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CHEST

Extracorporeal Membrane Oxygenation for Adult Respiratory Failure

2017 Update

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The use of extracorporeal membrane oxygenation (ECMO) for respiratory failure in adults is growing rapidly, driven in large part by advances in technology, which have made ECMO devices easier to implement and safer and more efficient. Accompanying this increase in use is a nearly exponential increase in ECMO-related literature. However, the great majority of the literature is composed of retrospective observational data, often in the form of single-center studies with relatively small numbers of subjects. The overall lack of high-quality data, including prospective randomized trials, makes it difficult to justify the rate at which ECMO use is increasing and calls attention to the need for more rigorously designed studies. Nonetheless, given its ability to support patients with severe gas exchange impairment and the potential for it to minimize the deleterious effects of invasive mechanical ventilation, there appears to be a legitimate role for ECMO in severe respiratory failure in adults.

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KEY WORDS: ARDS; extracorporeal membrane oxygenation; mechanical ventilation; lung transplantation

Initial investigations into the potential role of extracorporeal membrane oxygenation (ECMO) to support severe respiratory failure began in the 1970s. However, early versions of the technology were associated with high rates of complications and were unable to demonstrate a benefit beyond conventional management.[1,2] Since that time, there have been significant advances in ECMO technology, with improvements in gas exchange efficiency and cannula and pump designs, with associated decreases in complication rates so that the risk-benefit profile has improved substantially. In that context, there has been a renewed interest in using ECMO to support severe respiratory failure. Observational, often single-center, studies have reported improved survival with ECMO beyond what would be expected from conventional management alone for patients with high expected mortality.[3,4] However, because of a lack of standardization of indications for its use across the field and a lack of prospective high-quality randomized trials, the increased use of ECMO may not be entirely justified.[5] More data are needed on the appropriate target populations, thresholds for initiation, and management strategies for patients supported with ECMO so that the medical community can better understand the role ECMO should play in severe respiratory failure in adults.

ABBREVIATIONS: $ECCO_2R$ = extracorporeal carbon dioxide removal; ECMO = extracorporeal membrane oxygenation; VALI = ventilator-associated lung injury

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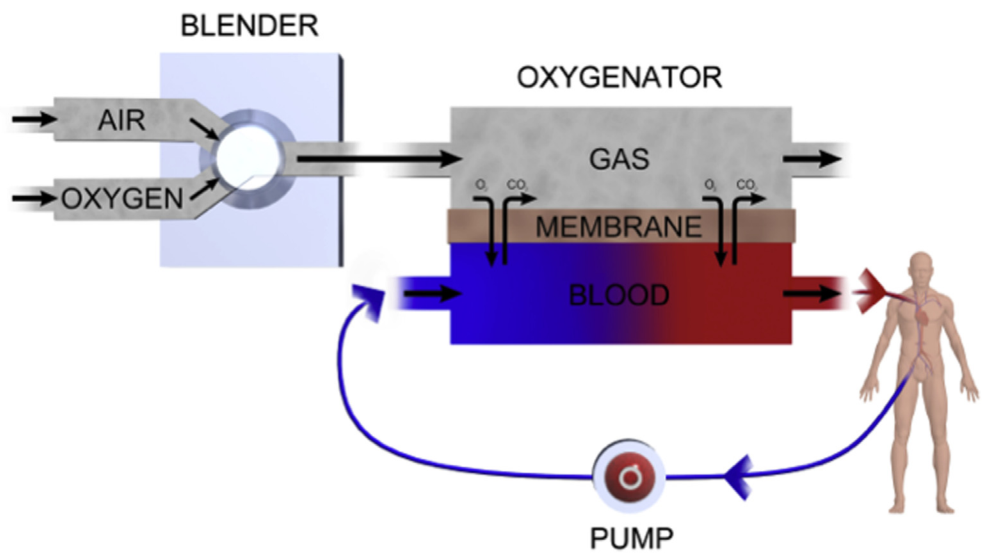

Figure 1 – *The membrane oxygenator in extracorporeal membrane oxygenation (ECMO). Gas exchange in ECMO is accomplished by pumping blood through an oxygenator consisting of two chambers divided by a semipermeable membrane. Venous blood passes along one side of the membrane and fresh gas, referred to as sweep gas, passes along the other side. Oxygen uptake and carbon dioxide elimination occur across the membrane. The fraction of oxygen delivered through the gas chamber is determined by a blender that typically mixes oxygen with room air. (Reprinted from Abrams and Brodie[6] with permission from www.collectedmed.com.)*

Physiology of ECMO

ECMO refers to a circuit that directly oxygenates and removes carbon dioxide from blood through an extracorporeal gas exchange device, commonly referred to as a membrane oxygenator (Fig 1).[6] The oxygenator consists of a semipermeable membrane that separates a blood compartment from a gas compartment, allowing only gas molecules to diffuse between compartments. At the time of ECMO initiation, catheters (or cannulas) are placed with their drainage and reinfusion ports located in central vessels. Deoxygenated blood is drained from the body by an external pump, after which it passes through the membrane oxygenator and is reinfused back into the patient. When the drainage and reinfusion cannulas are both located in central veins, the circuit is referred to as venovenous ECMO, and the device provides gas exchange support only.[7] When blood is drained from a vein and reinfused into an artery, it is referred to as venoarterial ECMO, and the circuit provides both gas exchange and circulatory support.[8]

Because ECMO directly oxygenates blood passing through the membrane oxygenator, the amount of extracorporeal blood flow, the fraction of oxygen delivered through the membrane, and the diffusion properties of the membrane itself determine the oxygen transfer across the membrane.[9] These factors, in conjunction with the gas exchange properties of the native lungs, determine the arterial oxygen saturation of the patient. Any reinfused oxygenated blood that is inadvertently drawn back into the circuit without passing through the systemic circulation, which is referred to as recirculation, does not contribute to systemic oxygenation and is a source of inefficiency for an ECMO circuit. However, the clinical significance of recirculation will depend on the degree of recirculation and the amount of extracorporeal support needed by the patient.[10] In contrast, because of the efficiency of carbon dioxide diffusion across the membrane, the major determinants of carbon dioxide removal are the rate of gas flow through the oxygenator, which is referred to as the sweep gas flow rate, and the partial pressure of arterial carbon dioxide, which creates the gradient for diffusion. Carbon dioxide removal may be accomplished with lower blood flow rates than needed for oxygenation, although blood flow rates become an increasingly significant determinant of carbon dioxide removal the lower they are set. The difference in blood flow rates needed for oxygenation and carbon dioxide removal may translate into different risk-benefit profiles for extracorporeal devices, depending on their intended use. Although oxygenation requires high rates of extracorporeal blood flow, which in turn means a need for larger cannulas, extracorporeal carbon dioxide removal ($ECCO_2R$) may be accomplished with smaller cannulas that may be safer to insert. If a more favorable risk-benefit profile is established for such approaches, $ECCO_2R$ may become a desirable option for providing support in specific clinical circumstances. However, such a benefit needs

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to be demonstrated in prospective randomized trials, as $ECCO_2R$, like ECMO, has been associated with clinically significant complications.[11,12]

ECMO Configurations

Venovenous ECMO traditionally involves cannulation at two distinct venous access points, one for drainage of deoxygenated blood and one for reinfusion of oxygenated blood (Fig 2). Drawbacks to two-site venovenous ECMO include the need for femoral access and the potential for excess recirculation when the drainage and reinfusion ports are in close proximity. Newer cannula designs include cannulas with two lumens so that a single cannula inserted typically into an internal jugular vein can accomplish both drainage and reinfusion with less recirculation (Fig 3).[13-15] Because these cannulas are designed to span from the superior vena cava to the inferior vena cava for optimal drainage and to be positioned so that the reinfusion port is directed toward the tricuspid valve, imaging guidance is highly recommended for placement.[16] This approach is additionally advantageous when the goal is ambulation while receiving ECMO support because of the ability to avoid femoral cannulation.

When using ECMO for severe impairment in cardiac function, venoarterial ECMO is the appropriate configuration. Peripheral venoarterial ECMO traditionally involves femoral venous drainage and

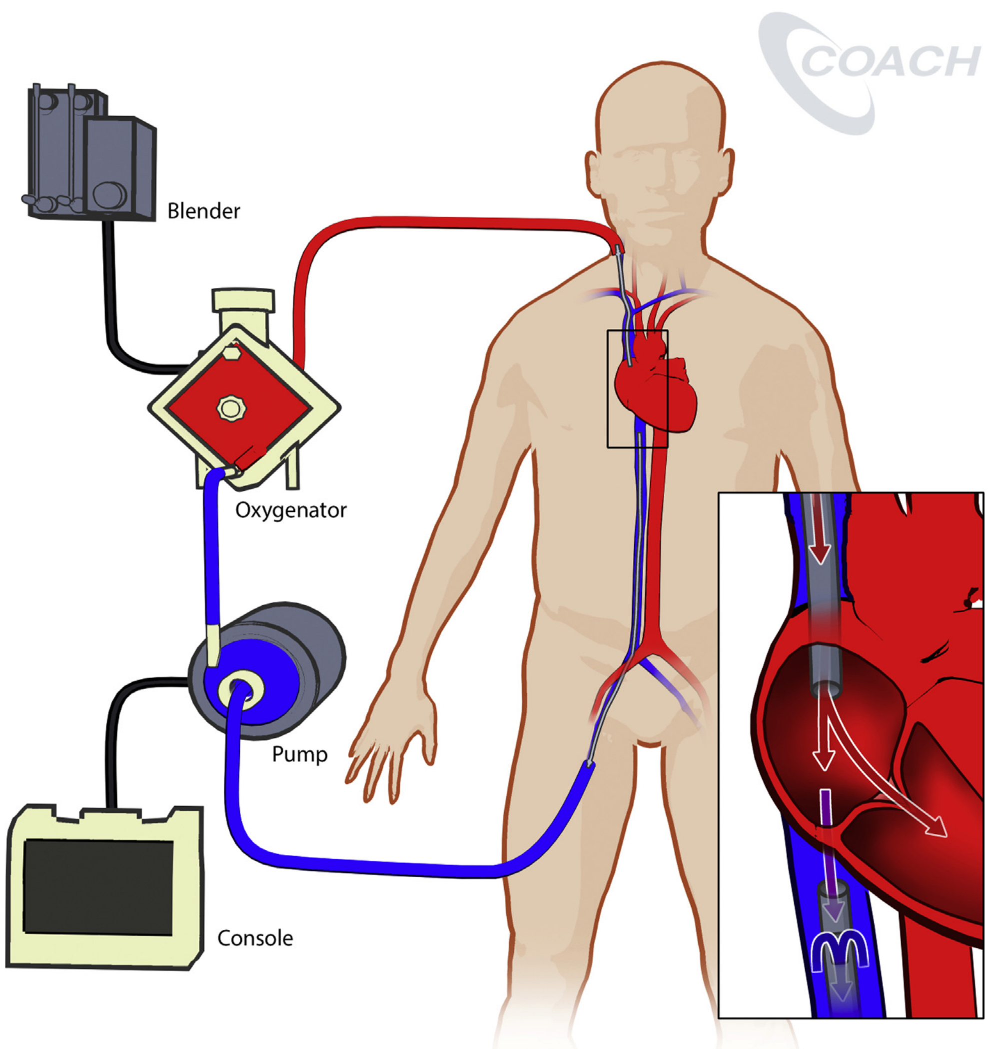

Figure 2 – *Two-site venovenous extracorporeal membrane oxygenation (ECMO). In venovenous ECMO, venous blood is withdrawn from a central vein, pumped through an oxygenator, and reinfused into a central vein. Venovenous ECMO supports gas exchange only, without providing any hemodynamic support. Inset, When drainage and reinfusion ports are in close approximation, some reinfused oxygenated blood may be drawn back into the circuit without having entered the systemic circulation, referred to as recirculation (purple arrow). (Reprinted from Abrams and Brodie[6] with permission from www.collectedmed.com.)*

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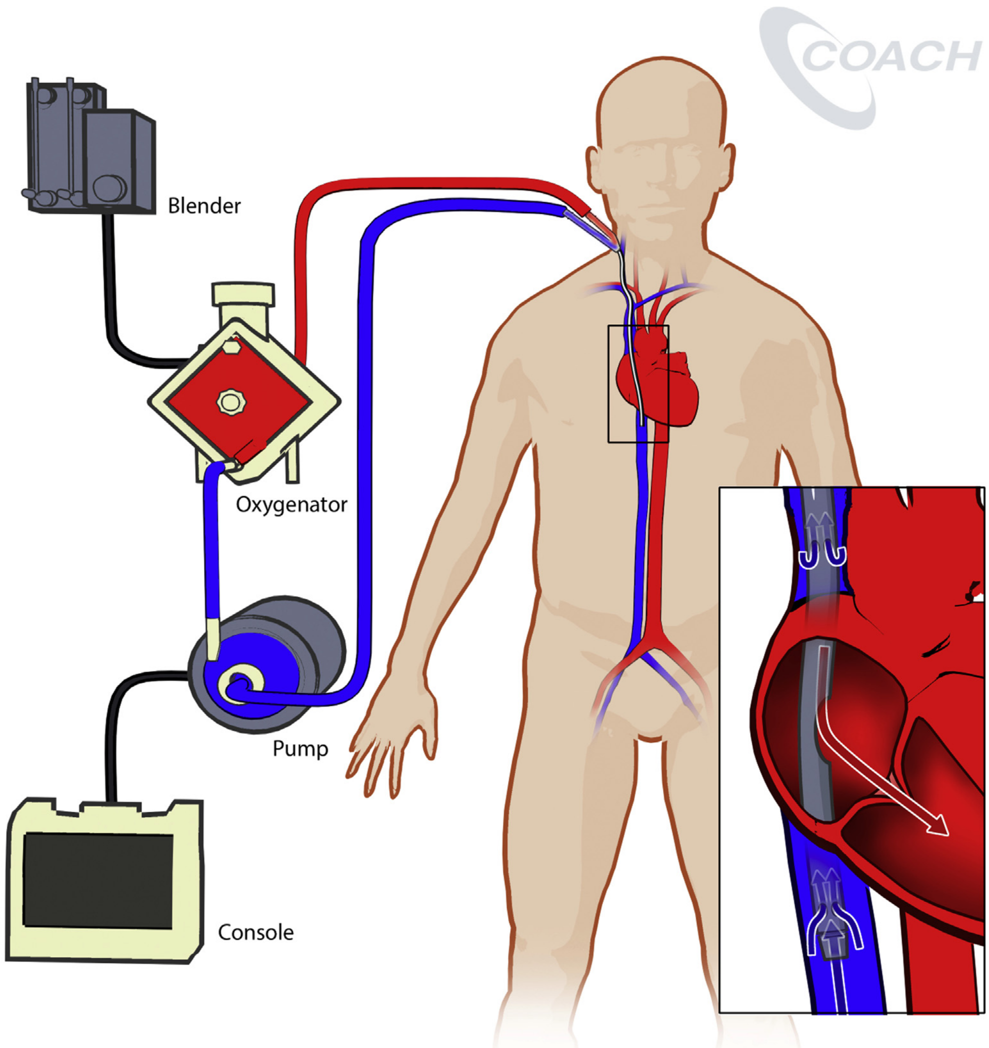

Figure 3 – *Single-site venovenous extracorporeal membrane oxygenation (ECMO). Bicaval dual-lumen cannulas permit the use of venovenous ECMO through a single venous access point. Inset, When the cannula is properly positioned, reinfused oxygenated blood is directed toward the tricuspid valve, minimizing recirculation. (Reprinted from Abrams and Brodie[6] with permission from www.collectedmed.com.)*

femoral arterial reinfusion. Because reinfused blood flows retrograde up the aorta, this approach has two significant drawbacks: (1) an increase in left ventricular afterload, which may further worsen already compromised cardiac function and (2) a potential inability for reinfused well-oxygenated blood to reach the aortic arch and therefore the coronary and cerebral circulations. This becomes problematic when there is residual native left ventricular function coupled with impaired native gas exchange so that deoxygenated blood is delivered to the aortic arch. Strategies to maximize upper body oxygenation include the addition of a venous reinfusion limb (venoarterial-venous ECMO) or use of an entirely upper body cannulation approach with arterial reinfusion closer to the aortic arch.[17-19]

Potential Indications for ECMO in Respiratory Failure

ARDS

The most common indication for ECMO in respiratory failure is severe ARDS, which is defined by the presence of bilateral infiltrates on chest imaging within 7 days of an inciting event and impaired oxygenation ($Pa{O_2}/F{IO_2}$ ratio < 100 mm Hg while receiving positive-pressure ventilation), which is not fully explained by cardiogenic pulmonary edema.[20] The standard of care for invasive mechanical ventilation in ARDS is a volume- and pressure-limited ventilation strategy, which improves survival, in large part through the minimization of ventilator-associated lung injury (VALI).[21,22] The target

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ventilator settings include a tidal volume of 6 mL/kg or less based on predicted body weight and a plateau airway pressure of 30 H_2O or less.[23] More advanced therapies that reduce mortality in ARDS, particularly when implemented early, include the use of neuromuscular blocking agents and prone positioning.[23-25]

For patients in whom gas exchange is refractory to conventional ventilation and other advanced therapies or in whom these approaches are unavailable, ECMO may be appropriate as salvage therapy. Venovenous ECMO may be able to support refractory hypoxemia in the setting of severe ARDS (Table 1). It may also be used for carbon dioxide removal when respiratory system compliance is severely compromised and efforts to maintain plateau airway pressures within acceptable parameters lead to unsustainable levels of hypercapnia and respiratory acidosis. The most recent prospective randomized controlled trial of ECMO in severe ARDS was the Conventional Ventilation or ECMO for Severe Adult Respiratory Failure (CESAR) trial, in which 180 subjects with severe ARDS were randomized to conventional mechanical ventilation or referral to a specialized center for consideration of ECMO.[26] Although there was improved 6-month survival without severe disability in the ECMO referral group (37% vs 53%; relative risk, 0.69; $P = .03$), lack of standardized mechanical ventilation in the control arm and the fact that not all patients referred for ECMO ultimately received it limit the conclusions that can be drawn about the effect of ECMO itself on the outcome. Subsequent matched-pair analyses of other patient populations with severe ARDS have shown conflicting data about the benefit of ECMO.[27,28]

Given the high-quality data in favor of lung-protective ventilation and other advanced therapies for moderate to severe ARDS, we currently recommend that if ECMO is implemented, it should be part of a larger algorithm that includes standard of care management for ARDS, with ECMO reserved for the most severe cases, when the current standard of care is insufficient to support the patient.[7,29] A randomized controlled trial (ECMO to Rescue Lung Injury in Severe ARDS [EOLIA], ClinicalTrials.gov identifier, NCT01470703) comparing conventional standard of care management (including lung-protective ventilation, neuromuscular blockade, and prone positioning) to venovenous ECMO in severe ARDS is ongoing and may help clarify the role of ECMO for this patient population.[30] Given the specialized nature of ECMO and the extensive resources it requires, its use should be reserved for centers with sufficient ECMO experience, as evidenced by data correlating higher ECMO case volume with improved outcomes.[31,32] If ECMO is unavailable at the patient's originating hospital, consideration should be given to referral to a center with ECMO transport capabilities.[33]

As previously mentioned, VALI is believed to play a central role in the excess morbidity and mortality in ARDS.[34,35] There are substantial animal and human data to suggest that lower tidal volumes and airway pressures than the current standard of care could further reduce VALI.[36,37] However, reductions in respiratory system compliance limit how low tidal volumes can be reduced before severe hypercapnia and respiratory acidosis ensue. When ECMO is used for severe ARDS, carbon dioxide can be decreased directly, and it has become common practice at many ECMO centers for tidal volumes and airway pressures to be

TABLE 1] Potential Indications, Primary Configurations, and Level of Evidence for ECMO Use in Respiratory Failure in Adults

Potential Indication	Primary Configuration	Level of Evidence
Severe ARDS	Venovenous ECMO (1 or 2 sites)	Randomized controlled trials
Acute hypercapnic respiratory failure	Venovenous $ECCO_2R$ (1 or 2 sites)	Prospective feasibility studies
Bridge to lung transplantation	Venovenous $ECCO_2R$ or ECMO	Cohort studies
Primary graft dysfunction post-lung transplantation	Venovenous ECMO	Cohort studies
Pulmonary hypertension with right ventricular failure	Venoarterial ECMO or bicaval dual-lumen venovenous ECMO in the presence of an atrial septal defect	Case series

$ECCO_2R$ = extracorporeal carbon dioxide removal; ECMO = extracorporeal membrane oxygenation.

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lowered beyond traditional lung-protective ventilation goals, so called ultra-lung-protective ventilation.[38] The issue becomes whether achieving these lower tidal volumes and airway pressures may be beneficial for patients with less severe forms of ARDS. Because $ECCO_2R$ can be achieved at lower blood flow rates than are required for oxygenation, patients with less severe ARDS who do not need extracorporeal oxygenation support may be candidates for $ECCO_2R$ with smaller, potentially safer, cannulas (comparable to hemodialysis catheters) for the purpose of assisting ventilation while an ultra-lung-protective ventilation strategy is implemented. Such a strategy has been tested in small nonrandomized clinical trials, with demonstration of improvement in surrogate markers of lung injury.[39,40] Larger prospective randomized trials are under way to clarify the potential role for $ECCO_2R$ in moderate to severe ARDS (ClinicalTrials.gov: NCT02282657, NCT02654327).

Acute Hypercapnic Respiratory Failure

Another potential target for $ECCO_2R$ is acute hypercapnic respiratory failure from COPD. Acute exacerbations of COPD requiring invasive mechanical ventilation are associated with a high rate of morbidity and mortality, particularly in patients in whom a trial of noninvasive ventilation failed,[41] with much of the excess morbidity and mortality attributed to the ventilator itself.[42,43] Much in the way $ECCO_2R$ can facilitate reduction in ventilator settings in ARDS, $ECCO_2R$ may likewise correct respiratory acidosis associated with COPD exacerbations, thereby minimizing the respiratory rate and tidal volumes on the ventilator necessary to manage hypercapnia, which might otherwise worsen dynamic hyperinflation and elevations in intrinsic positive end-expiratory pressure. Several case series and matched cohort studies have demonstrated the feasibility of using $ECCO_2R$ to rapidly wean invasive mechanical ventilation or avoid it altogether in those in whom noninvasive ventilation has failed.[44-47] However, prospective randomized studies are needed to demonstrate that this approach is equivalent or superior to conventional management in both clinical efficacy and cost-effectiveness before $ECCO_2R$ should be considered for COPD beyond the research setting. In cases of status asthmaticus associated with severe refractory respiratory acidosis despite optimal conventional management, $ECCO_2R$ should be considered as a means of correcting respiratory acidosis and minimizing the deleterious effects of positive-pressure ventilation.[48]

Bridge to Lung Transplantation and Posttransplantation Primary Graft Dysfunction

In patients with end-stage lung disease who are awaiting lung transplantation, severe gas exchange impairment may necessitate initiation of invasive mechanical ventilation, which has traditionally been associated with poor posttransplantation outcomes.[49] Furthermore, even with invasive mechanical ventilation, hypoxemia or hypercapnia may be severe enough to limit the patients' ability to participate in physical therapy and thus they become too deconditioned to maintain transplant candidacy. As a bridge to transplantation, ECMO may provide enough gas exchange support to facilitate physical therapy, especially when dyspnea is sufficiently managed. Success with this strategy is further maximized when combined with an awake nonendotracheal intubated approach, thereby avoiding the complications associated with sedation and invasive mechanical ventilation.[50-53] In such circumstances, an upper body ECMO configuration is preferred to maximize the opportunity for ambulation. The optimal patient population and timing of ECMO initiation are areas of uncertainty that require additional research, although such a strategy should be reserved for transplantation centers with sufficient experience in lung transplantation as well as managing ECMO and its complications.[54]

In the posttransplantation period, primary graft dysfunction, an ischemia-reperfusion injury that is clinically similar to ARDS, may warrant initiation of ECMO, especially for management of refractory gas exchange impairment or to minimize exposure of the allograft to excess ventilator-associated injury.[55]

Pulmonary Vascular Diseases

Acute decompensation of pulmonary hypertension with right ventricular failure remains a highly lethal condition that often is not amenable to medical management alone. A mechanical circulatory approach with ECMO has emerged as a viable strategy to support patients with acutely decompensated pulmonary hypertension by allowing for right ventricular decompression with hemodynamic and gas exchange support.[56] This strategy may be considered for patients in whom an acute reversible process can be identified and treated, often in conjunction with optimization of targeted pulmonary hypertension medical therapies.[57] For those in whom a reversible process cannot be identified and who have been deemed appropriate for lung transplantation, ECMO may likewise be considered as a bridge to transplantation. The traditional

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cannulation strategy—femoral venous drainage and femoral artery reinfusion—is used to decompress the right ventricle and bypass the high resistance of the pulmonary vasculature, yet it may not allow for effective upper body oxygenation because these patients often have impaired gas exchange and preserved left ventricular function. Upper body venoarterial strategies may mitigate this problem. Alternatively, in those patients with a pre-existing interatrial defect, a dual-lumen cannula may be oriented with the reinfusion jet directed across the defect (rather than across the tricuspid valve), effectively providing an oxygenated right to left shunt while simultaneously decompressing the right ventricle.[58]

Patients with acute massive pulmonary embolism may also benefit from institution of venoarterial ECMO. Selected patients may have more favorable outcomes when ECMO support is combined with directed therapies such as thrombolysis, catheter-directed embolectomy, or surgical embolectomy, although there are no randomized controlled trials to inform the optimal approach.[59,60] For some patients, venoarterial ECMO with standard IV unfractionated heparin therapy may be sufficient.

Contraindications to ECMO for Respiratory Failure

When considering ECMO for severe respiratory failure, one must consider the likelihood of recovery when the underlying process is thought to be reversible and the potential candidacy for transplantation when the respiratory failure is deemed to be irreversible. Relative contraindications to ECMO in acute respiratory failure include the prolonged use of high-pressure ventilation or high F_{IO_2}, limited vascular access, contraindications to the use of anticoagulation, and the presence of any condition or organ dysfunction that would limit the likelihood of overall benefit from ECMO (eg, severe irreversible brain injury or untreatable metastatic cancer). An absolute contraindication to ECMO is the presence of severe irreversible respiratory failure if transplantation will not be considered. Prognostic scoring systems have been devised for the ARDS population that may help risk stratify patients being considered for ECMO.[61,62] Patient characteristics for which the International Society for Heart and Lung Transplantation recommend against ECMO as a bridge to lung transplantation include septic shock, multiorgan dysfunction, severe arterial occlusive disease, heparin-induced thrombocytopenia, prior prolonged mechanical ventilation, advanced age, and obesity.[63]

Selected ECMO Management Considerations

Anticoagulation

Continuous systemic anticoagulation is generally needed to maintain ECMO circuit patency and minimize the risk of thrombosis in both the circuit and the patient. However, anticoagulation goals must balance thrombotic risk with potential hemorrhagic complications. There are currently no universally accepted anticoagulation goals for ECMO nor is there a consensus on how anticoagulation should be monitored. Activated clotting time, activated partial thromboplastin time, and thromboelastography, among others, have all been reported as monitoring tools.[64,65] Lower anticoagulation goals are increasingly being adopted as a strategy to mitigate bleeding risk (eg, activated partial thromboplastin time of 40-60 s), although this may be accompanied by increased rates of thrombotic events.[64] A strategy that combines low anticoagulation goals, restrictive transfusion thresholds, and reinfusion of circuit blood at the time of decannulation has been shown to be associated with favorable outcomes and minimal transfusion requirements.[66] Heparin is the most commonly used anticoagulant during ECMO support, with heparin-induced thrombocytopenia having been reported infrequently in this patient population.[67]

Pharmacokinetics

Analgesics, sedatives, anticoagulants, and antimicrobial agents are all commonly administered to patients receiving ECMO. Hemodilution from ECMO initiation, drug sequestration within the circuit, altered protein binding, and end organ dysfunction may all influence the pharmacokinetics of particular drugs.[68,69] Whether and how the pharmacokinetics of these medications are affected during ECMO support is an area of both great clinical relevance and active investigation. The ongoing Antibiotic, Sedative and Analgesic Pharmacokinetics during Extracorporeal Membrane Oxygenation (ASAP ECMO) study is a multicenter study of drug pharmacokinetics during ECMO, with the aim of deriving a better understanding of the pharmacokinetics of common important drugs in patients receiving ECMO.[70]

Early Mobilization

Active physical therapy, including early mobilization, has repeatedly been shown to be both safe and effective in improving clinical outcomes in critically ill patients,

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including those with respiratory failure requiring invasive mechanical ventilation.[71,72] These same practices have been performed successfully in several cohorts of patients receiving ECMO and are facilitated by the cannulation strategies that prioritize upper body configurations, minimize analgosedation, and avoid invasive mechanical ventilation when feasible.[73-75] The patients receiving ECMO in whom early mobilization is of the greatest urgency are those awaiting lung transplantation, in whom maintenance of physical conditioning is necessary to maintain transplant candidacy and optimize posttransplantation recovery. The bridge to recovery population may likewise benefit from active physical therapy, although improvements in clinical outcomes for those receiving physical therapy compared with those unable to perform physical therapy is inherently confounded by the underlying severity of illness.[74] A multidisciplinary team-based approach is strongly recommended for any program performing physical therapy with patients receiving ECMO to minimize complications and maximize patient mobility.[73]

Weaning from ECMO

Patients should be considered for weaning from venovenous ECMO once the underlying disease process for which ECMO was initiated has sufficiently resolved so that they can be safely and adequately supported with relatively low amounts of ventilatory and oxygenation support without evidence of excess work of breathing. Markers of sufficient native lung function recovery include adequate gas exchange reserve, acceptable respiratory system compliance, and improvement in chest radiographs. There are no universally accepted guidelines for how to wean venovenous ECMO, although one common approach involves incremental reductions in either or both the fraction of oxygen delivered through the membrane and the sweep gas flow rate until the sweep gas flow is turned off. The patient should then be observed for a time without extracorporeal gas exchange (eg, 30 min or longer) to ensure readiness for decannulation. The use of a “bridge” to divert extracorporeal blood flow away from the patient has also been described, although its use may be accompanied by additional complications such as circuit thrombosis.

Complications

Complications must always be considered whenever a novel therapy is being introduced, especially one as invasive as ECMO. Hemorrhage remains among the most commonly cited complications, although the rates of bleeding and their severity vary widely by center and anticoagulation practices.[76] Thrombosis, either within the circuit or related to the indwelling portions of the cannulas, poses an embolic risk to the patient. Other hematologic complications associated with ECMO include hemolysis, thrombocytopenia, acquired von Willebrand syndrome, and disseminated intravascular coagulopathy.[77] Infectious complications have been reported at varying rates, with longer durations of invasive mechanical ventilation, ECMO support, and hospital admission having been associated with increased risk of infections.[78] Limb ischemia and compartment syndrome are of concern in venoarterial ECMO when flow to the distal extremity may be compromised by the presence of the arterial cannula. Insertion of a distal reperfusion catheter connected to the arterial reinfusion cannula may mitigate these risks.[79] Cardiac or vascular perforation is a rare but potentially lethal complication of cannulation, the frequency of which depends on institutional experience, use of ultrasonographic guidance, and cannulation technique.[80]

Economic Impact

There is a paucity of data on the economic impact of ECMO, with costs varying widely by health system, choice of device components, duration of support, management strategies, and staffing models.[26,81] In the CESAR trial, the average total costs per patient were £73,979 vs £33,435, respectively (cost of ECMO per quality-adjusted life year, £19,252), which may be explained in part by increased ICU and hospital lengths of stay.[26] As ECMO is studied further, cost-benefit analyses will be a necessary adjunct to help guide the appropriate use of this intervention.

Ethical Considerations

ECMO for advanced respiratory failure has the potential to create ethical dilemmas much in the same way as any life-sustaining intervention (ie, in whom should it be started and if and when should it be withdrawn). However, the lack of an extracorporeal destination device for respiratory failure creates the potential for a particularly difficult situation in which a patient supported with ECMO with the intention of either recovery or transplantation is no longer able to achieve either, a so-called bridge to nowhere.[82] In the current state of extracorporeal technology, these patients are bound to the ICU and may be awake and interactive,

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particularly given the recent emphasis on strategies that minimize sedation. How such patients are approached regarding end of life care requires careful consideration, and patients and providers may benefit from ethics and palliative care consultations. Emphasis should be placed on careful patient selection prior to ECMO initiation and thoughtful discussions with patients and their surrogates throughout the duration of ECMO support to help prepare for, and ideally avoid, such situations.[83]

Future Directions

ECMO can provide support for patients with advanced respiratory failure only as a bridge to recovery or lung transplantation, as no destination device currently exists for respiratory failure, ie, the equivalent of a ventricular assist device in heart failure. As ECMO technology improves, including smaller more durable circuits with increasingly efficient membrane oxygenators, the field is moving toward a portable extracorporeal gas exchange device, effectively an artificial lung. Such a device would have the potential to dramatically alter the paradigm of how respiratory failure is managed. Until that time, more research is needed to better define the patient populations most likely to benefit from the existing technology and the long-term impact of ECMO support. Research networks, such as the International ECMO Network (http://www.internationalecmonetwork.org), seek to advance the field by facilitating high-quality rigorously designed studies through the coordination of centers with sufficient ECMO experience. The Extracorporeal Life Support Organization (http://www.elso.org) also maintains the largest single registry of ECMO use and is an important tool for both quality assurance and for generating research hypotheses. Strong consideration should be given to enrolling all patients receiving ECMO in an established registry or research database. Data from these sources will help to inform future guidelines on the recommended uses of ECMO and $ECCO_2R$ in severe respiratory failure.[23]

Conclusions

ECMO is capable of supporting severe derangements in gas exchange in both acute and chronic respiratory failure, with data showing potential for improving survival in patients with high rates of morbidity and mortality. Its use should remain in centers sufficiently experienced with the technology, and additional research is needed before ECMO can be recommended for more widespread application.

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