Ambulatory Extracorporeal Arteriovenous CO₂ Removal via Subclavian Vessels

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Introduction

Lung transplantation is the last recourse for patients with severe respiratory failure. However, transplantable lungs do not keep up with the demand, and 35.4% of patients die awaiting transplant. An alternative therapy is extracorporeal life support (ECLS), which uses a pump and an oxygenator to serve as a bridge to transplant. However, this technology limits ambulation and requires ICU care. This novel study implements simplex arteriovenous (SV) ECLS technology to remove CO₂ via the subclavian vessels, providing respiratory support and hyperventilation (excessive CO₂ retention) symptom relief for patients while allowing ambulation.

Methods

Following University of Michigan’s protocols, 4 healthy sheep (61±6.2 kg) were anesthetized. The left subclavian vessels were exposed surgically. Two vascular grafts were anastomosed to the artery and vein and subsequently cannulated (17Fr) to create an AV shunt. Each animal was extubated, recovered, and fitted with a low-resistance membrane gas exchanger. The device’s effectiveness at removing CO₂ was measured by analyzing pre- and post-device blood gases and sweep gas exhaust samples as room air sweep flow was incrementally raised from 0-15 L/min. This was done in awake, spontaneously breathing animals and repeated after they were re-anesthetized, placed on mechanical ventilation, and rendered hypercapnic by lowering minute ventilation to less than 2 L/min.

Results

To test if the proposed AV configuration was possible and would not negatively affect the animals, the first sweep study was performed on the healthy sheep after the gas exchanger was attached. The study assessed the CO₂ partial pressure of the pre- and post-device blood at the sweep flow rate was increased to 15 L/min. As seen in Figure 4, the post-device PaCO₂ was lower than the pre-device PaCO₂, and their difference was greatest for the higher flow rates, indicating the gas exchange did remove some amount of CO₂ and did so more effectively for higher flow rates. Figure 5 shows the rate at which CO₂ was removed, in ml/min, which was measured with the gas exhaust samples taken as the gas flow rate increased. There is almost a linear relationship until after 11 L/min of flow, where the rate of CO₂ removal stays increasing, likely because the performance of the gas exchange peaks about then, at a rate of 228.25 mL/min, due to its finite membrane surface area. The respiratory rate, measured in breaths/min, decreased in the animals by half because the drive to breathe decreased with less CO₂ in the blood.

In order to determine if the Novalung® gas exchange, in this configuration, could reduce the CO₂ in the blood of a healthy sheep, a second sweep study was performed. Figure 6 displays measured gas flow rates over time. The pressure in the animals were being made hypercapnic, but as soon as the sweep flow is turned on, there is an immediate PaCO₂ difference across the device. Once the gas flow rate is turned off, the decreasing PaCO₂ rates once more, demonstrating the effect of the air sweep flow through the gas exchange. Again using the gas exhaust samples, the CO₂ removal rate was calculated. As illustrated in Figure 7, the CO₂ removal rate increased along with the gas flow rate, though the gas exchange did display an optimal trend in performance at the highest flow rates.

Conclusion

The arteriovenous shunt was 13.9±1.3% (21.2±2.5 mL/min/kg) of cardiac output, yet systemic hemodynamics remained stable. Across the device, PaCO₂ decreased on average from 28.6 to 19.3 mmHg in the healthy sheep, while in the hypercapnic animals it decreased from 59.4 to 36.2 mmHg. Device efficacy was further evidenced by the rising CO₂ removal rate for both animal conditions as the sweep flow increased, achieving a maximum of 228.25 mL/min in the healthy animals and 202.5 mL/min in the hypercapnic ones. This demonstrates that the proposed configuration is not only feasible, but has the potential to be a bridge to lung transplantation and even a future destination therapy for hypercapnic patients.

Literature Cited

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Acknowledgements

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Cardiovascular Center Summer Undergraduate Research Fellowship & The Esperance Family Foundation Extracorporeal Life Support Laboratory team
Director: Dr. Bartlett
Research Fellows, Staff, and Students
University of Michigan & University of Nevada, Las Vegas
The Center for Academic Enrichment and Outreach, UNLV
Ronald E. McNair Scholars Institute

Further information

Extracorporeal Life Support Research Lab
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