43 Extracorporeal Membrane Oxygenation

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Extracorporeal membrane oxygenation (ECMO) refers to several interdependent technologies that operate in concert to support cellular respiration in patients with respiratory failure, cardiac failure, or both. It consists on removing deoxygenated blood through a cannula inserted into a vein (or venous reservoir such as the RA), driving the blood through an oxygenator that removes CO_2 and oxygenates the blood, and pumping it back into the body through a cannula placed into an artery (venoarterial [VA] ECMO) or a vein or venous reservoir (venovenous [VV] ECMO).

Cardiac ECMO (VA ECMO)

Indications

VA ECMO substitutes the gas exchange function of the lungs and the systemic distribution of blood performed by the heart. It is used for either isolated cardiovascular disease (e.g., ventricular stunning, arrhythmias, cardiomyopathy), or combined respiratory and cardiovascular disease (e.g., sepsis) poorly responsive to medical support alone.

Cardiac output (CO) on VA ECMO is defined by the following formula:

CO = flow in circuit + residual intrinsic CO

Flow on ECMO depends on:

- Cannula size (the larger the cannula, the better the flow)
- Cannula location
- Intravascular volume
- SVR

Cannulation Strategies

The patient's flow requirements and vessel size drive the cannulation strategy discussion. Patients with normal metabolic requirements need normal or mildly increased flow (typically 75-110% of their estimated CO), whereas patients with dramatically increased metabolic needs (e.g., high-output septic shock) may need flows that exceed 200-300% of normal CO. The cannula size (both diameter and length) determines flow rates through the ECMO circuit, but vessel diameter dictates cannula size.

VA cannulation can be accomplished in 2 ways:

Flow Calculations and Dilutional Calculations

CICU/PICU:

Patients weighing <10 kg
Flow = Wt (kg) x 150 mL/min

Patients weighing >10 kg
Flow = BSA x Cardiac Index

NICU:

All patients
Flow = Wt (kg) x 100 mL/min

$$BSA = \sqrt{\frac{Ht\ (cm) \times Wt\ (kg)}{3600}}$$

Note: If no height can be found to calculate BSA, then mL/kg/min can be used until a height can be determined. See mL/kg/min chart.

Cardiac Index		mL/kg/min	
0-2 yrs:	3.0	0-10 kg:	150
2-4 yrs:	2.8	10-15 kg:	125
4-6 yrs:	2.6	15-30 kg:	100
6-10 yrs:	2.5	30-50 kg:	75
>10 yrs:	2.4	>50 kg:	65

Figure 43-1. Chart used to calculate appropriate ECMO flows depending on age and size.

- **Peripheral cannulation.** Venous cannulation is performed most commonly through the right IJ vein or a femoral vein, and arterial cannulation is performed through the right carotid artery or a femoral artery. Femoral access is more commonly used in larger children (>30 kg), adolescents, and adults.
- **Central cannulation.** Used when the patient's flow requirements exceed the flow limits of cannulas placed peripherally or when direct cannulation and venting of the LA is required. Short, wide-bore cannulas are placed directly into the RA and the ascending aorta through a median sternotomy.

Avoidance of left-heart distention is important, especially when trying to optimize myocardial recovery. Inadequate left-heart decompression can also lead to pulmonary edema. As such, active cardiac decompression is particularly important when the cardiac function is so depressed that the heart is unable to pump against the pressure generated by the ECMO circuit. Options for active cardiac decompression include: creation of an ASD in the cath lab (for patients on peripheral VA ECMO), placement of a vent into the LA (for patients on central ECMO), or insertion of an Impella® device in the cath lab through either the femoral or axillary arteries (for patients >30 kg).

TCH General Guideline to VA ECMO Canulation

Patient Weight	Neck (Medtronic Biomedicus)		Groin (Maquet HLS)		Central (Medtronic DLP)			Tubing
	Venous	Arterial	Venous	Arterial	Rt Atrial	Lt Atrial	Arterial	
< 2kg	8/10	8			14	12	8	1/4
2-2.9 kg	10	8			16	12	8	1/4
3-3.9 kg	12	10			16	12	10	1/4
4-4.9 kg	12	10			18	14	10	1/4
5-5.9 kg	12	10			20	14	12	1/4
6-6.9 kg	14	10			20	14	12	1/4
7-7.9 kg	14	10			20	16	12	1/4
8-8.9 kg	14	12			20	16	12	1/4
9-9.9 kg	14	12			20	16	12	1/4
10-12 kg	14	12			20	16	14	3/8
13-14 kg	14	14			22	18	14	3/8
15-16 kg	14	14			22	18	14	3/8
17-18 kg	May need neck cannula due to size		19	15	22	18	14	3/8
19-20 kg			19	15	24	18	14	3/8
21-25 kg			19	15	24	18	16	3/8
26-30 kg			21	15	24	18	16	3/8
31-35 kg			21	15	24	18	16	3/8
36-40 kg			23	17	26	18	16	3/8
41-45 kg			25	17	26	20	16	3/8
46-50 kg			25	17	26	20	16	3/8
51-60 kg			29	19	28	20	18	3/8
61-65 kg			29	21	28	20	20	3/8
66-70 kg			29	21	28	20	20	3/8
>70 kg			29	21	30	20	22	3/8

Figure 43-2. Cannulation and circuit selection chart for VA ECMO.

Prime Constituents

CV/PICU Neonate/Infant - 200 mL (1/4-1/4) **<10 kg**

1. Fresh RBC	2 units
2. FFP	1 unit
25% albumin	100 mL (if FFP not available)
3. Heparin	200 units
4. NaH_2CO_3	25 mEq*
5. $CaCl_2$	500 mg*

NICU Neonate - 200 mL (1/4-1/4) **<10 kg**

1. Fresh RBC	2 units
2. Heparin	200 units
3. NaH_2CO_3	15 mEq*
4. Ca gluconate	200 mg*

CV/PICU Pediatric/Adult - 500 mL (3/8-3/8) **>10 kg**

Without Blood:		**With Blood Only:**		**With Blood & FFP:**	
1. Plasmalyte	400 mL	1. RBC	2 units	1. RBC	2 units
2. 25% albumin	200 mL	2. Heparin	1000 units	2. FFP	1 unit
3. Heparin	1000 units	3. NaH_2CO_3	15 mEq	3. Heparin	1000 units
4. NaH_2CO_3	10 mEq	4. $CaCl_2$	200 mg	4. NaH_2CO_3	25 mEq
5. $CaCl_2$	200 mg			5. $CaCl_2$	500 mg

*These amounts are what you should start with. After prime gas, you may need more.

Figure 43-3. Prime constituents for different patient populations.

Management

VA ECMO for Cardiac Support

VA ECMO for cardiac support aims to optimize tissue oxygen delivery (DO_2) to meet local metabolic demands and decrease myocardial work. VA ECMO helps with myocardial recovery by "unloading" the heart. This is accomplished by: 1) decreasing ventricular end-diastolic pressure, which optimizes coronary perfusion pressure and decreases wall stress, 2) improving BP, and 3) decreasing myocardial work by assuming much of the "pumping" function of the heart. Coronary perfusion occurs in a retrograde manner from blood returning into the ascending aorta from the arterial cannula, and in a prograde manner if there is aortic valve opening. Proper oxygenation of that blood is important to prevent coronary ischemia.

The CO provided by VA ECMO usually approximates 80% of the total CO, as there is always some blood return to the pulmonary veins from bronchial and collateral vessels that is then ejected through the aortic valve (provided there is enough cardiac function to do so). This residual endogenous CO helps prevent blood stasis and inappropriate

cardiac unloading. Sometimes, to achieve aortic valve opening, inotropic agents and/or vasodilators to decrease SVR may be required. If this is inadequate, active cardiac decompression will be necessary.

CO on VA ECMO depends on preload (circulating volume), flows (dependent on cannula size and location), and afterload (dependent on SVR and return cannula size and position). DO_2 depends on all of these factors in addition to oxygen carrying capacity, which is determined by hemoglobin (Hb) concentration. As such, DO_2 on ECMO can be enhanced by optimizing intravascular volume, increasing ECMO flows, controlling SVR, and increasing the Hb concentration >10 g/dL.

ECMO-CPR

ECMO-CPR refers to VA-ECMO cannulation while providing CPR due to the lack of return of spontaneous circulation. The best results are obtained when ECMO is instituted within 25-30 minutes of the start of a witnessed arrest. The most common cannulation strategy is peripheral VA ECMO as the procedure is faster than central cannulation (unless there is a fresh sternotomy). For details about ECMO-CPR, see Chapter 72.

Circulatory Support for Sepsis

VA ECMO is used as a rescue therapy in selected cases of refractory septic shock. Patients with severe vasoplegia and sepsis-induced myocardial dysfunction may be cannulated centrally and placed on high-flow VA ECMO. These patients have experienced better-than-expected survival rates, given prior dismal experiences with peripheral VA ECMO for this condition. These ECMO runs are usually short, with circulatory recovery occurring 2-4 days following cannulation.

Respiratory Support While on VA ECMO

ECMO takes over the ventilation and oxygenation function of the lungs. Mechanical ventilation support is therefore only needed to prevent lung collapse. The strategy used at TCH is to minimize ventilator-associated lung injury by limiting the rate to 8-10 breaths per minute, optimizing the PEEP to prevent lung collapse (8-10 cmH_2O), and minimizing the PIP (maximum of 20-25 cmH_2O). The use of the ventilator to optimize CO_2 removal and oxygenation is limited to those circumstances where there is still significant RV preload and output, as the gas exchange for that blood will depend on lung parenchymal conditions and thus affected by the mechanical ventilation strategies.

In general, at full VA-ECMO flows and with minimal RV preload and output (indicated by a low end-tidal CO_2), a lung-protective strategy would be set using the following parameters: PIP 20-25 cmH_2O, inspiratory time 1 sec, PEEP 8-12 cmH_2O, FiO_2 30-40%. Lung recruitment is followed with daily CXRs, and the ventilatory support is titrated to optimize PVR and achieve functional residual capacity (FRC) (see Chapter 56).

In situations where there is significant cardiogenic pulmonary edema (e.g., severe MR) and/or pulmonary hemorrhage, PEEP levels may need to be increased to provide a "tamponade" effect. PEEP helps by opening airways, recruiting alveoli and, possibly, redistributing excess lung water to sites where it interferes less with gas exchange.

Weaning

Weaning patients from VA ECMO for cardiac support requires evidence of improving cardiovascular function. Return of heart rate variability, control of dysrhythmias,

decreased vasoactive medication requirements, and improving pulse pressure indicate a recovering myocardium. A preliminary assessment of weaning readiness may involve decreasing ECMO flows to 30-50% predicted CO. This increases cardiac preload, and permits evaluation of the myocardial contractile response to that increased load. If a patient becomes tachycardic, hypotensive, and/or develops lactic acidosis, the patient may not be ready to wean or may need additional inotropic support for a successful separation from ECMO. Contractile function should also be assessed by echocardiogram on decreased ECMO flows to help predict how the heart will perform off mechanical support.

It is important to prepare the patient for a successful wean. To that end, it is essential to optimize ventilator support, institute appropriate inotropic therapy before weaning (to give the vasoactive medication time to work), optimize hematocrit level (>30%), and minimize excess oxygen consumption with adequate sedation and analgesia.

Respiratory ECMO (VV ECMO)

Most ECMO in CICU patients is VA. It provides both cardiovascular and respiratory support. Rarely, cardiac patients develop isolated severe gas exchange problems (oxygenation or ventilation). In these instances, they may be placed on VV ECMO until their respiratory disease improves enough to continue treatment with mechanical ventilation and adjunctive medical therapies.

CICU patients needing VV ECMO arrive by one of two routes. First, they may have been initially treated for multisystem disease, including heart and lung disease, with VA ECMO. As the cardiac dysfunction resolves but severe respiratory illness persists, the patient is converted from VA to VV ECMO until lung function recovers. Alternatively, patients in the CICU recovering from surgery or acquired heart disease, develop new or worsening respiratory failure, necessitating primary VV cannulation.

Indications

The indications for respiratory ECMO are severe, progressive respiratory failure unresponsive to conventional or unconventional mechanical ventilation. Several criteria can be used to determine the severity of respiratory failure:

- Oxygenation Index (OI) >30-40. OI is calculated by the following formula:
  $$OI = (FiO_2 \text{ x mean airway pressure x } 100) / PaO_2$$
- Oxygen Saturation Index (OSI) >12.3. OSI substitutes PaO_2 in the OI formula for SaO_2:
  $$OSI = (FiO_2 \text{ x mean airway pressure x } 100) / SaO_2$$
- P/F Ratio <70. This is calculated as: PaO_2 / FiO_2.
- Hypercapnic respiratory failure as manifested by pH <7.2 or $PaCO_2$ >90 mmHg on 2 or more blood gases
- Milder defects in oxygenation or ventilation combined with severe air leak syndrome

In general, the OI is the preferred method to score oxygenation defects in invasively ventilated patients (OSI would be alternative, though no ECMO thresholds have been accepted), as it accounts for the mean airway pressure and not just the ventilator FiO_2 and patient PaO_2.

Cannulation Strategies

When possible, patients who are candidates for respiratory ECMO should be cannulated at a single site. The preferred cannulation site is the right IJ vein with a double lumen VV-ECMO cannula, with or without a second cephalad venous drain in the same vessel. In this setup, deoxygenated blood is drained from the IVC and either the RA or intrahepatic IVC (as well as the jugular bulb with a cephalad drain), and oxygenated blood is returned to the RA directed towards the tricuspid valve to enter the RV and then be ejected to the lungs.

Alternatively, 2-site VV-ECMO cannulation is an option. The IJ and femoral veins are the most commonly cannulated vessels, with catheter tips in the RA and intrahepatic IVC. The ECMO circuit is usually configured so that deoxygenated blood is drained from the RA and returned to the IVC, though there may be circumstances when this is reversed.

Management

Ensuring Adequate Tissue Oxygen Delivery (DO_2)

VV-ECMO runs tend to be much longer than VA-ECMO runs since the lungs take more time to recover. As such, it is important to maximize conditions that ensure adequate DO_2, favor pulmonary recovery, and avoid sedation toxicity.

The major determinants of DO_2 are arterial blood oxygen content (CaO_2) and CO. CaO_2 is calculated according to the following formula:

$$CaO_2 \text{ (mL/100 mL of blood)} = 1.34 \times [Hb] \times SaO_2 + 0.003 \times PaO_2$$

DO_2 is the product of CaO_2 and CO, as expressed in the following formula:

$$DO_2 \text{ (mL/min)} = 10 \times CO \times CaO_2$$

In VV ECMO, SaO_2 will be – and *should be* – lower than in VA-ECMO patients, usually in the 70-80% range. The most common way to increase DO_2 in patients on VV ECMO is to increase their Hb concentration with transfusion of RBCs. It is not uncommon to maintain patients with a Hb of 13-15 g/dL and SaO_2 of 70-75%, as long as their SvO_2 is >60%, their lactate remains low, and their cerebral NIRS are stable. More infrequently, DO_2 can be increased by either adding inotropic support (to increase CO), or, even more rarely, reducing oxygen consumption (using sedation, neuromuscular blockade, or mild cooling).

Managing Recirculation

Recirculation occurs when oxygenated blood from the circuit is captured by the venous limb of the circuit and passed again through the ECMO circuit. Signs of recirculation include dropping patient arterial saturations and rising saturations of the venous drainage. The blood on the venous side of the circuit will have almost the same bright-red color as the blood postoxygenator. Recirculation is quantified using the following equation:

$$\text{Recirculation (\%)} = (S_{pre}O_2 - SvO_2) / (S_{post}O_2 - SvO_2) \times 100$$

$S_{pre}O_2$ and $S_{post}O_2$ refer to the blood oxygen saturations pre- and postoxygenator, respectively.

Managing recirculation may require multiple maneuvers to ensure adequate DO_2

including decreasing pump flow rates, adding inotropic support, infusing volume, correcting anemia, repositioning cannulas, reducing intrathoracic or intra-abdominal pressures, and adding venous drains at different sites.

Fostering Pulmonary Recovery

Optimizing the conditions to allow for pulmonary recovery is an important goal when managing patients on VV ECMO. Some important strategies to foster this include:

- **Reduce ventilator settings**. In the CICU, lung disease requiring VV ECMO is usually the result of infection or inflammation and some degree of ventilator-induced injury. How much the ventilator contributes to overall lung injury is unknown. However, it seems reasonable to assume that higher pressures, higher rates, and more days on the ventilator cause more damage than lower pressures and fewer cycles of distention and release. The therapeutic goal should be to minimize or eliminate the iatrogenic contribution to lung injury. In general, if a patient remains intubated or ventilated during VV ECMO, PEEP is reduced to 8-10 cmH_2O, PIP is limited to 20-25 cmH_2O, respiratory rate is set at 8-12 breaths per minute, and FiO_2 is reduced to 21-30% until the lungs begin to show spontaneous recovery.
- **Maintain airway clearance.** It is important to maximize efforts to clear the airway including discontinuation of neuromuscular blockade, mechanical clearance treatments, and frequent direct bronchoscopy, in order to prevent large-airway obstruction and promote distal-airway secretion removal.
- **Low threshold for diagnostic curiosity.** Many patients on VV ECMO will experience complete lung "whiteout" during their course. Lack of alveolar air renders intrathoracic structures indistinguishable on CXR and may hide processes preventing spontaneous reaeration of the lungs, such as a pleural effusion or intraparenchymal hematoma. When a patient's lungs remain consolidated longer than expected for the disease process, this should trigger a search for plausible causes including intrapleural processes (revealed by ultrasound or CT) or large-airway obstruction (identified by bronchoscopy).

Weaning

Weaning patients from VV ECMO is different from tapering them off VA ECMO. The question to be answered is straightforward: "Have the patient's lungs recovered sufficiently to support adequate oxygenation and ventilation?". Ideally, the patient should remain on VV ECMO until pulmonary recovery permits return to "nontoxic" ventilator settings. A patient who is starting to improve will experience reaeration of consolidated lungs, increasing SaO_2 without changes in ECMO FiO_2, and improving tidal volumes on stable pressure settings.

To determine the patient's readiness to wean off ECMO, ventilator settings must be increased to full-support levels and the oxygenator taken offline. To do this, both the inlet and exhaust gas ports must be capped off. If the patient tolerates this "capping trial" for 1-2 hours, the patient is decannulated.

ECMO Circuit and Monitoring

Prior to initiation of ECMO, it is important to determine: 1) the optimal blood flow range to optimize DO_2 for the patient, 2) the optimal cannula and circuit size, and 3) the blood products and solutions required for priming of the pump. Appropriate blood flows are calculated based on either mL/kg/min for patients <10 kg or based on BSA and cardiac index (CI) for patients >10 kg (Figure 43-1). Once the necessary blood flow is calculated, the optimal cannula and circuit size are selected based on the chart on Figure 43-2. The blood products and medications needed for priming of the ECMO circuit are detailed on Figure 43-3. All of these charts and flowsheets are attached to each of the ECMO pumps.

Renal-support devices are routinely used during ECMO. The most common type of renal assistance is ultrafiltration. This is the process of small-protein fluid passing through a semipermeable membrane by the use of a hydrostatic pressure difference. The byproduct is the passive movement of solutes through convection. The removal of fluid in the ultrafiltrator is controlled by the transmembrane pressure and blood flow. Fluid removal can be increased by increasing transmembrane pressure, increasing blood flow into the ultrafiltrator, restricting blood outflow, or changing the waste-side pressure. The use of the ultrafiltrator must be monitored closely. If too much fluid is removed, the patient can develop acute renal failure.

If the patient has renal failure, ultrafiltration may need to be transitioned to dialysis. Dialysis can be performed with the current ultrafiltrator if the patient is <20 kg by running the dialysate countercurrent to the blood. Larger patients require placement of a separate dialysis pump, which can be placed inline with the ECMO circuit or by using a separate dialysis catheter inserted into the patient.

Cannulation Strategies and Technique

The decision as to which cannulation technique (i.e., central vs. peripheral) is offered should be made on an individual basis considering the goal of ECMO support and overall picture of the patient (e.g., coagulopathy). The usual cannulation approach on peripheral VA ECMO is the neck (common carotid artery and IJ vein) in small children (<30 kg) and femoral cannulation in larger children. There is still some debate about the appropriateness of carotid cannulation in older patients, because of the risk of stroke on the ipsilateral side, though large retrospective studies have failed to find significant evidence to support the claim.

VA cannulation can be accomplished via ultrasound-guided percutaneous approach, the "open percutaneous" technique (surgical vascular exposure followed by needle puncture under direct visualization and Seldinger-guided serial vessel dilation and cannulation), or surgical cutdown with venotomy/arteriotomy and direct cannula insertion. No technique has demonstrated superiority and different operators are more comfortable with different techniques. The two latter techniques allow for the surgeons to secure the cannula directly to the vessels. This decreases the risk of cannula dislodgement, but may complicate decannulation, sometimes requiring the incision to be reopened.

In case of VV cannulation, placement of a double-lumen cannula in the right IJ vein is

our method of choice. Similar to VA cannulation, this can be achieved percutaneously or surgically. It is critical to optimize the depth and direction of the cannula so the outlet port of the cannula (i.e., where the oxygenated blood exits) points toward the tricuspid valve. This optimization can be done with echocardiographic guidance (at the bedside) or fluoroscopy (at the bedside, in the OR, or in the cath lab).

Anticoagulation

At this time, our anticoagulation strategy of choice is IV heparin. At the time of cannulation, an IV heparin bolus is given (50-100 Units/kg), which will cause a transitory elevation of activated clotting time (ACT). A continuous heparin drip is typically started when ACT is <200 sec. The anticoagulation plan should be made when the patient is stabilized on ECMO support at the end of cannulation. The range parameters for ACT, heparin level, PTT, and fibrinogen are set for every patient and left documented by the patient's bedside. In general, desired parameters are 180-220 sec for ACT, 0.2-0.4 U/mL for heparin levels, 60-80 sec for PTT, and >250 mg/dL for fibrinogen. In addition, we aim for an antithrombin (AT) ≥80%, a platelet count >100,000 /mcL, and normal INR. The ECMO panel includes all the previously labs as well as D-Dimer and PT levels. The ECMO panel is checked every 6 hours, with the exception of ACT, which is measured every 1-2 hours. A ROTEM® is run daily for a better understanding of each ECMO patient's homeostasis. Plasma-free Hb levels, a marker of hemolysis, are checked daily and the goal is to keep them <150 mg/dL, as higher levels may cause kidney injury. If the plasma-free Hb levels are >150 mg/dL, the ECMO circuit, or parts of it, may need to be changed. These are obviously reference goal parameters and may vary based on the patient's specific needs.

Bivalirudin is an alternative anticoagulant that is gaining widespread acceptance for VAD management at TCH, as well as other pediatric heart centers in North America. Bivalirudin has also been used in select ECMO patients at TCH. The strength of bivalirudin over heparin is the fact that the former is much less dependent on the inflammatory status of the patient, which can result in less fluctuation in the anticoagulation effects.

The transfusion medicine team at TCH rounds with the CICU team daily on every ECMO patient to help optimize their anticoagulation management.

Sedation on ECMO

Within minutes of ECMO initiation, or after a circuit change, the patient will require additional sedation and analgesia boluses, as sedative concentrations in the fresh-blood prime are much lower than they were in the blood prior to cannulation (or in the old circuit). Preferred starting agents include continuous infusions of a benzodiazepine (e.g., midazolam) and morphine or hydromorphone as opioids (less adherence to ECMO circuit as per a TCH pharmacy study).

On VA ECMO, an acute rise on SVR is commonly seen right after ECMO flows start. Appropriate sedation is fundamental to manage that SVR and be able to run at desired flows to adequately support the patient and optimize DO_2.

Since many respiratory ECMO runs are longer than cardiac ones, intubated ECMO

patients develop sedation complications, including habituation, tolerance, delirium, and need for multiple medications with different mechanisms of action. Removing major irritants like the endotracheal tube (by extubating or placing a tracheostomy) may be more effective in preventing sedation complications than treating those complications with polypharmacy.

Sedation is monitored hourly using an objective sedation scale, the State Behavioral Scale (SBS) (see Chapter 55). The goals of sedation are discussed on daily rounds and vary depending on the patient's condition. Daily holidays, brief cessations of continuous infusions, should be part of the respiratory ECMO sedation regimen.

Catheter-Based Procedures in Patients Requiring Mechanical Support

Impella®

The Impella® device is a catheter that bears an impeller pump. It can be placed percutaneously or surgically, and drives blood forward coaxially through the vessel in which it is situated. It supports the patient by augmenting forward CO and promoting ventricular unloading, allowing for improved end-organ perfusion and decreased myocardial workload.

Versions of the Impella® device can be used for support of the systemic or pulmonary circulation. Impella® catheters designed for systemic circulatory support (2.5, CP, 5.0, LD) are positioned across the aortic valve such that they draw blood through an inlet port in the LV and impel it through the catheter and out of an outlet port in the ascending aorta. The Impella® RP is designed for pulmonary circulatory support and is placed such that it draws blood from the inferior vena cava and impels it through an outlet port in the PA.

The function of the Impella® catheter is monitored and controlled via a controller console that remains by the patient's side. The console allows for titration of output and displays information on catheter position and hemodynamics in real time. Additional information on catheter position can be obtained as needed by bedside echocardiography.

Currently, the Impella® is used primarily for short-term support of CO, although successful medium-term use has been reported. Impella® devices can also be used as temporary support during cath procedures. Rapid percutaneous Impella® catheter placement can be performed in clinical scenarios demanding emergent support of cardiac output. It can also be used as an adjuvant for left-heart decompression while on VA ECMO.

The Impella® device can be placed in the femoral artery, axillary artery, ascending aorta, or femoral vein (for RP).

ASD Creation

In various clinical scenarios, patients with an intact atrial septum who are supported with VA ECMO may develop LA hypertension and pulmonary edema secondary to incomplete left-heart unloading. In these cases, catheter-based atrial septal interventions are performed to decompress the left heart. Infrequently, a conventional balloon atrial septostomy performed in the style of Rashkind procedure can be employed. In many patients, however, the atrial septum is too thick for this technique. An ASD is

therefore created by one of various other means, including transseptal puncture followed by static balloon dilation, blade septostomy, or atrial-septal stent placement.

Suggested Readings

Coleman RD, Goldman J, Moffett B, et al. Extracorporeal membrane oxygenation mortality in high-risk populations: an analysis of the Pediatric Health Information System Database. ASAIO J 2019; doi: 10.1097/MAT.0000000000001002.

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