Case Reports

Low-Flow Extracorporeal Carbon Dioxide Removal Using the Hemolung Respiratory Dialysis System® to Facilitate Lung-Protective Mechanical Ventilation in Acute Respiratory Distress Syndrome

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Abstract: Extracorporeal carbon dioxide removal (ECCO₂R) permits reductions in alveolar ventilation requirements that the lungs would otherwise have to provide. This concept was applied to a case of hypercapnia refractory to high-level invasive mechanical ventilator support. We present a case of an 18-year-old man who developed post-pneumonectomy acute respiratory distress syndrome (ARDS) after resection of a mediastinal germ cell tumor involving the left lung hilum. Hypercapnia and hypoxemia persisted despite ventilator support even at traumatic levels. ECCO₂R using a miniaturized system was instituted and provided effective carbon dioxide elimination. This facilitated establishment of lung-protective ventilator settings and lung function recovery. Extracorporeal lung support increasingly is being applied to treat ARDS. However, conventional extracorporeal membrane oxygenation (ECMO) generally involves using large cannulae capable of carrying high flow rates. A subset of patients with ARDS has mixed hypercapnia and hypoxemia despite high-level ventilator support. In the absence of profound hypoxemia, ECCO₂R may be used to reduce ventilator support requirements to lung-protective levels, while avoiding risks associated with conventional ECMO. Keywords: acute respiratory distress syndrome, hemo-lung, low flow, extracorporeal carbon dioxide removal (ECCO₂R). J Extra Corpor Technol. 2017;49:112–114

Artificial pulmonary support is being implemented increasingly to treat adult respiratory failure. However, substantial differences exist with respect to the requirements of artificial machinery for provision of adequate oxygen (O₂) supply and carbon dioxide (CO₂) removal. With respect to transmembrane O₂ transfer, O₂ has lower diffusion rates due to 1) hemoglobin as a saturable carrier capable of transporting a maximum of four O₂ molecules/hemoglobin molecule and 2) relatively low blood O₂ solubility (less than 5% of that for CO₂). Consequently, blood flow rates that are a high percentage of the cardiac output are required for adequate O₂ supply, as is the case for venoarterial or venovenous (VV) extracorporeal membrane oxygenation (ECMO) usage in the setting of severe hypoxemic respiratory failure (1).

In contrast, CO₂ has high blood solubility and is carried as bicarbonate in small blood volumes. Thus, blood

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flow requirements for CO₂ removal are far lower than for O₂ supply. Extracorporeal carbon dioxide removal (ECCO₂R) systems provide clinically significant CO₂ removal at blood flow rates of just 350–550 mL/min (2). With clinically significant CO₂ removal but not O₂ supply, and less invasiveness than conventional ECMO, there are circumstances under which ECCO₂R may be a reasonable alternative to ECMO. These include primary hypercapnic respiratory failure, as a bridge to recovery (3) or lung transplantation, or mixed hypercapnic/hypoxemic respiratory failure under conditions in which non-traumatic levels of ventilator support are inadequate to provide CO₂ removal but sufficient to provide oxygenation (4). The case presented is within the latter group.

DESCRIPTION

An 18-year-old man with a history of testicular cancer treated using a multi-modality approach developed a solitary mediastinal metastasis. Chemotherapy with bleomycin, cisplatin, and etoposide was initiated. Post-treatment, a residual mediastinal mass was found with extension to the left lung hilum. He underwent resection at the University of Texas MD Anderson Cancer Center, which required left pneumonectomy and en bloc partial excision of the left atrium. He was extubated postoperatively without issue. However, he subsequently became febrile, and in association with this, developed a progressively extensive right lung infiltrate. His condition worsened despite broad-spectrum antibiotics.

On postoperative day 5, the patient developed severe hypercapnia and hypoxemia, necessitating re-intubation and invasive mechanical ventilation; new onset systemic hypotension also developed. A norepinephrine infusion was initiated and titrated to 8 mcg/min. Transthoracic echocardiography identified mild tricuspid valve regurgitation with a calculated right ventricular systolic pressure of 40 mmHg, and leftward interventricular septal deviation. Inhaled epoprostenol was initiated. The patient was evaluated for artificial pulmonary support, and transferred to Memorial Hermann-Texas Medical Center.

On arrival, the patient’s condition was unchanged. Inhaled nitric oxide was instituted. With a respiratory rate of 22 breaths per minute, tidal volume of only 4 mL/kg but for a single lung, positive end-expiratory pressure (PEEP) of 10 cm H₂O, and fraction of inspired oxygen (F₁O₂) 65%, the peak and plateau airway pressures were 34 and 31 cm H₂O, respectively. The arterial PCO₂ was 73 mmHg and arterial PO₂ was 77 mmHg. The hemodynamic status was most consistent with acute cor pulmonale, possibly with systemic vasodilatation, and did not appear to warrant mechanical cardiac support. With respect to pulmonary support, CO₂ elimination appeared inadequate, and could not be improved in the setting of already traumatic ventilator settings (plateau pressure >30 cm H₂O). Oxygenation was not as severely impaired, and could have been managed with increased F₁O₂ (or PEEP if tidal volumes were decreased).

Conventional VV ECMO requires outflow port/cannula tip position in close proximity to the right atrium, or further downstream in the right ventricle/pulmonary artery. Because of post-pneumonectomy heart/great vessel shift, conventional VV ECMO cannulation was thought to be anatomically high risk. For all of the aforementioned reasons, ECCO₂R via a minimally invasive approach was chosen.

The Hemolung Respiratory Assist System (Hemolung RAS; ALung Technologies, Pittsburgh, PA) was chosen to provide ECCO₂R. A proprietary 15.5 French dual lumen venous catheter provides inflow and outflow, and is connected to a proprietary gas exchanger; this system provides ECMO with ultra-low volumetric blood flow rates. The small dual lumen cannula is capable of blood flow rates <600 mL/min for acceptable circuit hemodynamic parameters. The low blood flow rates through the gas exchanger permit CO₂ removal, but only small increases in O₂ delivery. As such, this system de facto provides ECCO₂R but not efficacious ECMO. In the United States, this has humanitarian device exemption from the Food and Drug Administration. Institutional and corporate regulations were satisfied. The catheter was percutaneously introduced into the right common femoral vein, at which time the patient was administered heparin, 80 U/kg as an intravenous bolus. ECCO₂R was initiated: blood flow rate ~450 mL/min and sweep gas flow rate ~10 L/min at F₁O₂ 100%. This provided CO₂ removal of ~76 mL/min. Arterial PCO₂ decreased from 73 to 53 mmHg within 4 hours (with a concomitant pH increase from 7.28 to 7.44), permitting tidal volume reduction to 3.5 mL/kg, and plateau airway pressure to 25 cm H₂O. Simultaneous hemodynamic improvement occurred such that the norepinephrine infusion was discontinued, consistent with reduced pulmonary vascular resistance. Ongoing anticoagulation was via a heparin infusion titrated to a partial thromboplastin time of approximately 60. The bolus and infusion were in accordance with the manufacturer’s instructions for use.

After 18 hours of support, with tidal volume yet 3.5 mL/kg, the plateau pressure had decreased to 20 cm H₂O and arterial PCO₂ was 46 mmHg: F₁O₂ was reduced to 50%, and arterial PO₂ was 85 mmHg. After 42 hours of support, the arterial PCO₂ was 48 mmHg, and F₁O₂ was reduced to 24%, with an arterial PO₂ of 96 mmHg. ECCO₂R was titrated to eliminate enough CO₂ to maintain an arterial PCO₂ between 45 and 50 mmHg. Using this strategy of mild permissive hypercapnia while on ECCO₂R support, ensuring sufficient serum bicarbonate levels without renal excretion, the patient was weaned from ECCO₂R and decannulated after 71 hours of support. He was liberated

from mechanical ventilation within 24 hours post-decannulation, and transferred to an intermediate care unit shortly afterward. No ECCO₂R-related complications were observed. His chest radiographs demonstrating findings consistent with post-pneumonectomy acute respiratory distress syndrome (ARDS) and improvement post-ECCO₂R are demonstrated below (Figure 1).

COMMENT

Novel aspects of this case include using the Hemolung RAS to treat ARDS, particularly post-pneumonectomy, clear demonstration of post-ECCO₂R improvements in lung function with reduced mechanical ventilatory support, and attendant hemodynamic improvements. Although the device has been used for ARDS in Europe, this is the first such case in the United States, and the fourth application of the Hemolung RAS in the United States overall (information from manufacturer). However, current ECCO₂R approaches have limitations. Pump-driven systems use conventional large single- or dual-lumen cannulae (5), whereas pumpless systems rely on left ventricle-generated driving pressure for flow through an arteriovenous circuit, i.e., arterial inflow and venous outflow (6). The Hemolung RAS has a conceptual advantage of using one small dual-lumen venous catheter, without additional arterial access and its attendant risks. In appropriately selected patients, this minimally invasive ECCO₂R approach may be useful.

REFERENCES