

The utility of parallel venovenous extracorporeal membrane oxygenation circuits for refractory hypoxemia in severely burned patients: A case report



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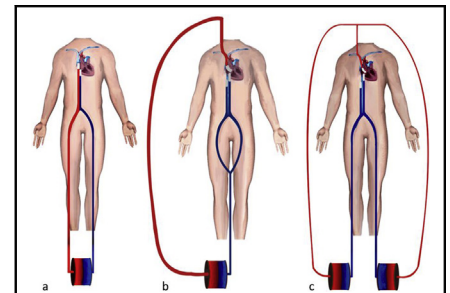
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While the role of extracorporeal membrane oxygenation (ECMO) in the management of severe respiratory failure and acute respiratory distress syndrome (ARDS) is well established, its utility in the management of patients with severe burn injury remains poorly understood. In previous literature, Soussi and colleagues¹ reported 9% in-hospital survival in burn injury patients with severe ARDS requiring ECMO in comparison with 50% in those who received conventional management. This is also significantly lower than the 58% survival to hospital discharge reported by the latest international registry (April 2022) from the Extracorporeal Life Support Organization in adults with respiratory failure requiring ECMO.² Complex pathophysiology of respiratory failure, other presenting injuries, and systemic changes secondary to severe burn injuries in this population may limit the effectiveness of an isolated ECMO circuit.^{1,3} We report the successful treatment of a patient with severe burns who developed refractory hypoxemia secondary to severe ARDS by combining 2 venovenous (VV) ECMO circuits in parallel.

CASE PRESENTATION

A 28-year-old male patient presented to the burn intensive care unit from an outside hospital after sustaining burn injuries while attempting to fuel an isopropyl alcohol tabletop fireplace. The patient was found to have mixed partial- and full-thickness, 53% total body surface area burns to his face, chest, bilateral upper and lower extremities, and abdomen. He was intubated at an outside hospital for airway protection and required minimal ventilatory support initially.



Different configurations of the venovenous ECMO (VV-ECMO) circuit.

CENTRAL MESSAGE

Parallel VV-ECMO circuits may be considered worthwhile in severely burned patients with refractory hypoxemia and concomitantly elevated cardiac output.

At arrival, he was found to have oxygen saturation (SpO₂) of 100% and arterial partial pressure of oxygen (PaO₂) of 326 mm Hg. Crystalloid fluid resuscitation was administered according to the Parkland formula (4 mL × total body surface area (%) × body weight (kg); 50% given in the first 8 hours; 50% given in the next 16 hours) and titrated while monitoring urine output.

Over the ensuing 72 hours, the patient progressed to develop acutely worsening hypoxemia, prompting escalation of inspired oxygen fraction (FiO₂) and high positive end-expiratory pressure. The patient remained sedated and was started on neuromuscular blockade subsequently. However, the patient's respiratory status continued to rapidly deteriorate to PaO₂/FiO₂ of 50 mm Hg. A radiograph of the patient's chest on hospital day 3 demonstrated increasing pulmonary bilateral infiltrates consistent with ARDS.

Given the patient's poor response to conservative therapy for severe ARDS, the decision was made to institute emergent VV-ECMO. A 19-French reinfusion cannula was placed at the junction of superior vena cava and right atrium through the right common femoral vein and a 23-French

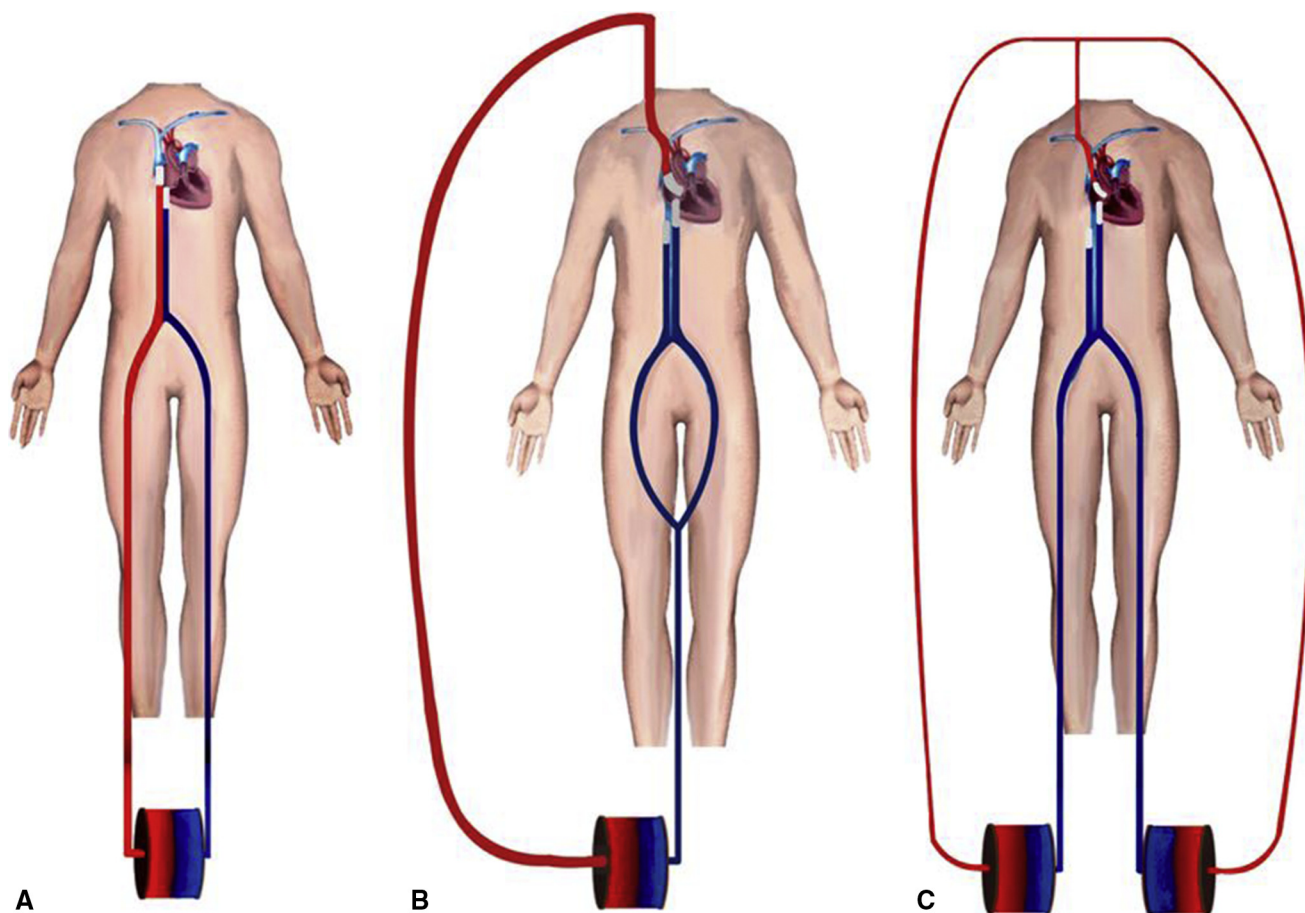


FIGURE 1. Different configurations of venovenous ECMO (VV-ECMO) circuit. A, Conventional VV-ECMO circuit with reinfusion cannulation of the right common femoral vein and drainage cannulation of the left common femoral vein. B, Venovenous-ECMO circuit with reinfusion cannulation of the right internal jugular vein and bilateral femoral vein drainage cannulation connected via “Y” configuration. C, Two VV-ECMO circuits arranged in parallel with each femoral vein drainage cannula draining into 2 separate ECMO circuits.

drainage cannula was placed at the junction of inferior vena cava and right atrium through the left common femoral vein (Figure 1, A). ECMO flows of 4.7 to 5.0 L/min were achieved and provided transient improvement in $SpO_2 > 90\%$.

Over the next several days, however, the patient’s oxygenation status worsened (PaO_2/FiO_2 of 43 mm Hg), notwithstanding exhausting ventilator and ECMO settings. Echocardiogram revealed elevated cardiac output (CO) at 10 to 11 L/min. The ECMO flow at this time, however, was limited to a maximum of 5 L/min due to drainage limitations with suction events at greater flows, resulting in an ECMO flow/native CO ratio of 0.45 to 0.50. Several strategies implemented to reduce the patient’s CO, such as decreasing the body temperature and initiation of beta-blockade, were unsuccessful in improving oxygenation.

To improve the ECMO flow/native CO ratio, the previously placed reinfusion cannula in the right common femoral vein was pulled back into the inferior vena cava

and used as an additional drainage cannula. Bilateral femoral vein drainage cannulas were connected in a “Y” configuration to create a single drainage circuit. A 20-French reinfusion cannula was placed in the right atrium through the right internal jugular vein (Figure 1, B). While the reconfigured veno-VV-ECMO circuit successfully increased the flows to 6 to 6.5 L/min, the patient’s hypoxemia was not corrected (PaO_2/FiO_2 of 48 mm Hg) and lactate dehydrogenase was elevated (>1400 units/L). Despite multiple ECMO oxygenator exchanges, postoxygenator PaO_2 also remained at 100 to 200 mm Hg. At this point, we were convinced that the achieved ECMO flow was exceeding the oxygenation capacity of our single system. Venovenous ECMO, however, was not considered at this time, to accommodate the patient’s frequent debridement requirements and avoid intensive anticoagulation use to reduce bleeding risks.

To provide adequate oxygenation in the setting of high ECMO flow, a second ECMO circuit was inserted in parallel with the first circuit. One of the original femoral drainage

cannulas was connected to the second ECMO circuit with both circuits now reinfusing into the existing reinfusion cannula (Figure 1, C). With 2 VV-ECMO circuits arranged in parallel, a combined flow of 6 L/min was achieved with each circuit providing 3 L/min of flow. Special care was made to synchronize both flows to avoid the risk of flow competition between 2 circuits.

With 2 ECMO circuits arranged in parallel, a combined flow of 6 L/min was achieved with each circuit providing 3 L/min of flow, resulting in improvements in ECMO postoxygenator P_{aO_2} (>350 mm Hg) and patient's S_{PO_2} ($>90\%$). In addition, a significant decrease in lactate dehydrogenase was noticed (<600 units/L). Over the next several days, his respiratory status continued to improve (P_{aO_2}/F_{IO_2} of 430 mm Hg) upon heavy diuresis and pulmonary hygiene and ventilator settings were weaned to F_{IO_2} of 40%.

Four days after the initiation of parallel VV-ECMO circuits, the patient was successfully weaned down to one system. The weaning process was accomplished by holding one system steady at a flow of 4 L/min and slowly decreasing the flows on the additional system to ensure that the patient would tolerate a single system configuration for several days. The patient successfully weaned off the remaining circuit and was decannulated completely from ECMO 10 days after his initial cannulation. His prolonged post-ECMO hospital course was notable for sepsis, pneumonia, bacteremia, fungemia, and gastrointestinal bleeding. He required multiple debridements and skin grafts but was discharged on room air after 3 months of total hospital stay.

Single-case studies conducted at the Loyola University Medical Center do not require a patient's consent per the university's institutional review board protocol.

DISCUSSION

The development of ARDS in patients with severe burns complicates their management and hospital course.¹ The options to treat this challenging group of patients are limited and lack clinical evidence. While the use of VV-ECMO in the management of patients with severe ARDS has increased greatly during recent years, its utility and benefits in patients with severe burns remain unclear. A systematic review and meta-analysis report insufficient evidence to support the use of ECMO and no improvement in survival for patients with burns suffering acute hypoxemic respiratory failure.³ In fact, a single-center study by Soussi and colleagues¹ reports a greater mortality rate (90-day mortality of 72%) and advises against the use of ECMO in this group. Meanwhile, findings from several other case studies suggest promising survival benefits and ECMO support as a possible rescue modality.³

The cause for variation in outcomes despite rescue attempts with VV-ECMO in this group of patients is attributed to complex pathophysiology and cardiovascular

changes. Especially, the resulting elevated CO in a hyperdynamic state prevents adequate oxygenation and leads to refractory hypoxemia. As illustrated in the present case, the utility of an isolated VV-ECMO in this setting may be deemed suboptimal, as a single system fails to provide adequate flow to meet the patient's CO demand and oxygenation. Despite our attempts to improve the ECMO flow/native CO ratio via beta-blockade, cooling, and additional drainage cannula, the patient's hypoxemia persisted.

Several novel ECMO configurations have been suggested in situations in which isolated ECMO support may be insufficient. In a case study, Malik and colleagues⁴ describe adding 2 VV-ECMO circuits in parallel to successfully treat a patient with refractory hypoxemia with concomitantly elevated CO in the setting of ARDS secondary to sepsis. Similarly, the present case illustrates the utility of dual parallel ECMO circuits in a patient with severe burns. In our case, the ECMO flow required to keep up with the patient's CO exceeded the oxygenation capacity of a single circuit. Connecting 1 of the 2 existing drainage cannulas to a new, separate VV-ECMO circuit allowed each circuit to capture an adequate fraction of CO and provide optimal oxygenation. This was evident by an immediate improvement in postoxygenator P_{aO_2} and patient's S_{PO_2} and P_{aO_2} .

Another potential benefit of parallel VV-ECMO circuits is a reduction in hemolysis with lower revolutions per minute in the ECMO pump, as indicated by a significant decrease in lactate dehydrogenase upon the initiation of parallel circuits in the present case. It is known that hemolysis is a common complication in patients with ARDS treated with VV-ECMO.⁵ Although the exact mechanism remains unknown, high ECMO flow (>3 L/min) and negative pressure within the drainage cannula are associated with hemolysis. Hence, the addition of a second ECMO circuit in parallel may reduce the flow and negative pressure through each circuit and increase the total radius through which drained red blood cells can circulate without intense mechanical stress. Combined effects may reduce the risk of hemolysis and allow more red blood cells and hemoglobin available for oxygenation.

Another case study reported using a serial connection of 2 VV-ECMO circuits in a similar setting.⁶ However, this configuration was considered less favorable for the present case. While Kang and colleagues⁶ suggest that a parallel configuration would reduce blood flow to each circuit and, therefore, limit oxygenation, we argue that this reduction provided more adequate oxygenation of blood circulating through each circuit. Furthermore, we suspected that a serial connection would increase the overall length of the circuit, thereby increasing the risk for hemolysis. For these reasons, a decision was made to add 2 VV-ECMO circuits in parallel.

Although novel ECMO configurations may prove useful in treating selected patients, all other strategies to maximize the standard ECMO platform must be considered. These include optimizing the technical application of the circuit and medical management to address underlying problems. As shown by the Extracorporeal Life Support Organization data, only a small subset of patients on ECMO require novel ECMO configurations, with worse survival outcomes likely attributed to the severity of illness.²

While the present study is not the first to use parallel ECMO circuits in challenging patients, to our knowledge, this is the first study to use 2 VV-ECMO circuits arranged in parallel configuration in treating a patient with severe burns with refractory hypoxemia. In conclusion, the addition of a second VV-ECMO circuit in parallel can improve oxygenation in this group of patients when hypoxemia is not improved with an isolated VV-ECMO circuit.

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