Extracorporeal Membrane Oxygenation and Continuous Kidney Replacement Therapy: Technology and Outcomes – A Narrative Review

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The number of patients using critical care is increasing as our populations live longer thanks to advances in medical therapies. As our population ages and we make advances in medical therapies, the number of patients using critical care is increasing. In the United States over the course of 1 decade, critical care beds increased by 17.8%, despite a 2.2% decrease in the total number of hospital beds. Many of these intensive care unit-level patients suffer from multiorgan dysfunction, including but not limited to cardiac, respiratory, and kidney failure. For those who develop acute kidney injury (AKI), there is an associated increase in both morbidity and mortality. These patients often require mechanical support in the form of ventilators, kidney replacement therapy (KRT), and occasionally extracorporeal membrane oxygenation (ECMO). The incidence of AKI in patients receiving ECMO has been reported at 60%-80% and portends a worse prognosis. In this article, we review the literature regarding the history, technology, indications, and outcomes of synchronous extracorporeal membrane oxygenation and kidney replacement therapy.

HISTORY
The evolution of ECMO as a technology was eloquently laid out by Makdisi and Wang in a recent review. Dating back to 1944, Kolff and colleagues' first noted blood became oxygenated as it passed through cellophane chambers in their artificial kidney. This concept was later applied by Gibbon in 1953 who performed the first successful open-heart surgery. Gibbon employed the use of artificial oxygenation and perfusion support during the case. In the 1960s, Rashkind and colleagues, followed by Dorson and colleagues, applied the use of bubble oxygenators and cardiopulmonary bypass, respectively, in the treatment of pediatric populations suffering from cardiac and respiratory failure. This technology was subsequently adopted by Baffes and colleagues in 1970 to facilitate ECMO support in infants undergoing repair of congenital heart defects. Throughout the 1970s, ECMO was used for longer-term respiratory support, however, fell out of favor in the 1990s when a randomized trial studying acute respiratory distress syndrome showed no benefit when compared with conventional ventilatory support. It was not until the publication of the CESAR trial (Conventional ventilatory support versus Extracorporeal membrane oxygenation for Severe Adult Respiratory failure) in 2009 when ECMO saw renewed enthusiasm. It was this randomized trial that established the benefit of ECMO when used by an experienced ECMO center as compared with its use in centers without protocolized ECMO care. ECMO is now being increasingly used in the management of severe respiratory and/or cardiopulmonary failure. Goals of ECMO therapy include the following: (1) bridge to recovery, (2) bridge to transplant, (3) bridge to destination (in which a long-term durable device is placed and ECMO removed), or (d) bridge to decision. Continuous KRT (CKRT) was first discovered by Peter Kramer in 1977. At its advent, CKRT was configured as continuous arteriovenous hemofiltration that immediately opened doors across intensive care units for kidney replacement in patients otherwise too unstable for either peritoneal dialysis or intermittent hemodialysis. While continuous arteriovenous hemofiltration offered several advantages as compared with peritoneal dialysis and intermittent hemodialysis, arterial cannulation came with significant morbidity. This resulted in a transition from continuous arteriovenous hemofiltration to continuous venovenous (VV) hemofiltration (CVVH),...
hemodiafiltration, and hemodialysis. Over time, particularly over the past decade, advancements have been made to improve performance and monitoring. With new user-friendly interfaces, self-priming machines, and self-loading cartridges, nursing burden has diminished, while safety has increased.

Not unexpectedly, many patients who require ECMO are also initiated on CKRT (40%-60% of those who develop AKI) – though few studies are available to assess outcomes in these patients. In fact, most data that do exist stems not from adult but from pediatric literature. There are numerous reasons as to why AKI is so abundant in the ECMO population. Etiology is often multifactorial and includes comorbidities, acute inflammatory and immune-mediated processes, hemodynamic instability, ischemia-reperfusion injury, coagulopathies, exposure to nephrotoxins, and ECMO-related injury (red cell stress, hemolysis, release of free iron).

**INDICATIONS**

There are two configurations of ECMO, each with its own indications offering cardiac support, respiratory support, or both. VV ECMO offers respiratory support alone. Venoarterial (VA) ECMO offers either cardiac support alone or cardiopulmonary support. Indications for VV and VA ECMO, though not an exhaustive list, are found in Table 1. Contraindications to either configuration include (1) unrecoverable myocardial damage in a patient who is not a transplant candidate, (2) disseminated malignancy, (3) known severe brain injury, (4) unwitnessed cardiac arrest, (5) prolonged cardiopulmonary resuscitation without adequate tissue perfusion, (6) unrepaired aortic dissection, (7) severe aortic regurgitation, (8) severe chronic organ dysfunction, and (9) peripheral vascular disease (VA ECMO). In the CESAR trial which studied ECMO vs conventional management of adults with acute respiratory distress syndrome, both ventilation of > 7 days and contraindication to anticoagulation (ie, multitrauma at high risk of bleeding, intracranial bleeding, and so on) were also considered exclusionary. A more complete list of contraindications (though again, not exhaustive) can also be found in Table 1.

Traditional indications for the initiation of CKRT include both metabolic and fluid derangements for which the kidneys are unable to compensate (ie, acidosis, electrolyte disturbances, intoxications, uremia, fluid overload [FO]). Timing of initiation, however, is not as clear. It is often a clinical decision made between the nephrologist and intensivist on a case-by-case basis for each patient. In a recently published multinational, randomized, open label, controlled trial (STARRT-AKI) comparing accelerated initiation and standard initiation of KRT with physician equipoise at the forefront of decision making, accelerated initiation was not associated with lower risk of death at 90 days.

For patients requiring simultaneous KRT and ECMO, the question regarding when to initiate KRT remains. In the limited data available, FO seems to be the most common indication for initiation of kidney support. Fleming and colleagues conducted a survey of participating Extracorporeal Life Support Organization centers that revealed large variation among practice; however, the most common indications for KRT were as follows: FO (43%), FO prevention (16%), AKI (35%), and electrolyte disturbances (4%).

**TECHNICAL ASPECTS**

Once the decision has been made to start simultaneous CKRT and ECMO, there are many technical considerations. The key components for both VV ECMO and VA ECMO are as follows: large-bore access cannulas, a blood pump, and gas and heat exchanges connected via circuit tubing. In a recent publication, Karkala and Junco described the basics of the ECMO circuit in the following way – centrifugal pumps produce a negative prepump pressure which draws blood from the patient. The positive pressure drives blood through the ECMO circuit and subsequently back to the patient. The flow is driven by pump speed, access/tubing characteristics, and intravascular volume status. The gas-exchange membrane oxygenates and removes carbon dioxide from the blood via an exchange between the patient’s blood and the sweep gas. The blood is warmed and returned to the patient. In most cases, cannulation of the patient comprised two large-bore cannula, the configuration of which is dependent on whether the patient will be receiving VV or VA ECMO. During VV ECMO, blood is drained through a cannula near the right atrial inlet and returned via a cannula back into the right atrium. This can be accomplished by either two separate cannulation sites (typically internal jugular and femoral vein) or through a single cannulation site with the placement of a bicaval double-lumen cannula housing multiple ports (typically internal jugular placement with atrial jet facing the tricuspid valve). Malposition of these cannula can result in recirculation which results in decreased efficacy of the circuit. In contrast, during VA ECMO, blood is drained from the venous system and then returned to the arterial system via retrograde blood flow toward the aorta at a stable rate of 3-7 L/min (typically femoral vein/femoral artery cannulation). This retrograde flow is met with anterograde flow from the native cardiac activity, resulting in a watershed point. All blood flow distal to the watershed point originates from the ECMO circuit.

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**CLINICAL SUMMARY**

- Acute kidney injury in patients requiring extracorporeal membrane oxygenation is common and often results in the initiation of kidney replacement therapy.
- There are multiple configurations for the integration of continuous kidney replacement therapy and extracorporeal membrane oxygenation.
- Acute kidney injury and acute kidney injury requiring continuous kidney replacement therapy portend worse outcomes in the extracorporeal membrane oxygenation population.
Table 1. Examples of Indications and Contraindications for VV ECMO and VA ECMO

<table>
<thead>
<tr>
<th>Indication/Contraindication</th>
<th>VV ECMO</th>
<th>VA ECMO</th>
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<tbody>
<tr>
<td>Indications</td>
<td>• Severe acute respiratory distress syndrome</td>
<td>• Cardiogenic shock/severe cardiac failure</td>
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<td></td>
<td>• Lung rest (pulmonary contusion, smoke inhalation, and so on)</td>
<td>• Postcardiomyotomy with inability to wean off cardiopulmonary bypass</td>
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<td></td>
<td>• Lung transplant (graft failure, bridge to transplant, intraoperative support)</td>
<td>• Post heart transplant with graft failure</td>
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<td></td>
<td>• Status asthmatic</td>
<td>• Bridge to transplant</td>
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<td></td>
<td>• Pulmonary hemorrhage/massive hemoptysis</td>
<td>• Perioperative support for high-risk cardiac interventions</td>
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<tr>
<td></td>
<td>• Barotrauma</td>
<td>• Massive pulmonary embolism</td>
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<tr>
<td></td>
<td>• Airway obstruction</td>
<td>• Massive hemoptysis/pulmonary hemorrhage</td>
</tr>
<tr>
<td></td>
<td>• Support in infants suffering from congenital diaphragmatic hernia</td>
<td>• Acute anaphylaxis</td>
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<tr>
<td></td>
<td>• Aspiration syndromes (meconium and so on)</td>
<td>• Peripartum cardiomyopathy</td>
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<tr>
<td></td>
<td>• Murray score &gt; 3</td>
<td>• Sepsis with severe cardiac depression</td>
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<td></td>
<td>• PaO2/FiO2 &lt; 100 (mm Hg) despite high PEEP (10-20 cm H2O) on FiO2 &gt; 80%</td>
<td>• Cardiac index &lt; 2 L/min/m2</td>
</tr>
<tr>
<td></td>
<td>• Severe hypercapnia w/PaCO2 &gt; 80 on FiO2 &gt; 90% or pH &lt; 7.2</td>
<td>• Persistent cardiopulmonary arrest despite traditional resuscitative efforts</td>
</tr>
<tr>
<td>Contraindications Absolute</td>
<td>• Irreversible cardiac or pulmonary disease</td>
<td>• Unrecoverable heart and not a candidate for transplant or ventricular assist device</td>
</tr>
<tr>
<td></td>
<td>• Metastatic malignancy</td>
<td>• Chronic organ dysfunction (emphysema, cirrhosis, renal failure)</td>
</tr>
<tr>
<td></td>
<td>• Significant brain injury</td>
<td>• Prolonged cardiopulmonary resuscitation without adequate tissue perfusion</td>
</tr>
<tr>
<td></td>
<td>• Current intracranial hemorrhage</td>
<td>• Aortic dissection</td>
</tr>
<tr>
<td></td>
<td>• Major pharmacologic immunosuppression (absolute neutrophil count &lt; 400)</td>
<td>• Severe aortic valve regurgitation</td>
</tr>
<tr>
<td>Relative</td>
<td>• Age &gt; 65-70 y, considering increasing risk with increasing age</td>
<td>• Current intracranial hemorrhage</td>
</tr>
<tr>
<td></td>
<td>• Mechanical ventilation at high settings (FiO2 &gt; 90%, plateau pressure &gt; 30) for &gt; 7-10 d</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Multitrauma with high risk of bleeding</td>
<td></td>
</tr>
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Abbreviations: ECMO, extracorporeal membrane oxygenation; ECLS, extracorporeal life support; ELSO, extracorporeal life support organization.
Examples of indications and contraindications for venovenous (VV) ECMO and venoarterial (VA) ECMO. This does not represent an exhaustive list of indications/contraindications for either modality.
As per ELSO guidelines: the primary indication for ECLS is acute severe heart and/or lung failure with high mortality risk despite optimal conventional therapy.
ECLS is considered at 50% mortality risk. ECLS is indicated in most circumstances at 80% mortality risk. Information adapted from the review on ECMO written by Makdissi et al.21 and Zangrillo.21

Conversely, flow proximal to the watershed point is mixed with blood being circulated through lungs and natively pumped via the left ventricle. With severe pulmonary compromise this blood may still be hypoxic, resulting in cardiac and/or brain damage despite adequate ECMO flows and oxygenation. This phenomenon is known as differential hypoxia, otherwise known as Harlequin syndrome. Differential hypoxia may also occur in those with right-to-left cardiac shunt, pulmonary hypertension, and in patients who are large in size.24,25 The oxygen discrepancy is often noted when an arterial blood gas from the upper body circulation is compared with that of the lower body, which is why an upper right (preferably radial) arterial line is paramount. Should differential hypoxia be noted, attempt at either lung recruitment or reduction of native cardiac output (ie, with a beta blocker or reduction in inotropy) is first-line management.26 Failure to improve may result in placement of an additional venous drainage catheter to vent the right atrium or right ventricle. This additional drainage is later connected via a Y-connector to the original venous catheter and returns to the ECMO circuit as a single cannula.16 The unofficial term for this cannulation strategy is VVA cannulation. VVA ECMO may also be required to reduce preload to the left ventricle.
as retrograde flow not only creates a watershed point but also increases cardiac afterload. The continued blood return from the bronchial and Thebesian veins to the cardiac system sometimes results in left ventricular distention and pulmonary congestion. This is improved by the additional venting offered through VVA cannulation. Finally, when arterially cannulated (whether that be VA or VVA and so on), a distal perfusion catheter is often placed at the site of the arterial cannula to maintain blood flow to the distal extremity. It should be noted the aforementioned troubleshooting strategies are for a peripherally established ECMO circuit and would not apply to central cannulation (which is typically established in an operating room). With central cannulation, the venous drainage is established through a cannula inserted into the right atrium and arterial return via cannula inserted directly into the ascending aorta. Whether be it VV or VA cannulation, many experienced centers are now opting for all upper body cannulation to facilitate “awake” ECMO and promote rehab/increased mobility in patients awaiting either resolution of symptoms or more permanent therapies.

When integrating CKRT with ECMO, there are three predominant configurations: in-line, in-series, and two systems in-parallel. An international cross-sectional survey showed that while 21.5% of centers use in-line hemodiafiltration, 50.8% of centers exclusively use a CKRT device spliced into the ECMO circuit (in-series). Fig 1 depicts both in-line and in-series configurations. It should be mentioned that splicing a CKRT device into the ECMO circuit is not Food and Drug Administration approved. There are several advantages and disadvantages for each arrangement, which will be discussed individually. Notably, there are no comparison studies between these techniques, thus practice is based on expert opinion and local experience.

The addition of a hemofilter in-line is not only simple but inexpensive. The filter is connected after the blood pump but before the oxygenator as demonstrated in Fig 1 (A). This allows the ECMO pump to provide forward flow through the hemofilter and maintains the oxygenator’s ability to act as a clot and air trap. Blood is returned to the ECMO circuit prepump. Ultrafiltration (UF) is typically monitored/controlled (albeit imprecisely) with infusion pumps which limit flow to approximately 1 L/h. This arrangement creates a shunt through the hemofilter resulting in a disparity between pump-measured flow and flow delivered to the patient. To account for this, an ultrasonic flow probe can be attached to the arterial return line of the ECMO circuit. Subtracting pump flow from measured flow results in blood flow rate through the hemofilter. Advantages of this configuration include ease of arrangement and cost; however, there are many disadvantages as well. Lack of pressure monitoring through the hemofilter makes it difficult to ascertain if there has been compromise of the filter itself (ie, clotting or fiber rupture). In addition, this method leads to limited

Figure 1. ECMO and CKRT configurations. Abbreviations: CKRT, continuous kidney replacement therapy; ECMO, extracorporeal membrane oxygenation.
clearance of solute, as well as imprecise control filter blood flow and UF—some reporting UF errors of up to 800 cc/24 h. The use of stopcocks or other flow-restricting devices to control flow through the filter has been accomplished; however, this often leads to increased hemolysis and/or clotting. Symons and colleagues found that while free-flow (in-line hemofilter) UF has the advantage of simplicity and low cost, integrated KRT (in-series) provides more accurate fluid management during ECMO support. This configuration is depicted in Fig 1 (B and C). KRT devices are manufactured for access pressures ranging from 0 mmHg to 20 mmHg. The machine generates a negative pressure typically ranging between -50 and -150 mmHg to draw blood from the patient and achieve blood flow rates between 200 and 300 mL/min. Return of blood back to the patient generally results in positive pressures ranging from +50 to 150 mmHg. ECMO circuit pressures are markedly negative prepump and markedly positive between the pump and the oxygenator. This translates into access pressures that are either more positive or more negative than typical for CKRT use when run in-series with ECMO. Most CKRT devices are programmed to stop when pressures are detected outside of safety thresholds, which may reduce CKRT efficiency. To overcome this, flow-restricting clamps are often used to generate resistance, mimicking pressures more acceptable to the CKRT device. Some devices will allow for disabled/altered pressure alarms; however, not all are equipped with this override and may require adjustments to ECMO blood flow to facilitate compatibility. Table 2 details the advantages and disadvantages of multiple integrative options when connecting a CKRT device to the ECMO circuit.

Finally, CKRT and ECMO can be arranged in parallel—each through their own separate access sites. This eliminates concerns related to access pressures as the two systems run independently from one another. One additional advantage to having the systems run in parallel is that the CKRT circuit can be exchanged by the bedside nurse without involving the ECMO perfusionist. However, drawbacks include the need for additional access sites and increased volume of blood in the extracorporeal circuit. Additional access sites pose risks of bleeding, infection, vascular damage, and so on.

There is no data-supported optimal method for integration of CKRT with ECMO. What is common among all arrangements is the application of standard principles of KRT once the two systems are combined. The success of CKRT depends on prescribed vs achieved doses which are a function of fluid replacement and/or dialysate administration rates, treatment duration, type of dialyzer, method of dialysis, quality of vascular access, and dose of anticoagulation. CKRT is the dialysis mode of choice in patients receiving ECMO because it is typically better tolerated in the hemodynamically tenuous patient as compared with intermittent hemodialysis. There modalities of CKRT are CVVH (convective clearance), continuous VV hemodialysis (diffusive clearance), and continuous VV hemodiafiltration (convective and diffusive clearance). All modalities can be safely and effectively run with ECMO, but few studies have examined the impact of different CKRT modalities on survival in adult patients receiving ECMO with AKI. In a retrospective nationwide cohort study of approximately 1000 adult patients receiving ECMO in Taiwan who received either CVVH or continuous VV hemodialysis for AKI, it was found that CVVH may be associated with a lower risk of in-hospital mortality. This is the only study of its kind and requires further investigation. In non-ECMO populations, CKRT modality outcomes have been well studied. While there is no evidence of benefit for one modality over another, the dose matters. In three major multicenter randomized controlled trials: ATN (Acute renal failure Trial Network), RENAL (Randomized Evaluation of Normal versus Augmented Level), IVOIRE (high Volum in Invasive care) comparing 20 vs 35 mL/kg/h, 25 vs 40 mL/kg/h, and 35 vs 70 mL/kg/h, respectively, it was confirmed that increasing dose intensity greater than 20-25 mL/kg/h does not improve survival in critically ill patients with severe AKI. What has been shown in additional studies is that higher doses of CKRT leads to increased rates of hypophosphatemia, hypokalemia, loss of amino acids, proteins, vitamins, selenium, folic acid, and increased clearance of water-soluble antibiotics leading to inappropriately low/ineffective doses.

It should be noted that prescribed dose is often not the delivered dose of CKRT (filter clotting, time away from machine for studies, and so on). Thus, the Kidney Disease Improving Global Outcome clinical practice guidelines recommend prescribing 25-30 mL/kg/h to achieve a delivered dose of 20-25 mL/kg/h. These principles are retained in patients receiving ECMO on CKRT.

**COMMON ISSUES/COMPLICATIONS**

Complications often noted in the ECMO population include bleeding, systemic thromboembolism, circuit clotting, heparin-induced thrombocytopenia, neurological complications, arrhythmias, and infection. Additional complications specific to VA ECMO include cardiac thrombosis, coronary and/or cerebral hypoxia, and cannulation-related complications (ie, vessel perforation/hemorrhage, arterial dissection/pseudoaneurysm, distal ischemia, and incorrect placement/malposition/migration of the cannula). As with ECMO, CKRT also comes with its own array of technical complications: vascular access dysfunction, activation of the coagulation cascade, air embolism, hypothermia, fluid and electrolyte balance errors, and immune system activation. A systematic review looking at 19 studies reported complications commonly seen in patients requiring combined ECMO and CKRT. Chen and colleagues found that hemolysis seemed to be higher in this combination group than those requiring ECMO or CKRT alone.

To mitigate risk, certain practices have become commonplace. With circuit clotting being prevalent in both ECMO and CKRT, anticoagulation has been a well-studied arena often resulting in the protociled use of systemic...
Table 2. Advantages and Disadvantages Based on Various configurations for Synchronous ECMO and CKRT

<table>
<thead>
<tr>
<th>CKRT Access/Return Line Pressures (mmHg)</th>
<th>CKRT Access Line Connection</th>
<th>CKRT Return Line Connection</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Access &lt; +200 Return &lt; +350</td>
<td>Post-ECMO pump</td>
<td>Preoxygenator†</td>
<td>-No risk of air embolism -Return line on + pressure -No oxygenation membrane shunt -No recirculation</td>
<td>-Access on + pressure</td>
</tr>
<tr>
<td>Access &gt; +200</td>
<td>Pre-ECMO pump</td>
<td>Preoxygenator</td>
<td>-Access connected on – pressure -Return connected on + pressure -No oxygenation membrane shunt -No recirculation</td>
<td>-Theoretical risk of air embolism</td>
</tr>
<tr>
<td>Return &gt; +350</td>
<td>Pre-ECMO pump</td>
<td>Pre-ECMO pump</td>
<td>-Access connected on – pressure -No oxygenation membrane shunt -No recirculation</td>
<td>-Theoretical risk of air embolism -Return line connected on –pressure*</td>
</tr>
</tbody>
</table>

Abbreviations: CKRT, continuous kidney replacement therapy; ECMO, extracorporeal membrane oxygenation.
* A clamp attached to return line to increase resistance can mitigate negative pressure below low pressure alarm, but this may lead to more hemolysis and turbulent flow.
† Connecting the CKRT return line back to the ECMO circuit pre oxygenator allows for the oxygenator to serve as a trap for both clot and air that may have developed/entered within the CKRT circuit.

Information in the above table is adapted from the de Tymowski et al. recent publication in ASAIO Journal detailing the advantages and disadvantages of various arrangements when integrating CKRT into ECMO circuit.

bivalirudin, systemic UFH, and/or regional citrate. Giani and colleagues found that the combination of UFH and citrate resulted in less filter replacement owing to clotting than in UFH alone (12% vs 60%, P < 0.001). However, not all patients tolerate systemic anticoagulation. For those who are at high risk of bleeding, regional citrate alone is a reasonable choice. Shum and colleagues found that regional citrate was a safe, effective, and feasible anticoagulation technique in low-heparin and heparin-free ECMO/CKRT situations. Moreover, adjustment of the CKRT filtration fraction (FF) can also help reduce clotting risk. The FF represents the fraction of plasma water that is removed from the blood during UF. In general, the FF should not exceed 20-25%. An FF higher than this corresponds to a higher postfilter hematocrit that promotes clot formation and degradation of filter performance.

OUTCOMES

The etiology of AKI in patients on ECMO is multifactorial, which limits extrapolation of data even when patients are matched for severity of illness. AKI is highly contextual and affected not only by the pre-ECMO status but also by the sequelae of diminished pulsatility, hemolysis, and rapid volume shifts during fluid removal.5 Few studies have assessed survival outcomes with relation to AKI requiring KRT in adult patients receiving ECMO.5

Chen and colleagues reviewed mortality, fluid balance, ECMO duration, and renal function recovery for those on combined ECMO and CKRT. They found there was a statistically significant increase in the risk of mortality in the patients receiving ECMO + CKRT compared with patients receiving ECMO only (odds ratio: 5.89; 95% confidence interval: 4.38 to 7.92, P < 0.00001). In the subset of patients receiving ECMO who survived, those receiving CKRT had an overall reduced fluid balance than those survivors who did not receive CKRT. When the group looked at the duration of ECMO in both CKRT and non-CKRT groups, they found conflicting reports. While some studies reported shorter duration of ECMO in CKRT-requiring patients, other studies showed longer duration of ECMO in those requiring CKRT. With regard to renal recovery, the vast majority of studies occurred in pediatric groups. Only 4 of 14 studies in the review by Chen and colleagues reviewed adult populations. In these primarily pediatric cohorts, data showed either full recovery or very high rates of recovery (~96%) before hospital discharge across multiple studies.4,6 This, however, may not be representative of adult populations in which data remain sparse.

In a more recent analysis of adult patients receiving ECMO, Gunning and colleagues found that volume overload and AKI have significant prognostic value in patients treated with ECMO. In their retrospective analysis of 98 patients who required ECMO, 85% developed AKI, 49% required KRT, and 19% developed volume overload by 72 hours after cannulation (defined as a positive fluid balance 10% greater than admission weight). They found those with volume overload were at increased risk of 90-day mortality, even after correcting for KRT, APACHE score, weight, diabetes, and heart failure.

Consistent with the aforementioned studies, Gbadegesin and colleagues reported less fluid accumulation in pediatric survivors as compared with nonsurvivors. Schmidt and colleagues also found that the overall 90-day mortality was 24% for those requiring both ECMO and CKRT and that positive fluid balance at ECMO day 3 was an independent predictor of mortality. Interestingly, positive fluid balance during the first 2 days on ECMO did not show this same association. This is likely because ECMO centrifugal pumps are preload, dependent, and require intravenous resuscitation, especially in the first 48 hours after initiation, to counteract the inflammatory response of the body to ECMO itself.
CONCLUSIONS AND FUTURE DIRECTIONS
AKI during ECMO is common and those requiring KRT are at increased risk of mortality.16,49 The implementation of CKRT can be technically achieved in a multitude of fashions, none of which have a known improved outcome over another. The integration of ECMO and CKRT is often based on center experience and expertise – resulting in very heterogenous practice across the world. It has been suggested by Askenazi and colleagues51 that a novel KRT device be made specifically to interact with patients on ECMO to facilitate safe, accurate, effective, and simple implementation of KRT in these complex patients.

REFERENCES


