterial or intracardiac thromboembolic events have dire consequences [30,63]. (See 'Maintenance of anticoagulation' below.)

Maintenance of anticoagulation — Providing adequate ECMO circuit anticoagulation while avoiding bleeding or thrombosis is a challenging balancing act in these patients [64-68]. Hypercoagulability is common due to coagulation abnormalities associated with the profound inflammatory response induced in some COVID-19 patients [1,69] (see "COVID-19: Hypercoagulability", section on 'Routine testing'). Vigilant monitoring is necessary to detect development of disseminated intravascular coagulation (DIC) with thrombocytopenia, prolonged prothrombin time, and increased D-dimer, or evidence of thrombosis in the ECMO circuitry or patient sites such as the pulmonary arteries, inferior vena cava, or right atrium [1,15,59,60,69-76]. On the other hand, a high incidence of intracranial hemorrhage in anticoagulated patients receiving VV ECMO for COVID-19-related acute respiratory distress syndrome (ARDS) has also been reported [64]. Daily prothrombin time (PT), PTT, fibrinogen, and

D-dimer levels are obtained to monitor for evidence of hypercoagulability, coagulopathy, and/or DIC (table 3). Some centers also monitor viscoelastic tests such as thromboelastography (TEG), or an adaptation of TEG known as rotational thromboelastometry (ROTEM) [64,65].

As in all patients supported with ECMO, adequate continuous anticoagulation is required to maintain ECMO circulation [1,67]. Monitoring anticoagulation during ECMO therapy is challenging, even in non-COVID-19 patients. Most institutions target an activated partial thromboplastin time (aPTT) that is at least 1.5 times the institutional control value, although higher targets are often used (eg, 2.0 to 2.5 times the institutional control value) [77]. A continuous intravenous heparin infusion is employed in some institutions. Many centers also use activated clotting time (ACT) to guide anticoagulation. However, ACT correlates poorly with aPTT [6,78]. Viscoelastic tests (eg, TEG, ROTEM) have also been employed to guide anticoagulation [64,65,79,80].

Some centers perform daily transthoracic echocardiography in COVID-19 patients on VV ECMO to monitor for early signs of acute cor pulmonale due to PE [5,58]. Formation of thrombi in the oxygenator or circuit with evidence of hypoxemia that is not due to other causes (eg, shunting through the lungs) requires oxygenator exchange. Intracardiac clot formation during ECMO is rare and mortality is high; management may involve full systemic anticoagulation or surgical embolectomy [63,75]. (See "Extracorporeal membrane oxygenation (ECMO) in adults", section on 'Thromboembolism' and "COVID-19: Hypercoagulability", section on 'Clotting of intravascular access devices'.)

Weaning from ECMO — Improvements in lung compliance and arterial oxyhemoglobin saturation indicate that the patient may be ready for weaning from ECMO [1,6]. Typically, institutional weaning protocols are employed (algorithm 1 and algorithm 2) [1,5].

Patients with other types of ARDS may have a median duration of ECMO of 10 days, with a total length of stay in the ICU of approximately one month. However, early data for COVID-19 patients indicate that considerably longer durations of ECMO support may be necessary, with a median duration of 29 days in one study [49], with other studies reporting use of ECMO for as long as three to six weeks [3,5,19].

Continuous risk:benefit evaluation of ECMO therapy is necessary [1,3]. Although definitions of futility are institution-specific, some centers consider returning to conventional management if no lung or cardiac recovery is noted after approximately 21 days.

COMPLICATIONS OF ECMO

Complications of cannula insertion for ECMO include bleeding, neurologic injury (from hypoxemia or thrombosis), thrombocytopenia (heparin-induced or other), and cannula-related vascular complications. These complications are discussed separately. (See "Extracorporeal membrane oxygenation (ECMO) in adults", section on 'Complications'.)

In a 2020 review of the Extracorporeal Life Support Organization (ELSO) Registry that included 1035 COVID-19-positive patients in more than 200 internationally located hospitals, 90 day estimated mortality after ECMO support was <40 percent [81]. Similarly, in a 2020 retrospective study of 492 COVID-19-positive patients who received ECMO in French hospitals, estimated mortality was 31 percent [82]. These results are comparable to mortality in adult patients receiving ECMO support for acute respiratory failure due to other diagnoses [81-83]. Although the earliest reports from China and Europe had noted very high mortality rates >80 percent for COVID-19 patients receiving ECMO [9,84], subsequent studies have noted more encouraging results [3,5,13,20,49,81,82,85-87].

After successful weaning from ECMO, additional time in intensive care is typically required for COVID-19 patients. Most remain on mechanical ventilation for some period of time, then additional care is typically necessary to achieve partial recovery from the severe delirium that may occur after prolonged periods of sedation necessary for mechanical ventilation and ECMO support, and/or profound weakness after use of neuromuscular blocking agents (NMBAs) to facilitate mechanical ventilation [49,52,88].

Long-term complications occur in survivors of severe COVID-19-related acute respiratory distress syndrome (ARDS) and ECMO. Poor health-related quality of life is common due to physical limitations, psychiatric symptoms (eg, anxiety, depression, post-traumatic stress disorder), and chronic pain, similar to other patients undergoing prolonged intensive care with mechanical ventilation [89-92].

SOCIETY GUIDELINE LINKS

Links to society and government-sponsored guidelines from selected countries and regions around the world are provided separately. (See "Society guideline links: COVID-19 – Index of guideline topics".)

INFORMATION FOR PATIENTS

UpToDate offers two types of patient education materials, "The Basics" and "Beyond the Basics." The Basics patient education pieces are written in plain language, at the 5th to 6th grade reading level, and they answer the four or five key questions a patient might have about a given condition. These articles are best for patients who want a general overview and who prefer short, easy-to-read materials. Beyond the Basics patient education pieces are longer, more sophisticated, and more detailed. These articles are written at the 10^{th} to 12^{th} grade reading level and are best for patients who want in-depth information and are comfortable with some medical jargon.

Here are the patient education articles that are relevant to this topic. We encourage you to print or e-mail these topics to your patients. (You can also locate patient education articles on a variety of subjects by searching on "patient info" and the keyword(s) of interest.)

- Basics topics (see "Patient education: COVID-19 overview (The Basics)")

SUMMARY AND RECOMMENDATIONS

- Extracorporeal membrane oxygenation (ECMO) is a resource-intensive therapy requiring involvement of a multidisciplinary team of experienced medical professionals with training and expertise in initiation, maintenance, and discontinuation of ECMO in critically ill patients. Preparation for geographical regional surges of patients with severe novel coronavirus disease 2019 (COVID-19 or nCoV) disease have focused on four components: personnel, equipment, facilities, and support systems. (See 'Preparations' above.)

- Institutions without a well-established ECMO program should **not** attempt to initiate a new program when resources are scarce during a pandemic. Even institutions experienced in ECMO therapy may reach full capacity if large numbers of hospitalized COVID-19 patients require mechanical ventilation, such that use of ECMO in even a limited number of cases may overwhelm hospital resources. (See 'Resource considerations' above.)

- Indications for ECMO in patients with acute respiratory distress syndrome (ARDS) due to COVID-19 are similar to the indications for other causes of ARDS. However, data regarding use in COVID-19 patients are scant. We advocate that ECMO be reserved as a last resort after other mechanical ventilatory strategies have failed (including prone positioning, high positive end-expiratory pressure [PEEP], recruitment maneuvers, neuromuscular blocking agents [NMBAs], and pulmonary vasodilators). (See 'Indications' above and "Extracorporeal membrane oxygenation (ECMO) in adults", section on 'Indications'.)

- There are two types of ECMO support, venovenous (VV) and venoarterial (VA) (figure 1 and figure 2). VV ECMO is typically selected for management of severe ARDS refractory to optimal ventilator management and adjuvant strategies. VA ECMO for COVID-19 patients with respiratory failure is usually reserved for those who also have right ventricular dysfunction due to severe ARDS or pulmonary emboli, persistent malignant arrhythmias, or cardiogenic shock due to acute myocardial infarction or acute myocarditis. (See 'Venovenous (VV) ECMO' above and 'Venoarterial (VA) ECMO' above and 'Conversion to venoarterial ECMO' above.)

- Absolute contraindications for use of ECMO in COVID-19 patients include the presence of severe comorbidities incompatible with recovery (eg, multiorgan failure, advanced malignancy, severe neurologic injury, cardiac arrest for a prolonged period). Relative contraindications for COVID-19 patients, particularly in centers with significant resource constraints, may include older age, obesity with body mass index >40 kg/m^2, severe immunocompromised status, or advanced chronic heart failure. Acute kidney injury is not a contraindication. (See 'Contraindications' above and "Extracorporeal membrane oxygenation (ECMO) in adults", section on 'Relative contraindications'.)

- Vascular cannulation and initiation of ECMO are accomplished at bedside in the intensive care unit (ICU) when feasible, thereby avoiding the need for patient transport to a procedural suite with fluoroscopy equipment. The airway should already be secured by endotracheal intubation. Participating surgeons, anesthesiologists, and other clinicians should wear personal protective equipment (PPE) optimal for contact, droplet, and airborne precautions. (See 'Precautions for vascular cannulation' above and "COVID-19: Anesthetic concerns, including airway management and infection control", section on 'Infection control for anesthesia'.)

- For COVID-19 patients, we suggest a two-catheter approach for VV ECMO involving drainage from an inflow cannula placed in the femoral vein and threaded up into the proximal inferior vena cava, with return of oxygenated blood via an outflow cannula inserted into an internal jugular vein and positioned near the superior cavoatrial junction, rather than using a dual lumen single cannula (image 1) (**Grade 2C**). This approach avoids the need for catheter positioning by using fluoroscopy (which involves patient transport within the hospital) or transesophageal echocardiography (which is an aerosol-generating procedure). (See 'Techniques for vascular cannulation' above.)

- Goals for maintaining oxygenation and ventilation during ECMO are the same for patients with COVID-19 as for non-COVID-19 patients, with the following notable issues (see 'Management of venovenous ECMO' above):

  - Weaning moderate to heavy sedation levels may be difficult due to severe agitation that may lead to dislodgement of ECMO cannulae or ventilator dyssynchrony.

  - Tracheostomy is an aerosol-generating procedure that may be reasonably deferred in COVID-19 patients.
  - COVID-19 patients with ARDS may require longer durations of ECMO support than other critically ill patients on ECMO support

- Hypercoagulability is common in COVID-19 patients, and they may develop thrombosis in the ECMO oxygenator or other sites such as the lung. Daily prothrombin time (PT), PTT, fibrinogen, and D-dimer levels are obtained to monitor for evidence of hypercoagulability or disseminated intravascular coagulation (DIC) (table 3). Vigilant monitoring to ensure adequate continuous anticoagulation and maintenance of adequate ECMO circulation is necessary. Most institutions target an activated partial thromboplastin time (aPTT) that is at least 1.5 times the upper limit of normal, and many target a higher level of anticoagulation (eg, 2.0 to 2.5 times the upper limit of normal). Daily transthoracic echocardiography is performed in some centers to monitor for early signs of acute cor pulmonale due to PE. (See 'Maintenance of anticoagulation' above and "COVID-19: Hypercoagulability", section on 'Routine testing'.)

- Improvements in lung compliance and arterial oxyhemoglobin saturation indicate that the patient may be ready for weaning from ECMO. Typically, institutional weaning protocols are employed (algorithm 1 and algorithm 2). After successful weaning from ECMO, an additional period of time in intensive or closely monitored care is typically necessary to achieve partial recovery from delirium after prolonged periods of sedation in the ICU and/or profound weakness that may occur if NMBAs were temporarily employed. (See 'Weaning from ECMO' above.)

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Topic 127765 Version 15.0

GRAPHICS

Venovenous (VV) ECMO for isolated respiratory failure

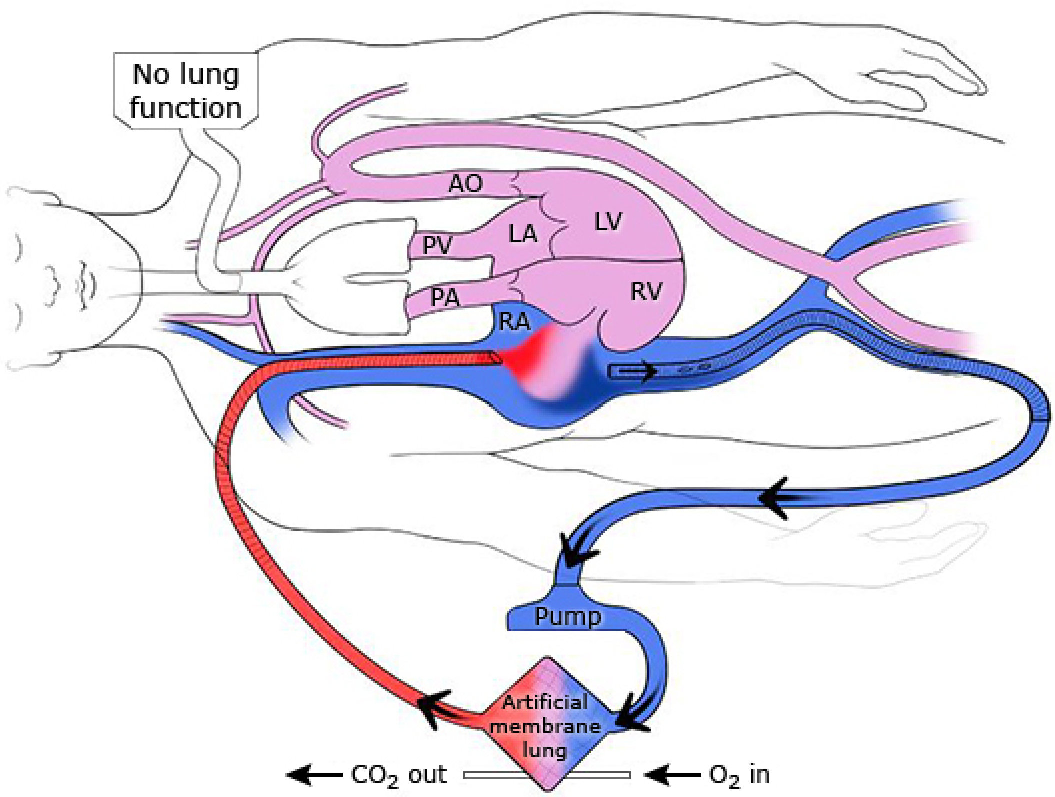


Diagram of venovenous ECMO for respiratory failure. When there is no native lung function the arterial saturation will be 75 to 85 percent. VV access: Blood is withdrawn from the IVC, circulated through the artificial membrane, and returned via the SVC to the RA.

ECMO: extracorporeal membrane oxygenation; AO: aorta; PV: pulmonary vein; PA: pulmonary artery; LA: left atrium; LV: left ventricle; RA: right atrium; RV: right ventricle; CO_2: carbon dioxide; O_2: oxygen; VV: venovenous; IVC: inferior vena cava; SVC: superior vena cava.

Revised and updated from: Bartlett RH, Gattinoni L. Current status of extracorporeal life support (ECMO) for cardiopulmonary failure. Minerva Anestesiol 2010; 76:534.

Graphic 56622 Version 5.0

Venoarterial extracorporeal membrane oxygenation

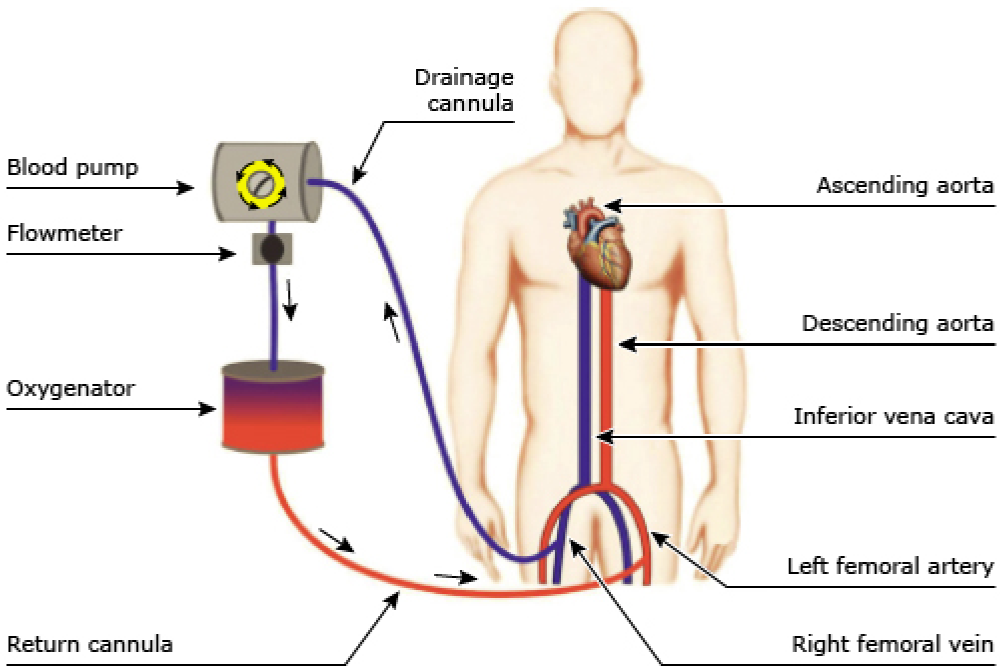


Diagram of a peripheral venoarterial extracorporeal membrane oxygenation circuit. The blood from the inferior vena cava is drained through a cannula in the right femoral vein. Then, the blood passes through the blood pump and the oxygenation membrane, returning to the arterial system of the patient through the left femoral artery.

From: Chaves RCF, Rabello Filho R, Timenetsky KT, et al. Extracorporeal membrane oxygenation: a literature review. Rev Bras Ter Intensiva 2019; 31:410. Available at: http://www.scielo.br/scielo.php?script=sci_arttext&pid=S0103-507X2019000300410&lng=en&nrm=iso&tlng=en.

Graphic 127771 Version 1.0

ECMO options in COVID-19 patients

ECMO type	Description	Advantages	Disadvantages
Conventional venovenous*	Drain from venous system, return through venous system	Easy to establish at bedside, good oxygenation and ventilation	No cardiac support
Venoarterial	Drain from venous system return to arterial circulation	Easy to establish at bedside, provides biventricular support	Pulmonary shunting may result in hypoxemia, peripheral ischemia
Avalon	Drain from SVC and IVC return to RA near tricuspid valve	Single cannula, allows easier mobilization	Often requires fluoroscopy for placement, requires adequate RV function
Protek Duo	Drain from right atrium return to pulmonary artery	Single cannula, easy mobilization, provides RV support	Requires fluoroscopy for placement

ECMO: extracorporeal membrane oxygenation; COVID-19: coronavirus disease 2019; SVC: superior vena cava; IVC: inferior vena cava; RA: right atrium; RV: right ventricle.

* Femoral-femoral or femoral-jugular.

Graphic 128287 Version 1.0

Peripheral cannulation strategies for extracorporeal membrane oxygenation

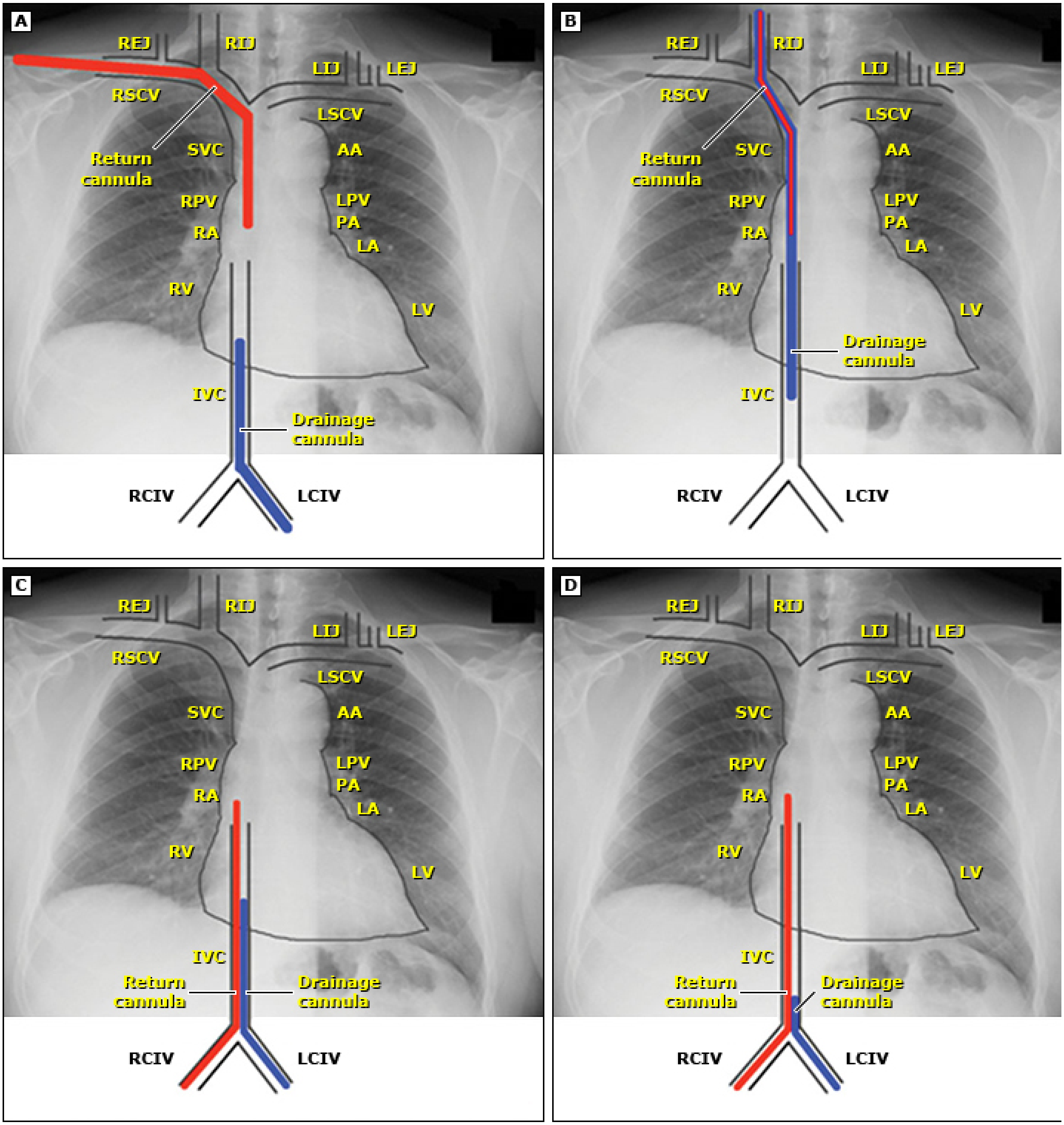
ECMO type	Description	Advantages	Disadvantages	COVID-19 considerations
Venovenous (VV)	Drainage of blood from the venous system with return of oxygenated blood via the venous system	▪ Easy and quick to establish at bedside	▪ Relies on adequate function of the RV and LV ▪ Subject to recirculation if malpositioned	▪ Easiest form of VV ECMO to establish without the need for fluoroscopy
Venoarterial (VA)	Drainage of blood from the venous system with return of oxygenated blood via the arterial system	▪ May be quickly established at bedside ▪ Provides oxygenation, ventilation, and biventricular support	▪ Limits patient mobility ▪ Risks compromise of peripheral circulation due to impairment of arterial blood flow distal to the femoral arterial cannula ▪ High rate of complications requiring surgical interventions	▪ Provides both cardiac and pulmonary support for patients manifesting COVID-19-associated myocarditis
Bicaval dual-lumen ECMO	Drainage of blood from cannula ports in the SVC and IVC, with return of oxygenated blood to the RA but directed across the tricuspid valve	▪ Single catheter ▪ Allows mobilization	▪ Relies on adequate function of the RV and LV ▪ Subject to recirculation if malpositioned ▪ Commonly requires fluoroscopy for placement	▪ Need for fluoroscopy requires movement to catheterization suite or hybrid operating room risking exposure of additional providers ▪ Confirmation that oxygenated

				blood is flowing across TV may require use of TEE (which generates aerosol, although this is less likely in intubated patients)
Atriopulmonary ECMO	Drainage of blood from the venous system via the RA, with return of oxygenated blood to the pulmonary artery	▪ Single catheter ▪ Provides RV hemodynamic support ▪ Allows mobilization	▪ Requires fluoroscopy for placement	▪ Need for fluoroscopy requires movement to catheterization suite or hybrid operating room, risking exposure of additional providers ▪ Provision of RV support is advantageous in patients with pulmonary hypertension and COVID-19-associated RV dysfunction ▪ Temporary FDA approval for use to provide ECMO during COVID-19 crisis

ECMO: extracorporeal membrane oxygenation; COVID-19: coronavirus disease 2019; SVC: superior vena cava; IVC: inferior vena cava; RV: right ventricle; TV: tricuspid valve; TEE: transesophageal echocardiography; FDA: US Food and Drug Administration.

Graphic 128250 Version 1.0

Common venovenous ECMO cannulation strategies



Venovenous ECMO relies upon drainage of venous blood from the body and then a return of blood that has been oxygenated to the venous circulation. If the sites of venous drainage and return of oxygenated blood are too close, mixing can occur between the cannulae. Thus, the tips of the two cannula should be separated.

Blue lines denote drainage cannulas, which deliver venous blood from the patient to the membrane oxygenat Red lines denote return cannulas, which deliver oxygenated blood from the membrane oxygenator to the patient.

(A) Femoral-right internal jugular cannulation.

(B) Dual-lumen right internal jugular cannulation with Avalon Elite cannula. With this cannula, drainage occurs in the SVC and IVC, and blood is returned to the RA.

(C) Femoral-femoral cannulation with the return cannula at the junction of the IVC and RA and drainage in the IVC.

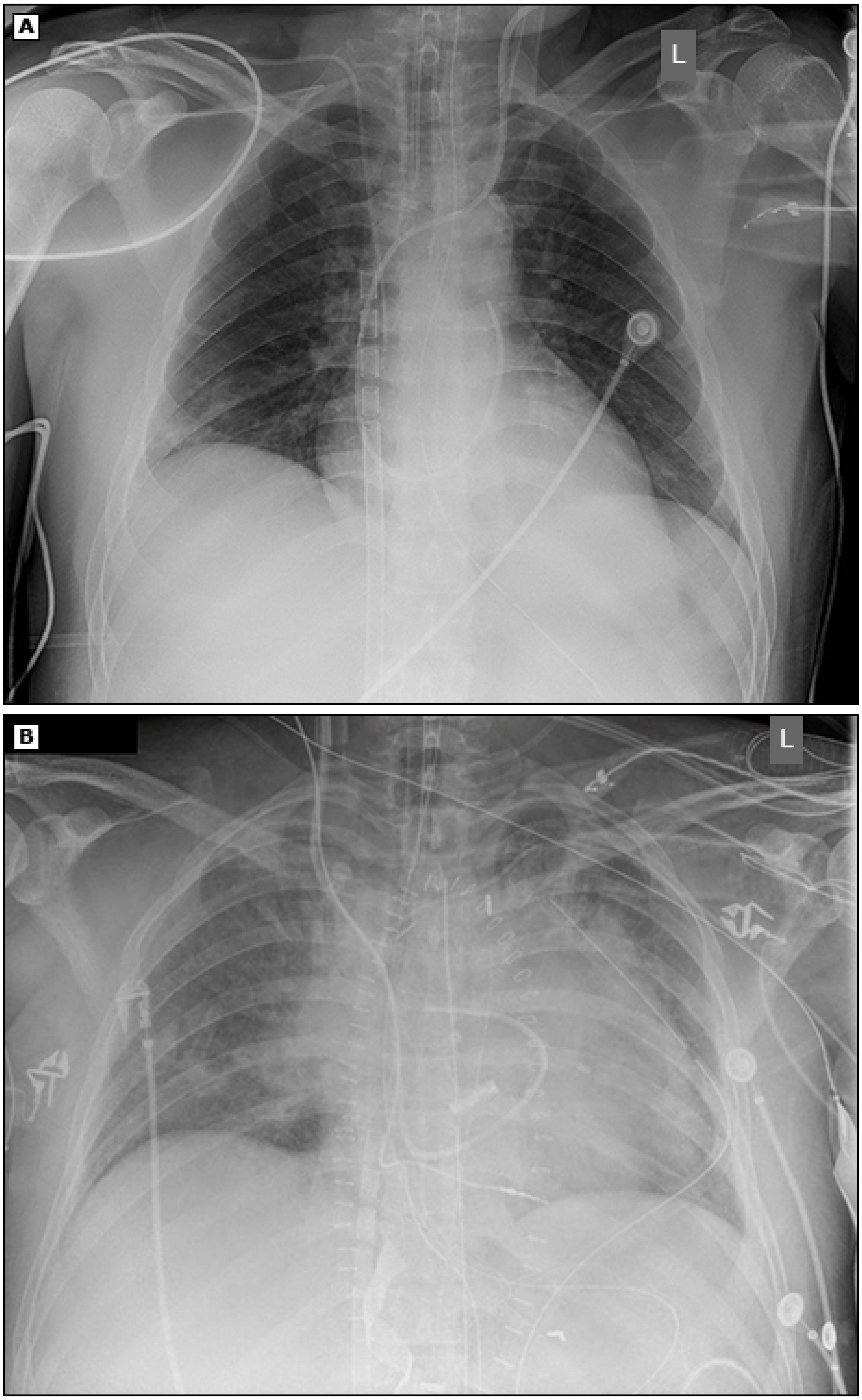
(D) Femoral-femoral cannulation with the return cannula in the RA and the drainage cannula in the femoral ve and distal IVC. Femoral cannulae are inserted into the femoral vein, which drains into the common iliac vein.

ECMO: extracorporeal membrane oxygenation; REJ: right external jugular vein; RIJ: right internal jugular vein; LIJ: left internal jugular vein; LEJ: left external jugular vein; RSCV: right subclavian vein; LSCV: left subclavian ve SVC: superior vena cava; AA: aortic arch; RPV: right pulmonary vein; LPV: left pulmonary vein; RA: right atrium; PA: pulmonary artery; LA: left atrium; RV: right ventricle; LV: left ventricle; IVC: inferior vena cava; RCIV: right common iliac vein; LCIV: left common iliac vein.

From: Fierro MA, Daneshmand MA, Bartz RR. Perioperative management of the adult patient on the venovenous extracorporeal membra oxygenation requiring noncardiac surgery. Anesthesiology 2018; 128:181. DOI: 10.1097/ALN.0000000000001887.

Graphic 116518 Version 3.0

Positioning of venous return cannula for ECMO

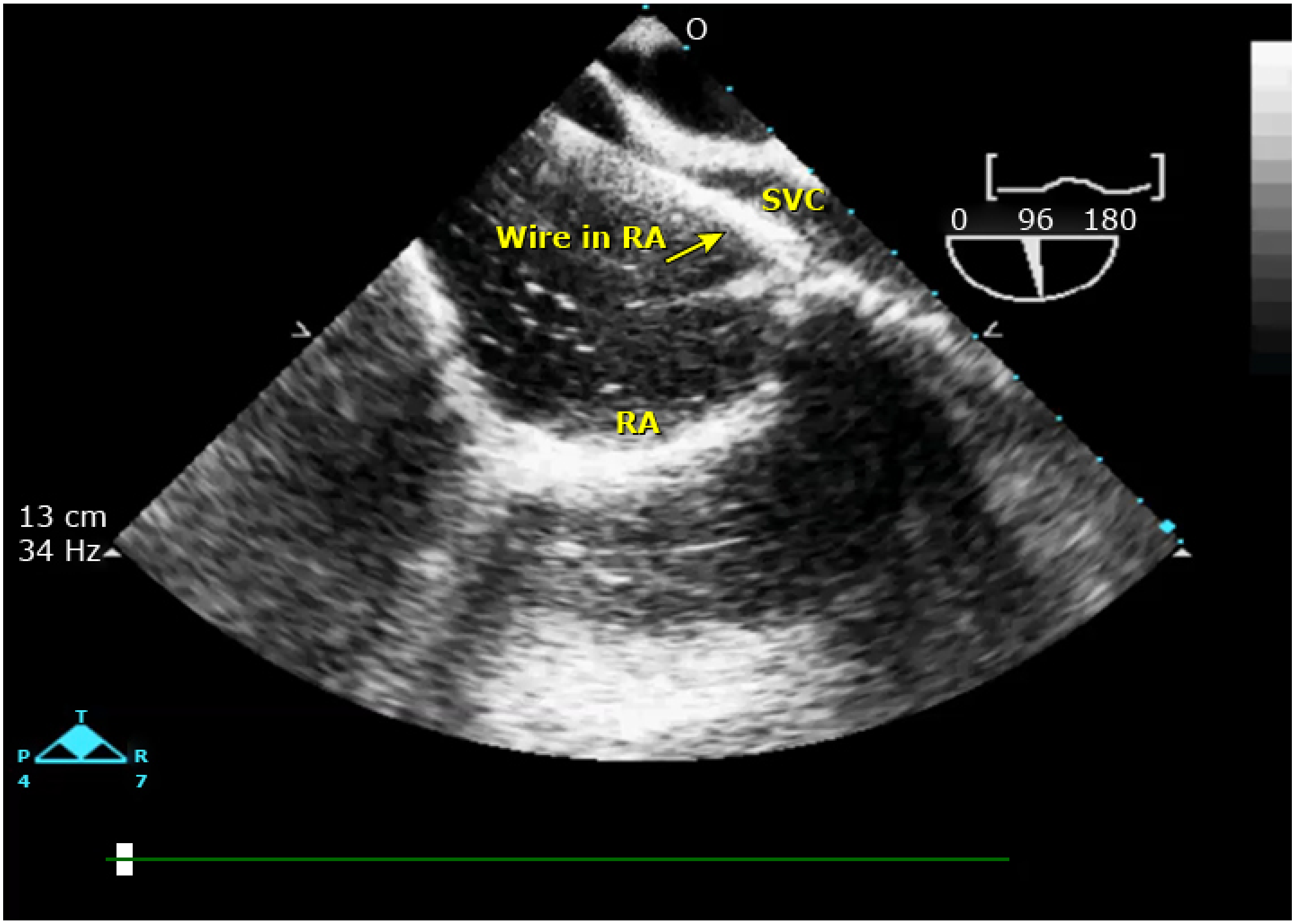


The first chest radiograph (A) shows the correct position of the venous return cannula for ECMO, while the second chest radiograph (B) shows positioning that is too low in the inferior vena cava.

ECMO: extracorporeal membrane oxygenation.

Graphic 116234 Version 1.0

TEE-guided placement of wire for extracorporeal membrane oxygenation (ECMO) cannulation

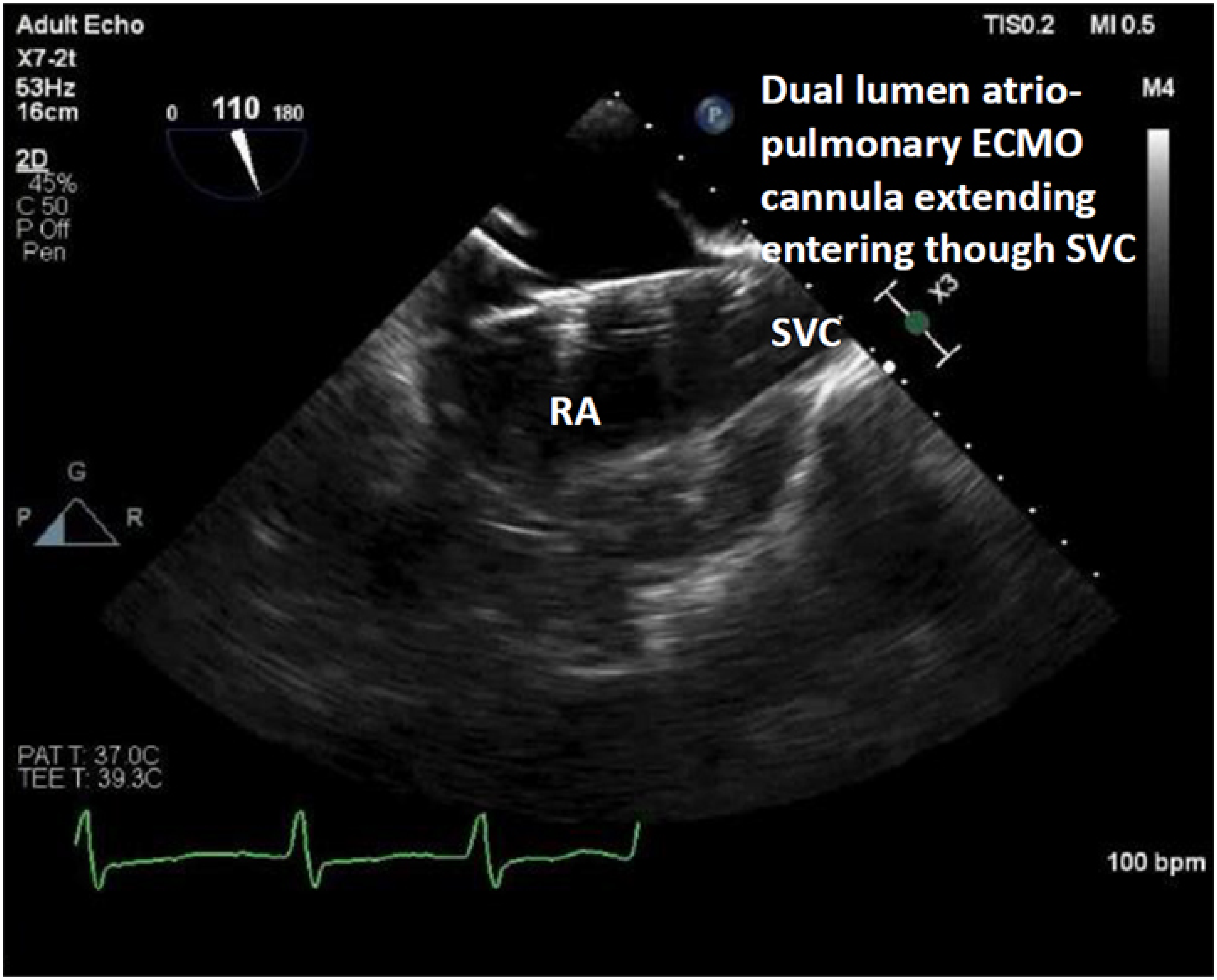


Transesophageal echocardiography midesophageal bicaval view of the right atrium showing a guidewire extending from the inferior vena cava to the junction of the right atrium and superior vena cava.

TEE: transesophageal echocardiography; ECMO: extracorporeal membrane oxygenation; SVC: superior vena cava; RA: right atrium.

Graphic 116454 Version 1.0

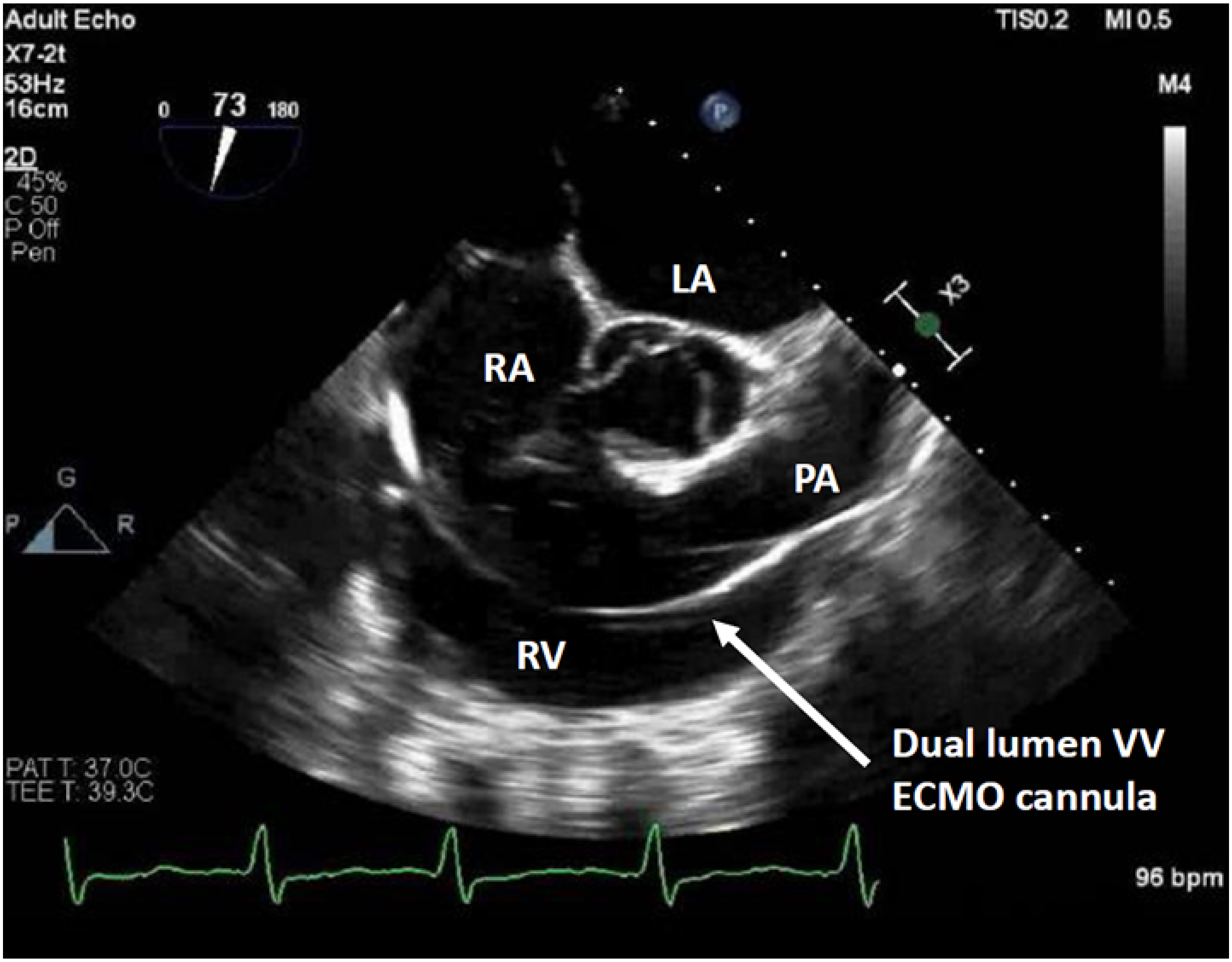
Dual lumen atriopulmonary ECMO cannula entering right atrium through the superior vena cava



ECMO: extracorporeal membrane oxygenation; RA: right atrium; SVC: superior vena cava.

Graphic 128288 Version 1.0

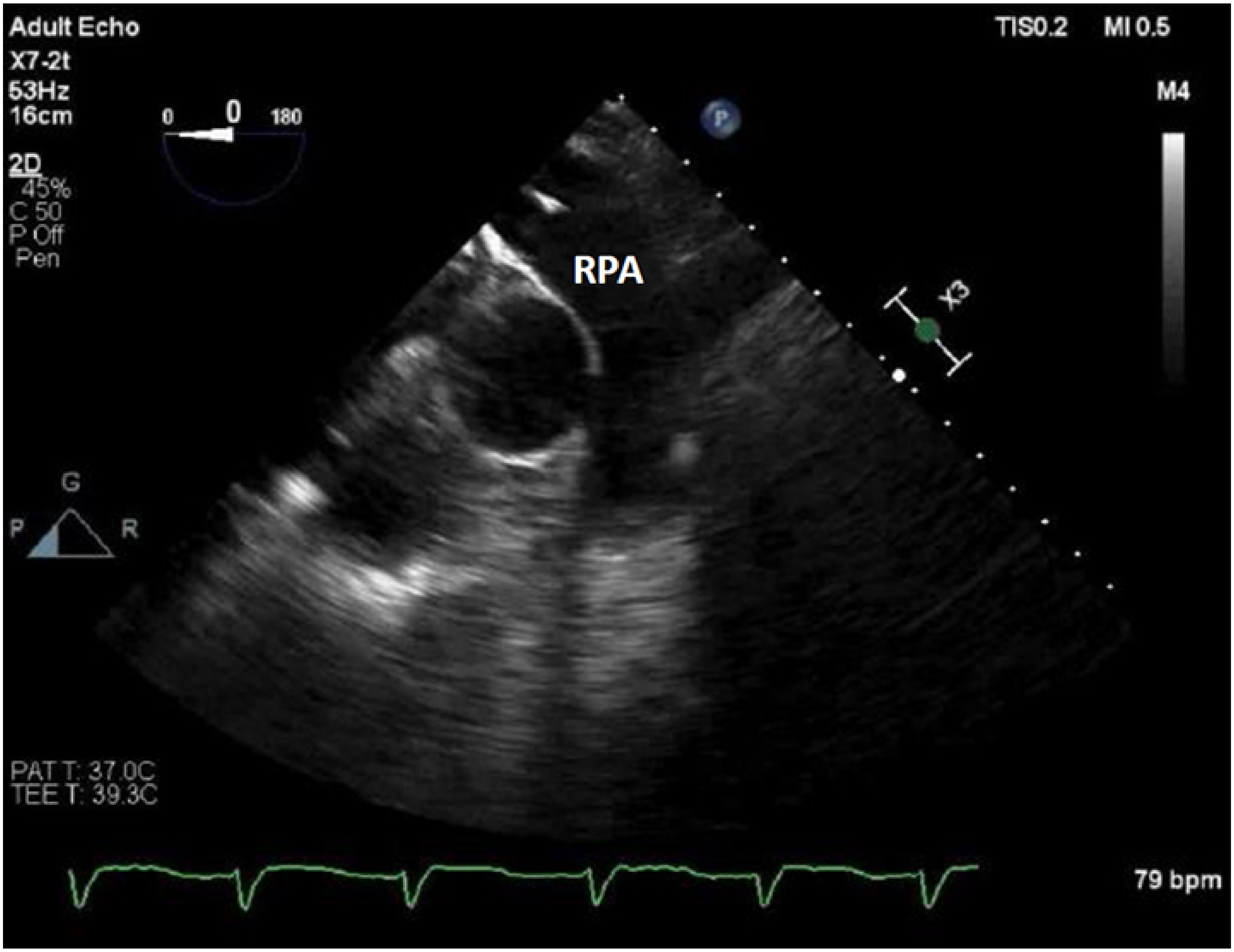
Dual lumen atriopulmonary cannula extending from the internal jugular vein through the right atrium, right ventricle, and into the pulmonary artery



RA: right atrium; LA: left atrium; RV: right ventricle; PA: pulmonary artery; VV: venovenous; ECMO: extracorporeal membrane oxygenation.

Graphic 128289 Version 1.0

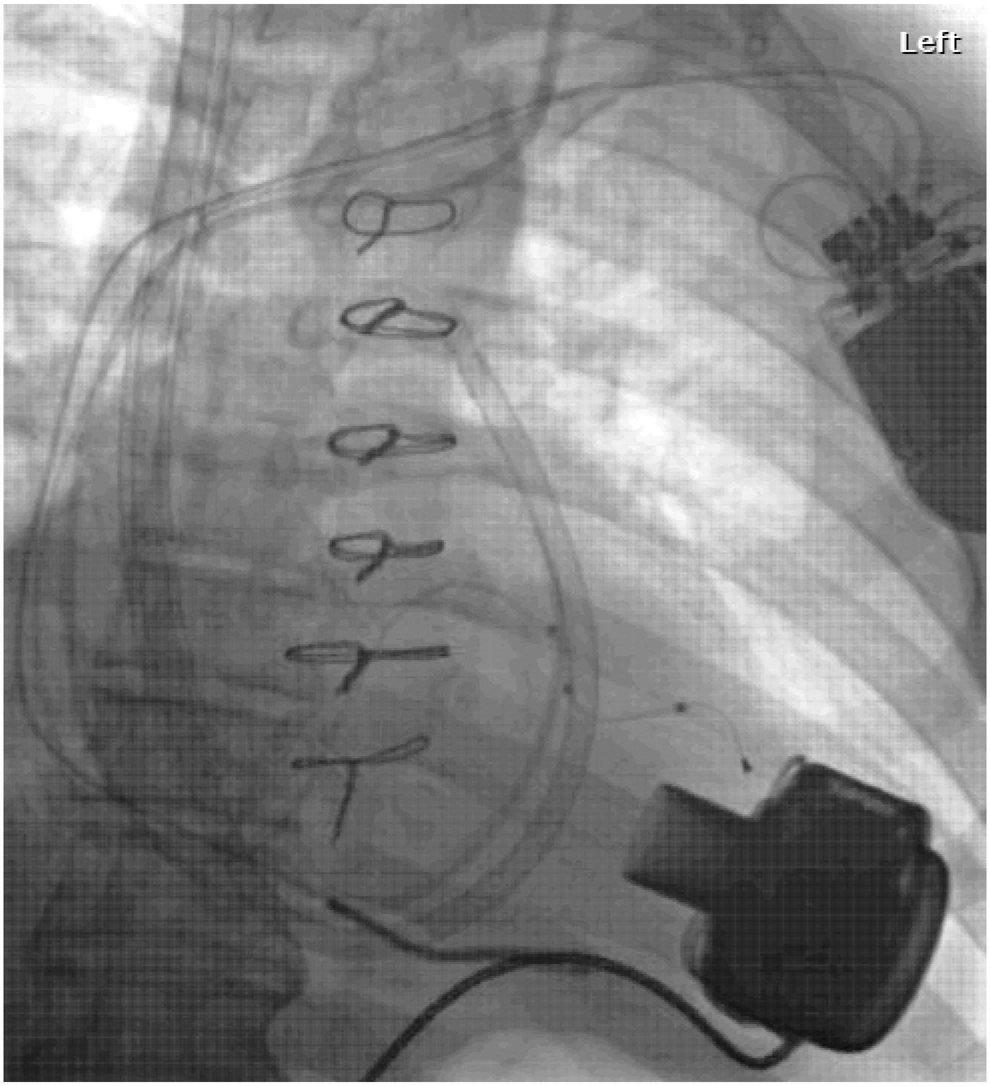
Dual lumen atriopulmonary catheter with tip in the right pulmonary artery



RPA: right pulmonary artery.

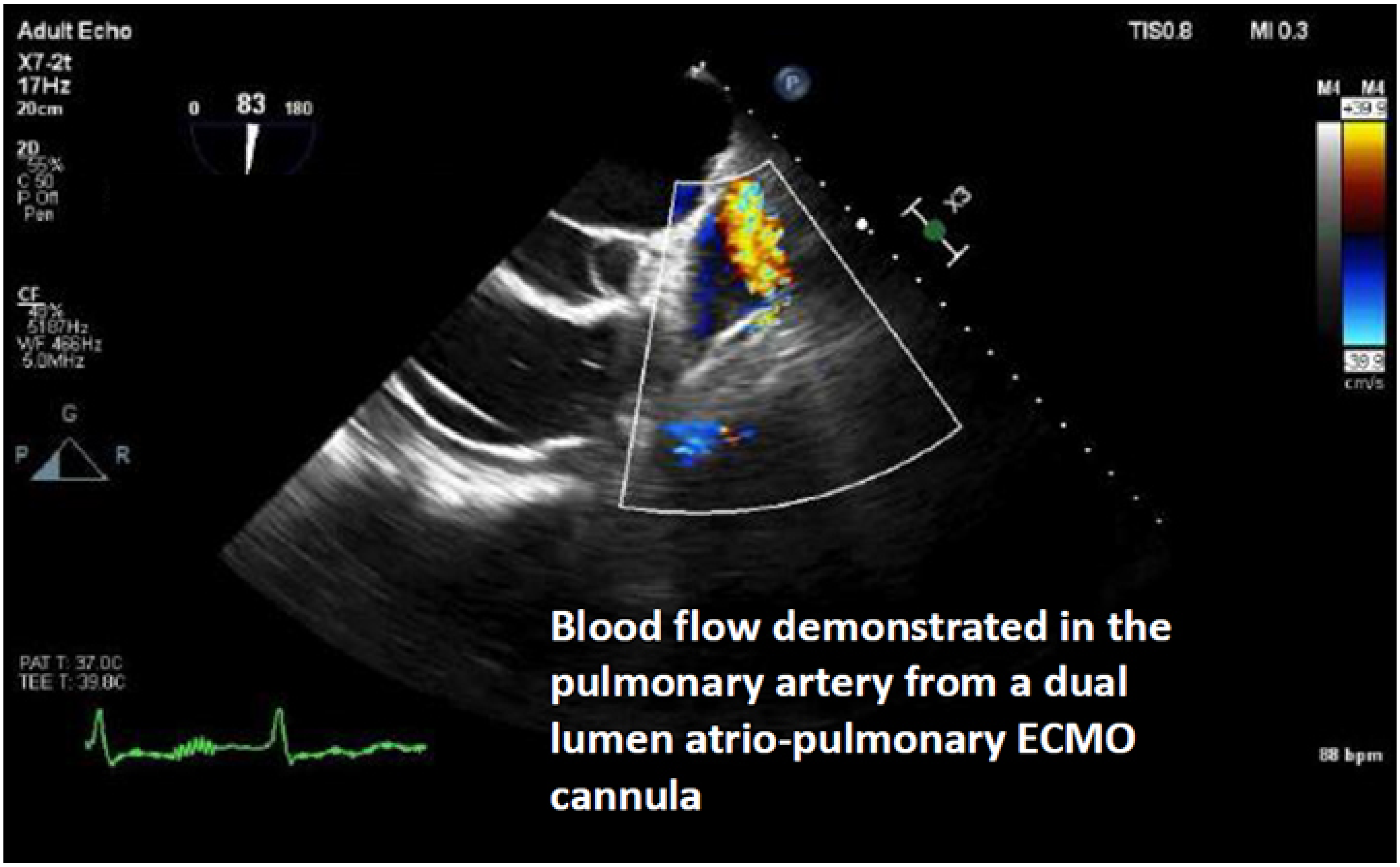
Graphic 128290 Version 1.0

Fluoroscopy of dual lumen atriopulmonary ECMO cannula localized in the pulmonary artery



Graphic 128291 Version 1.0

Blood flow entering the pulmonary artery from a dual lumen atriopulmonary ECMO cannula



PA: pulmonary artery.

Graphic 128292 Version 1.0

Quick reference for evaluation and management of COVID-19-associated hypercoagulability

Evaluations and monitoring	
Inpatients	▪ Daily PT, aPTT, fibrinogen, D-dimer; frequency may be reduced depending on acuity and trend in values ▪ Diagnostic imaging studies if feasible for clinically suspected DVT or PE; consult PERT team ▪ Alternative evaluations if standard imaging studies are not feasible
Outpatients	▪ Routine coagulation testing is not required
Management	
Abnormal coagulation studies	▪ Use for prognostic information and level of care ▪ Do not intervene solely based on coagulation abnormalities
VTE prophylaxis	▪ Prophylactic dosing preferred over higher dosing in most inpatients, including those in the ICU ▪ Dose adjustments may be made for increased body weight or decreased kidney function ▪ LMW heparin is generally preferred over other anticoagulants ▪ Thromboprophylaxis is generally not continued following discharge, with rare exceptions ▪ Thromboprophylaxis is generally not used in outpatients, with rare exceptions
VTE treatment	▪ Therapeutic (full-dose) anticoagulation for documented VTE or high suspicion for VTE • Initiate in hospital per standard protocols • Continue for at least 3 months ▪ Reserve fibrinolytic agents (eg, tPA) for limb-threatening DVT, massive PE, acute stroke, or acute MI; consult PERT or stroke team
Clotting in vascular catheters or extracorporeal circuits*	▪ Therapeutic (full-dose) anticoagulation ▪ Standard protocols for continuous renal replacement therapy or ECMO
Bleeding	▪ Similar to individuals without COVID-19 • Transfusions for anemia or thrombocytopenia • Anticoagulant reversal and/or discontinuation for anticoagulant-associated bleeding • Specific treatments (eg, factor replacement) for underlying bleeding disorders

	▪ Avoid antifibrinolytic agents in individuals with acute decompensated DIC¶

Refer to UpToDate for discussions of COVID-19 management and related topics. Resources are also available from the International Society on Thrombosis and Haemostasis (https://onlinelibrary.wiley.com/doi/10.1111/jth.14853), the American Society of Hematology (https://www.hematology.org/covid-19/covid-19-and-coagulopathy), and the American College of Cardiology (https://www.acc.org/latest-in-cardiology/articles/2020/04/17/14/42/thrombosis-and-coronavirus-disease-2019-covid-19-faqs-for-current-practice).

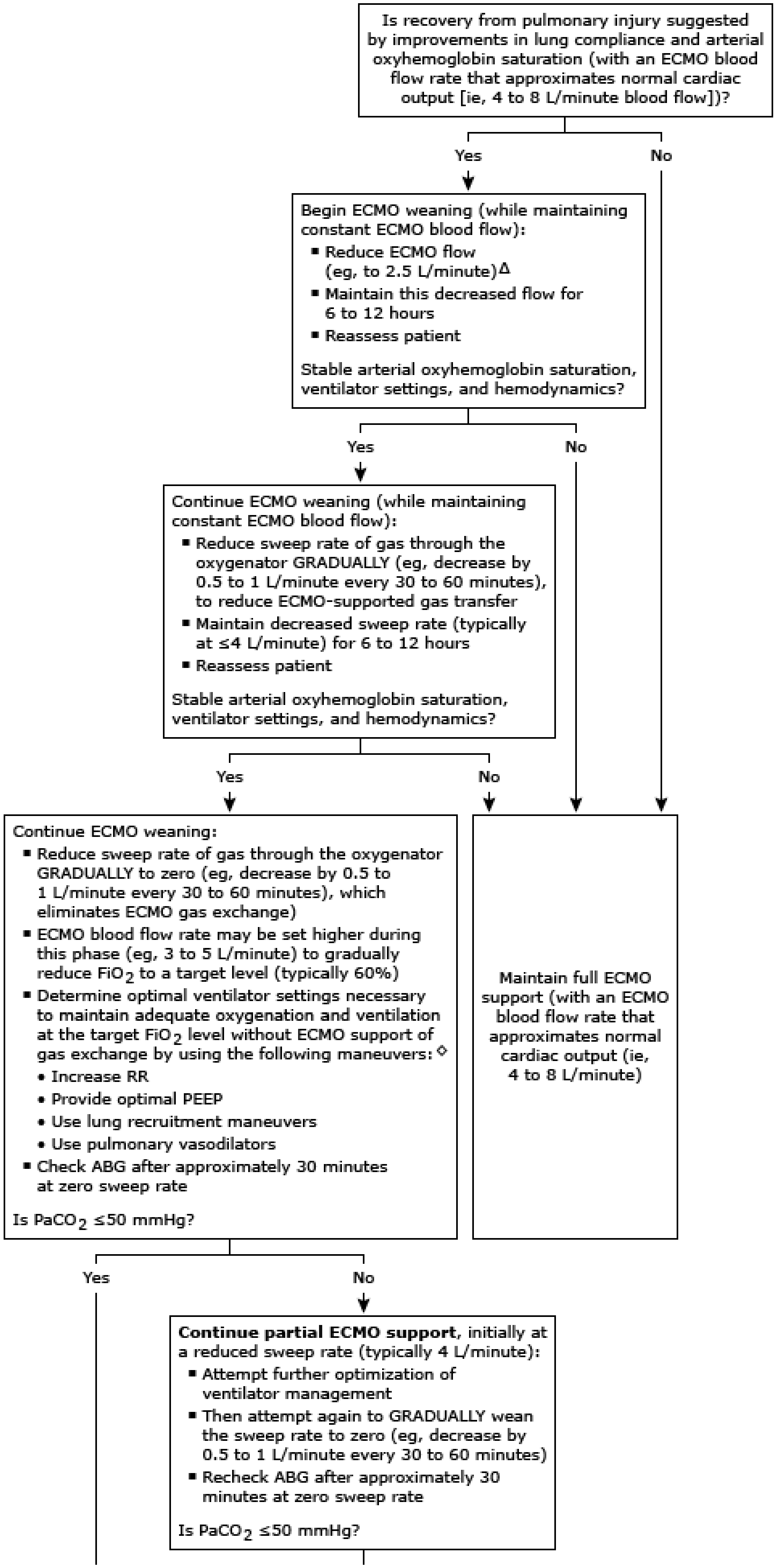
COVID-19: coronavirus disease 2019; PT: prothrombin time; aPTT: activated partial thromboplastin time; DVT: deep vein thrombosis; PE: pulmonary embolism; PERT: pulmonary embolism response team; VTE: venous thromboembolism; ICU: intensive care unit; tPA: tissue plasminogen activator; MI: myocardial infarction; ECMO: extracorporeal membrane oxygenation; DIC: disseminated intravascular coagulation.

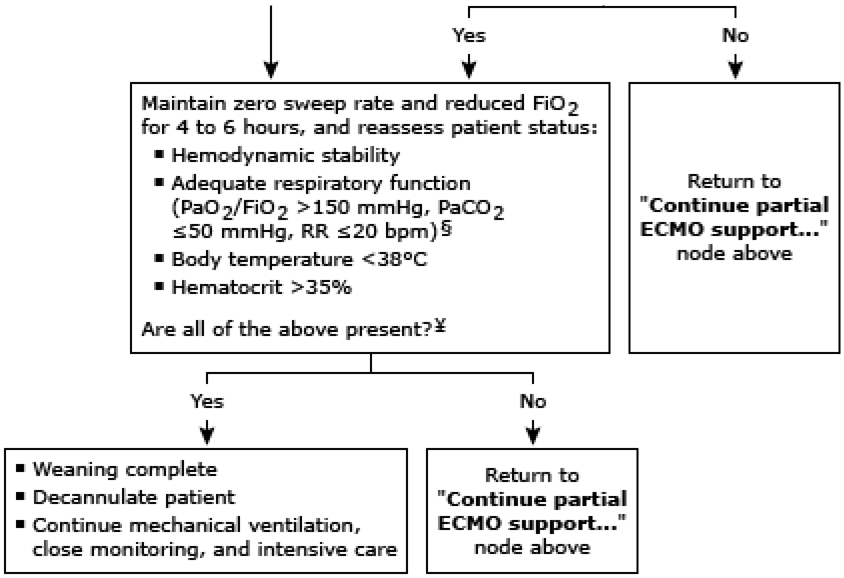
* Includes continuous renal replacement therapy (hemodialysis), ECMO, or other extracorporeal circuits.

¶ Acute decompensated DIC is associated with clinical bleeding and/or thrombosis and laboratory findings including prolonged PT and aPTT, thrombocytopenia, and hypofibrinogenemia. Antifibrinolytic agents (tranexamic acid and epsilon aminocaproic acid) are avoided because they may tip the balance towards thrombosis. Refer to UpToDate for details.

Graphic 127960 Version 4.0

Suggestions for weaning patients with ARDS from VV ECMO*¶


Is recovery from pulmonary injury suggested by improvements in lung compliance and arterial oxyhemoglobin saturation (with an ECMO blood flow rate that approximates normal cardiac output [ie, 4 to 8 L/minute blood flow])?
Yes
No
Begin ECMO weaning (while maintaining constant ECMO blood flow):
▪ Reduce ECMO flow (eg, to 2.5 L/minute)Δ
▪ Maintain this decreased flow for 6 to 12 hours
▪ Reassess patient
Stable arterial oxyhemoglobin saturation, ventilator settings, and hemodynamics?
Yes
No
Continue ECMO weaning (while maintaining constant ECMO blood flow):
▪ Reduce sweep rate of gas through the oxygenator GRADUALLY (eg, decrease by 0.5 to 1 L/minute every 30 to 60 minutes), to reduce ECMO-supported gas transfer
▪ Maintain decreased sweep rate (typically at ≤4 L/minute) for 6 to 12 hours
▪ Reassess patient
Stable arterial oxyhemoglobin saturation, ventilator settings, and hemodynamics?
Yes
No
Continue ECMO weaning:
▪ Reduce sweep rate of gas through the oxygenator GRADUALLY to zero (eg, decrease by 0.5 to 1 L/minute every 30 to 60 minutes), which eliminates ECMO gas exchange)
▪ ECMO blood flow rate may be set higher during this phase (eg, 3 to 5 L/minute) to gradually reduce FiO_2 to a target level (typically 60%)
▪ Determine optimal ventilator settings necessary to maintain adequate oxygenation and ventilation at the target FiO_2 level without ECMO support of gas exchange by using the following maneuvers:◊
• Increase RR
• Provide optimal PEEP
• Use lung recruitment maneuvers
• Use pulmonary vasodilators
▪ Check ABG after approximately 30 minutes at zero sweep rate
Is $PaCO_2$ ≤50 mmHg?
Maintain full ECMO support (with an ECMO blood flow rate that approximates normal cardiac output (ie, 4 to 8 L/minute)
Yes
No
Continue partial ECMO support, initially at a reduced sweep rate (typically 4 L/minute):
▪ Attempt further optimization of ventilator management
▪ Then attempt again to GRADUALLY wean the sweep rate to zero (eg, decrease by 0.5 to 1 L/minute every 30 to 60 minutes)
▪ Recheck ABG after approximately 30 minutes at zero sweep rate
Is $PaCO_2$ ≤50 mmHg?



ARDS: acute respiratory distress syndrome; VV: venovenous; ECMO: extracorporeal membrane oxygenation; FiO_2: fraction of inspired oxygen; RR: respiratory rate; PEEP: positive end-expiratory pressure; ABG: arterial blood gas; $PaCO_2$: arterial partial pressure of carbon dioxide; PaO_2: arterial partial pressure of oxygen.

* Refer to UpToDate's content on extracorporeal membrane oxygenation.

¶ Note that there are patient-dependent and institution-dependent variations in weaning protocols. Most centers implement weaning protocols during daytime hours when clinicians with appropriate expertise are available.

Δ We maintain flows >2 L/minute at this stage to avoid formation of thrombi, unless additional heparin is administered.

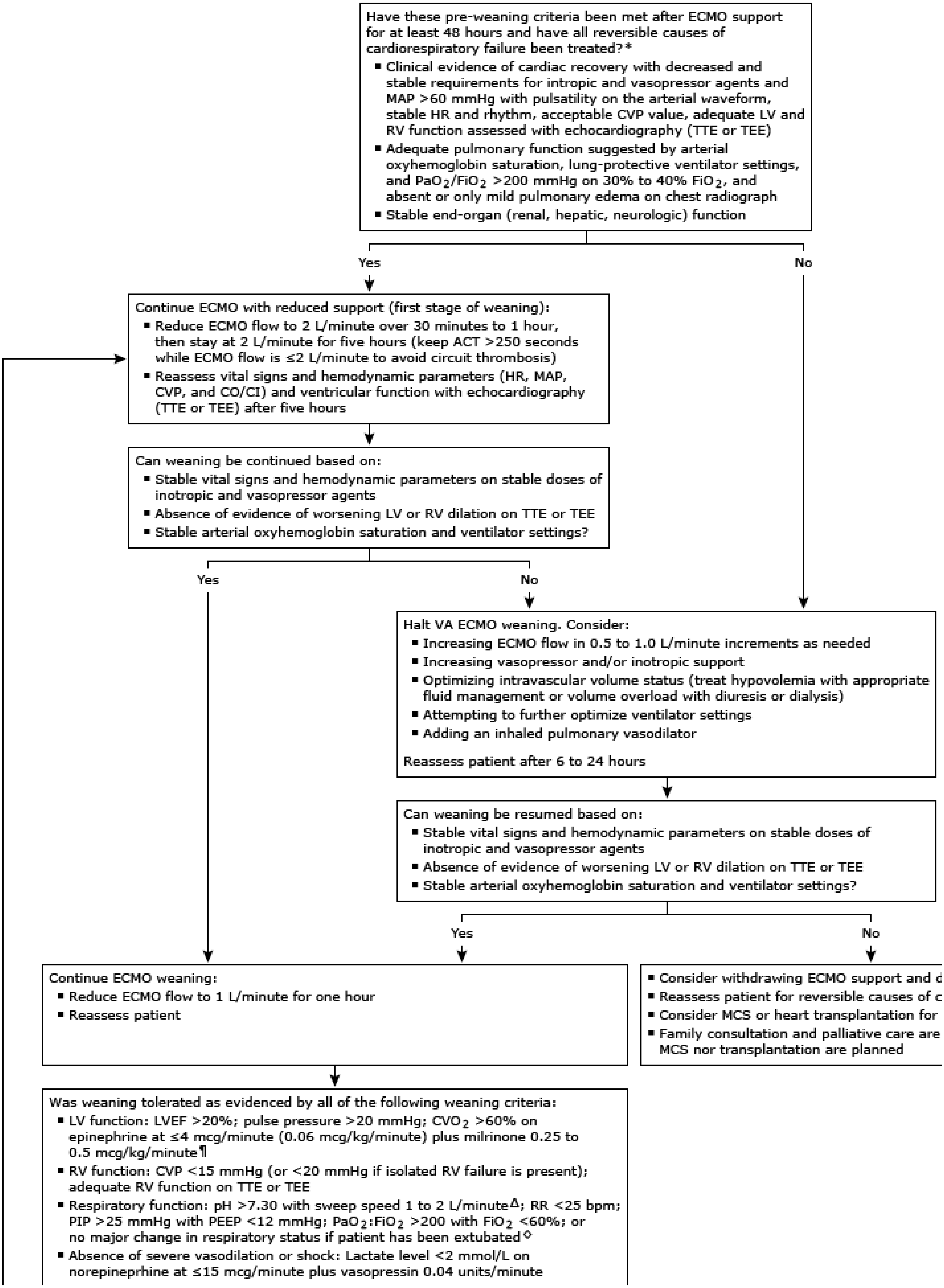
◇ Refer to UpToDate's content on ventilator management strategies for adults with ARDS.

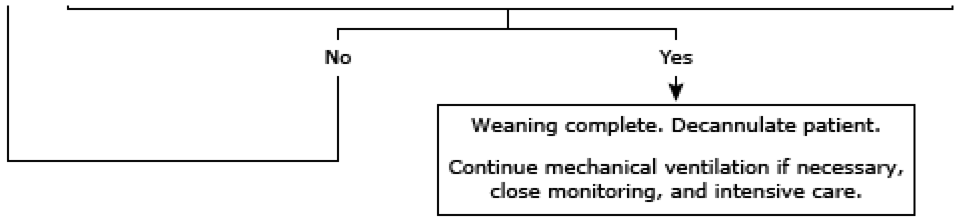
§ Some centers allow a PCO_2 >50 mmHg if renal function is intact, there by allowing compensation.

¥ It is important to have some ventilatory "reserve" in these parameters in case there are temporary periods of worsening (eg, during patient turning or sedation holidays).

Graphic 128540 Version 1.0

Suggestions for weaning patients from VA ECMO[1,2]


Have these pre-weaning criteria been met after ECMO support for at least 48 hours and have all reversible causes of cardiorespiratory failure been treated?*
Clinical evidence of cardiac recovery with decreased and stable requirements for intropic and vasopressor agents and MAP >60 mmHg with pulsatility on the arterial waveform, stable HR and rhythm, acceptable CVP value, adequate LV and RV function assessed with echocardiography (TTE or TEE)
Adequate pulmonary function suggested by arterial oxyhemoglobin saturation, lung-protective ventilator settings, and PaO_2/FiO_2 >200 mmHg on 30% to 40% FiO_2, and absent or only mild pulmonary edema on chest radiograph
Stable end-organ (renal, hepatic, neurologic) function
Yes
No
Continue ECMO with reduced support (first stage of weaning):
Reduce ECMO flow to 2 L/minute over 30 minutes to 1 hour, then stay at 2 L/minute for five hours (keep ACT >250 seconds while ECMO flow is ≤2 L/minute to avoid circuit thrombosis)
Reassess vital signs and hemodynamic parameters (HR, MAP, CVP, and CO/CI) and ventricular function with echocardiography (TTE or TEE) after five hours
Can weaning be continued based on:
Stable vital signs and hemodynamic parameters on stable doses of inotropic and vasopressor agents
Absence of evidence of worsening LV or RV dilation on TTE or TEE
Stable arterial oxyhemoglobin saturation and ventilator settings?
Yes
No
Halt VA ECMO weaning. Consider:
Increasing ECMO flow in 0.5 to 1.0 L/minute increments as needed
Increasing vasopressor and/or inotropic support
Optimizing intravascular volume status (treat hypovolemia with appropriate fluid management or volume overload with diuresis or dialysis)
Attempting to further optimize ventilator settings
Adding an inhaled pulmonary vasodilator
Reassess patient after 6 to 24 hours
Can weaning be resumed based on:
Stable vital signs and hemodynamic parameters on stable doses of inotropic and vasopressor agents
Absence of evidence of worsening LV or RV dilation on TTE or TEE
Stable arterial oxyhemoglobin saturation and ventilator settings?
Yes
No
Continue ECMO weaning:
Reduce ECMO flow to 1 L/minute for one hour
Reassess patient
Consider withdrawing ECMO support and d
Reassess patient for reversible causes of c
Consider MCS or heart transplantation for
Family consultation and palliative care are
MCS nor transplantation are planned
Was weaning tolerated as evidenced by all of the following weaning criteria:
LV function: LVEF >20%; pulse pressure >20 mmHg; CVO_2 >60% on epinephrine at ≤4 mcg/minute (0.06 mcg/kg/minute) plus milrinone 0.25 to 0.5 mcg/kg/minute¶
RV function: CVP <15 mmHg (or <20 mmHg if isolated RV failure is present); adequate RV function on TTE or TEE
Respiratory function: pH >7.30 with sweep speed 1 to 2 L/minute Δ; RR <25 bpm; PIP >25 mmHg with PEEP <12 mmHg; $PaO_2:FiO_2$ >200 with FiO_2 <60%; or no major change in respiratory status if patient has been extubated ◊
Absence of severe vasodilation or shock: Lactate level <2 mmol/L on norepineprhine at ≤15 mcg/minute plus vasopressin 0.04 units/minute



VA: venoarterial; ECMO: extracorporeal membrane oxygenation; MAP: mean arterial pressure; HR: heart rate; C venous pressure; LV: left ventricular; RV: right ventricular; TTE: transthoracic echocardiography; TEE: transesop echocardiography; PaO_2: arterial partial pressure of oxygen; FiO_2: fraction of inspired oxygen; ACT: activated c cardiac output; CI: cardiac index; MCS: mechanical circulatory support; LVEF: left ventricular ejection fraction; C venous blood oxygen content; RR: respiratory rate; bpm: beats per minute; PIP: peak inspiratory pressure; PEE expiratory pressure; VV: venovenous.

* Refer to UpToDate content regarding extracorporeal membrane oxygenation. Note that there are patient-de institution-dependent variations in weaning protocols. Most centers implement weaning protocols during day clinicians with appropriate expertise are available.

¶ Further increases in inotropic support may be appropriate if weaning criteria are not met when decannulatio due to evidence of vascular complications.

Δ Sweep speed is defined as the rate that oxygen is delivered via the ECMO circuit.

◇ Transition from VA ECMO to VV ECMO can be considered if biventricular function has recovered, but respirat remains inadequate.

References:

1. *Hoyler MM, Flynn B, Iannacone EM, et al. Clinical management of venoarterial extracorporeal membrane oxygenation. J Cardioth 2020; 34:2776.*
2. *Aissaoui N, El-Banayosy A, Combes A: How to wean a patient from veno-arterial extracorporeal membrane oxygenation. Intensive 41:902.*

Graphic 131446 Version 1.0

Contributor Disclosures

Michael G Fitzsimons, MD Nothing to disclose **Jerome Crowley, MD, MPH** Nothing to disclose **Michael F O'Connor, MD, FCCM** Consultant/Advisory Boards: Intensix/CLEW [Predictive analytics in medicine]. **Jonathan B Mark, MD** Nothing to disclose **Nancy A Nussmeier, MD, FAHA** Nothing to disclose **Geraldine Finlay, MD** Nothing to disclose

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