Case Report

Pumpless arteriovenous carbon dioxide removal: A novel simplified strategy for severe asthma in children

Avinash Aravantagi, Kamakshya P. Patra, Suman Shekar, L. Keith Scott

Abstract

Status asthmaticus unresponsive to pharmacotherapy is conventionally managed with mechanical ventilation, which has its inherent challenges due to barotrauma, dynamic hyperinflation and autopositive end-expiratory pressure (auto-PEEP). Extracorporeal membrane oxygenation has been used as a last resort in respiratory failure due to refractory asthma; however, it entails many complications. In contrast, arteriovenous carbon dioxide removal (AVCO$_2$R) is a novel strategy that has been shown to be highly effective in adults with acute respiratory failure. Only one pediatric case series of pediatric asthma managed with AVCO$_2$R have been published so far. We herein report a case of severe asthma in a 9-year-old boy who developed severe hypercapnia (Pco2 97 mmHg) and acidosis (pH 7.09) despite being on mechanical ventilation. Within 4 h of initiation of AVCO$_2$R, PCo$_2$ drastically reduced to near-normal levels. He was discharged on day 9 of hospital stay without any complications..

Keywords: Arteriovenous carbon dioxide removal, extracorporeal life support, severe asthma

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Introduction

Asthma is a common cause for admission to a pediatric intensive care unit, and is associated with a high mortality.[1] Most of these patients respond well to pharmacotherapy. The few patients who develop respiratory failure may need mechanical ventilation, which can cause barotrauma, dynamic hyperinflation, hypercapnia and severe acidosis. Extracorporeal membrane oxygenation (ECMO) has been used as the last resort in life-threatening asthma.[2] However, it is a pumped circuit with complications like bleeding, hemolysis, fibrinolysis and tubing rupture. Although with current dual lumen percutaneous cannulas, coated circuits, minimal heparination and centrifugal pumps, ECMO is relatively safe, but it needs a dedicated ECMO specialist and much higher resource utilization. In contrast, arteriovenous carbon dioxide removal (AVCO$_2$R) is a pumpless extracorporeal circuit that utilizes an arterio-venous pressure gradient to remove CO$_2$ and to add a small amount of oxygen via a gas exchanger. It has been shown to be highly effective in adults with acute respiratory failure.[3] Only one case series of pediatric asthma managed with AVCO$_2$R have been reported.[4] We report a case of life-threatening asthma that developed severe hypercapnia and acidosis on mechanical ventilation and was successfully managed with AVCO$_2$R.

Case Report

A 9-year-old African American male with a known history of moderate persistent asthma presented to the emergency room with status asthmaticus. He showed no improvement with inhaled beta agonists, inhaled anticholinergics, intravenous corticosteroids and intravenous magnesium. Noninvasive ventilation was not well tolerated and did not decrease his work of

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breathing; hence, he was intubated and transferred to our pediatric intensive care unit for respiratory failure. On arrival, he was placed on the volume support with peak pressure of 40 cm H2O and tidal volume of 7 cc/kg. Later, he was changed to the pressure-regulated volume control mode with high peak pressures of 42 cm H_2O to deliver a tidal volume of 3–5 cc/kg and ventilator rate of 20 breaths per min. The PEEP was set to match the auto-PEEP at 14 cm H_2O. The ventilator flow waveform showed prolonged incomplete exhalation. Arterial blood gas revealed severe respiratory acidosis with pH 7.09 and PCo_2 97. Chest X-ray showed hyperinflated lungs with bilateral infiltrates. Different ventilatory strategies like volume support mode and pressure-regulated volume control mode were unsuccessful. In view of progressive hypercapnia and rapidly increasing pressures, we instituted an $AVCO_2R$ circuit. Ultrasound-guided 10Fr femoral arterial cannula and 16Fr venous catheter were placed via the Seldinger technique. Heparin-flushed catheters were connected to the oxygenator. The initial blood flow was 500 mL/min (20 mL/kg/min). The systemic blood pressure remained stable, with systolic blood pressure between 90 and 110 mmHg. Spontaneous blood flow through the device was blood pressure-dependent, but ranged from 450 to 700 mL/min. Within 4 h of placement of $AVCO_2R$, his PCo_2 decreased to 57 and pH improved to 7.23. Minute ventilation was also reduced with improvement in PaO_2 [Figure 1]. Oxygen flow (sweep gas) was titrated with patient's PCo_2. The patient was on $AVCO_2R$ for a total of 5 days, with improvement in lung compliance and gas exchange. The trends of fall of PCo_2 and rise of pH are shown in Figure 2. A 24-h "trial off" was successful prior to discontinuation of $AVCO_2R$. Femoral arterial and venous cannulas were removed and pressure dressing applied without any complications. Patient's ventilator settings were changed to pressure support and was extubated on day 10 and transferred to the pediatric ward on day 13. He was continued on bronchodilators during his stay in the pediatric ward for 48 h, and was discharged home on day 15.

Discussion

$AVCO_2R$ is a technique that accomplishes removal of carbon dioxide using a low-resistance hollow fiber oxygenator and a simplified extracorporeal circuit.[4]

Principle

The arteriovenous pressure gradient drives blood through the oxygenator at a flow rate proportional to the arteriovenous gradient and inversely proportional to the resistance of the oxygenator and cannula.

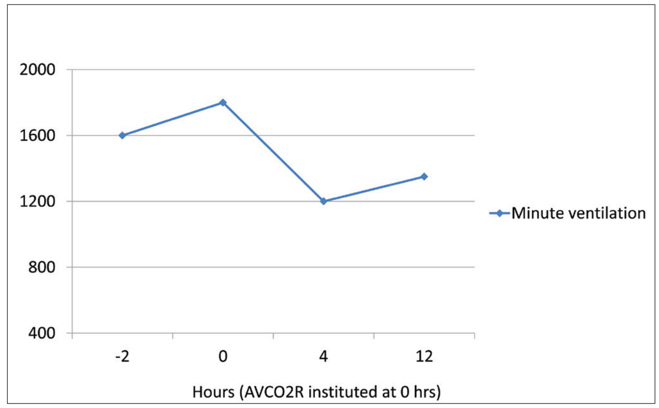

Figure 1: Minute ventilation in the patient over the course of the first 12 hr. Arteriovenous carbon dioxide removal was initiated at hour 0

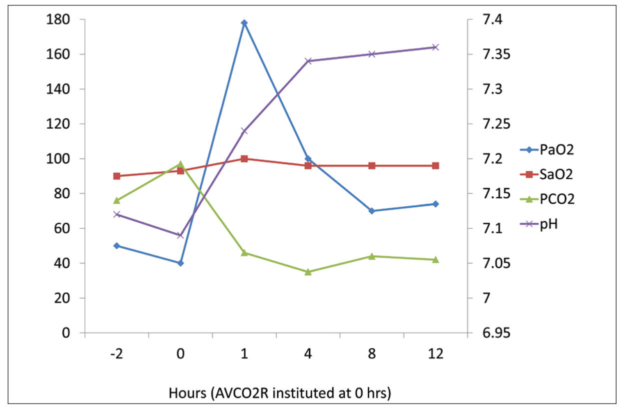

Figure 2: Arterial PaO_2, SaO_2, PCo_2 and pH in the patient over the course of the first 12 hr. Arteriovenous carbon dioxide removal was initiated at hour 0

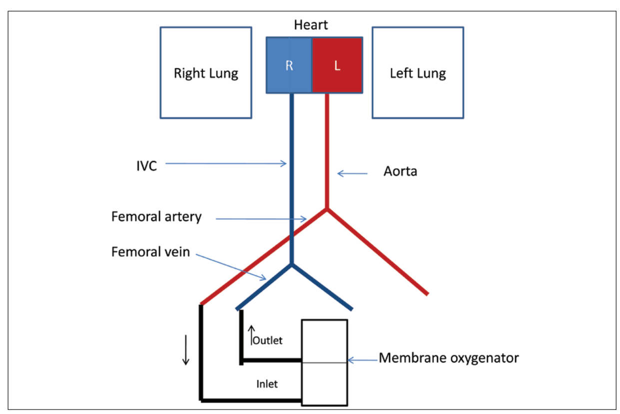

Figure 3: Schematic diagram of the extracorporeal circuit for arteriovenous carbon dioxide removal. Cannulas placed in the femoral artery and vein are respectively attached to the inlet and outlet of the membrane oxygenator

$AVCO_2R$ circuit

It consists of an oxygenator, oxygen source with flowmeter and arterial/venous access. [Figure 3]. The oxygenator consists of a trilium-coated microporous hollow fiber. We used Medtronic Affinity NT, which has a surface area of 2.5 M^2 with high efficient gas exchange and low blood phase pressure drop. Circuit is primed with 1L Normosol (pH 7.4) as per the manufacturer's directions before it is connected to arterial/venous catheters. Volume of blood in this circuit is approximately 290 cc, of which nearly 270 cc lies in the oxygenator.[3,4]

Sweep gas consists of oxygen provided by a commercial flow meter. Gas flow is initially set to be at five-times the blood flow. This gas flow and blood flow ratio is derived by Conrad *et al.* using mathematical simulations and experimental models.[5] Sweep gas flow rate is adjusted based on PCo_2. At 3 L/min of sweep gas flow rate, CO_2 removal is nearly linearly related to sweep gas flow.

Use of ultrasound allows selecting cannula size that provides sufficient flow yet avoids luminal occlusion and ischemia. Arterial cannula of 6.5 cm length and 10 Fr or 12 Fr diameter and venous cannula of 6.5 cm length and 14 Fr or 16 Fr diameter catheters were used for cannulation using the modified Seldinger technique. The size of the arterial cannula and the high-resistance component of the circuit determine the blood flow. Minimum flow requirement for an oxygenator is 500 ml/min, as blood flow depends on arterial catheter size and arteriovenous gradient using at least 10 Fr arterial catheter. Because of smaller femoral arteries in smaller children, this method is limited. Heparin 50 units/kg is flushed through the catheters and connected to the primed circuit thus allowing uncontrolled blood flow to the oxygenator. Blood flow is monitored with an external ultrasonic bypass flow meter. Heparin is titrated to maintain the activated coagulation time at around 180–200 s as measured by a commercial bedside analyzer.

$AVCO_2R$ support is continued until bronchospasm resolves with adequate spontaneous ventilation (pressure support $\leq$10 cm H_2O and Fio_2 $\leq$0.40). A trial off is performed by discontinuing the sweep gas for several hours to assess the adequacy of CO_2 removal through the natural lungs only. Once this is successful, decannulation is performed following discontinuation of anticoagulation.

Advantages of $AVCO_2R$ when compared with ECMO

$AVCO_2R$ relies on the patient's own blood pressure to drive the system; hence, it has fewer complications like hemolysis, fibrinolysis and platelet dysfunction compared with ECMO due to the absence of pump. It requires a lesser amount of priming fluid unlike ECMO, which needs blood products for priming the circuit. Overall, it is less invasive and cost effective than ECMO.

Limitations

Need for an adequate-sized femoral artery and a minimum blood flow through the oxygenator (at least 10 Fr and blood flow >500 ml/min). In smaller children, the femoral artery may not accommodate the 10 Fr arterial cannula.

Conclusions

$AVCO_2R$ provides extrapulmonary removal of CO_2, secondarily allowing reduction in ventilator settings that can prevent dynamic hyperinflation, worsening auto-PEEP and barotraumas. It has been demonstrated to be both safe and effective in adult patients with acute lung injury exhibiting hypercapnea and respiratory acidosis. This case supports that $AVCO_2R$ is a less-invasive, cost-effective and promising technique as an alternate to ECMO in refractory status asthmaticus with hypercapnia in children.

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