

Obstructive Ventilator Injury at the End of Cardio-pulmonary Bypass, Treated with Extracorporeal Membrane Oxygenation

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Keywords: Obstructive pulmonary injury; Cardio-pulmonary bypass; ECMO

Abbreviations: VA ECMO: Veno-Arterial Extracorporeal Membrane Oxygenation; CPB: Cardio-Pulmonary Bypass; ICU: Intensive Care Unit; RCC: Red Blood Cell; FFP: Fresh Frozen Plasma; CVP: Central Venous Pressure; TEE: Trans-Esophageal-Echocardiogram; OLV: One Lung Ventilation; PIP: Peak Inspiratory Pressure; PEEP: Positive End Expiratory Pressure

Case Summary

Although lung injury is common complication of Cardio-Pulmonary-Bypass (CPB), obstructive lung injury is a rare and possibly catastrophic complication reported to result from acute bronchospasm and non-cardiogenic pulmonary edema. Some previous reports have described acute bronchospasm at the end of CPB [1,2] in most such cases, bronchodilator treatments were effective, and patients could soon be weaned from CPB [1,2]. Accordingly, continued CPB until bronchial dilation became effective was the recommended protocol.

However, we describe herein a case in which treatments for acute bronchospasm were not sufficiently effective to wean the patient from CPB even after a 1 hour period.

This patient's lungs could not be deflated at the end of CPB, a condition that was refractory to treatment and could not be managed with standard ventilation. The patient was accordingly switched from CPB to Veno-Arterial Extracorporeal Membrane Oxygenation (VA ECMO) to maintain valid oxygenation and improve hemostasis. The respiratory function improved gradually after aggressive treatment for pulmonary edema, and ECMO was successfully terminated. Hemostasis was also achieved with aggressive transfusion after ECMO termination.

Case Report

A 65-year-old woman was scheduled for thoraco-abdominal aortic replacement, her sixth cardiac surgery since developing aortic dissection in 2003. She had a history of repeated ascending aorta replacement, aortic root and valve replacement, proximal

descending aorta replacement, and total arch replacement which approximately 1 month earlier. She also had a history of atrial fibrillation treated with ablation.

The following abnormal laboratory data indicated consumptive coagulopathy, likely due to the dissected descending aorta: hemoglobin, 9.8 g/dl ; platelet count, $8.9 \times 10^4/\mu\text{l}$; prothrombin time-international normalized ratio, 1.05; activated partial thromboplastin time, 28.4 sec; D-Dimer, 31.6; and fibrinogen, 108 mg/dl.

The patient was placed under general anesthesia with an artery line, Central Venous Pressure (CVP), and Trans-Esophageal Echocardiogram (TEE) monitoring and positioned right laterally. One Lung Ventilation (OLV) was achieved without difficulty using a bronchial blocker, with the following ventilation targets: tidal volume, 4 ml/kg and Positive End Expiratory Pressure (PEEP), 5 cm H₂O. Intraoperative TEE revealed normal left ventricle function, mild dilation and reduced function in the right ventricle, mild mitral regurgitation, mild tricuspid regurgitation, a small patent foramen ovale, and a dissected descending aorta.

CPB was established and initiated without difficulty through the right femoral vein and artery under TEE observation. Cooling was initiated, and circulation arrest was achieved with a bladder temperature of 23°C.

The cerebral ischemia time was 15 min, accompanied by 8 min of retro-cerebral perfusion with a target CVP of 10-15 cm H₂O. Selective abdominal branch perfusion was initiated 26 minutes after circulation arrest and continued for 95 minutes. The lower body ischemic time was 121 minutes. The abdominal branch arteries and Adamkiewicz artery were reconstructed, and the

thoraco-abdominal aorta was replaced successfully. Rewarming was initiated, and a sinus rhythm was achieved after defibrillation. Additionally, during CPB, 10 units of Red Blood Cells (RBCs) were administered to maintain a hemoglobin value >7 g/dl.

Despite resuming right-side OLV, the patient could not be ventilated. Bilateral lung ventilation was required, and the left lung appeared and remained inflated, with little deflation. Pressure control ventilation with a Peak Inspiratory Pressure (PIP) of 30 cm H₂O and PEEP of 8 cm H₂O yielded a tidal volume of only 30 ml.

Bronchoscopy revealed that the bronchial tube and bronchial blocker were positioned normally. There were no obstructions evident at the first carina, and no signs of bleeding or sputum, despite mildly edematous bronchus. No wheezing sound was auscultated with manual ventilation; however, the lung sound was too low for diagnosis from the details. Concomitant TEE revealed no signs of pneumothorax or hemothorax of the right lung.

At this point, acute bronchospasm treatment was initiated, including epinephrine administration through intramuscular and continuous intravenous infusion, bronchodilator and high-concentration sevoflurane inhalation, and dexamethasone and magnesium sulfate injections. The PIP and PEEP settings of 30 and 10 cm H₂O, respectively, were used to gradually increase the tidal volume from 50 and 100 ml to approximately 200 ml. A capnometer figure appeared but unexpectedly did not exhibit an obstructive pattern. At this point, the patient began to exude copious red or pink secretions from the bronchial tube, and the following treatments for non-cardiogenic pulmonary edema were started: high PEEP ventilation, diuretics, 25% albumin administration, and inotropic support. However, as this patient had developed vascular hyper-permeability during CPB and continued to bleed profusely, large amounts of fluids were needed to maintain CPB. As the situation could potentially worsen further despite aggressive treatment, the decision was made to attempt to wean the patient from CPB for better hemostasis.

The patient was placed on bilateral lung ventilation and gradually weaned from CPB. However, RV and subsequent LV dysfunction appeared suddenly after weaning, and the patient was returned to CPB after oxygenation and hemodynamics could not be maintained. Next, a switch to VA ECMO was initiated through the femoral vein and artery immediately after CPB cessation. The ventilator settings for lung fluid removal were PIP, 20 cm H₂O and PEEP, 15 cm H₂O. Protamine was subsequently administered, and large amounts of blood components were administered rapidly to treat hemostasis.

Despite the restoration of the active coagulation time and blood test results to near-normal values, the team struggled for nearly 3 hours to achieve hemostasis while on ECMO. As the lung function recovered over time, an attempt at weaning from ECMO was made with the expectation of better hemostasis. The patient was ventilated with 100% oxygen, the tidal volume was approximately 300 ml with PIP and PEEP settings of 30 and 8 cm H₂O, respectively, and no bronchial secretion was observed. TEE indicated normal heart function. The patient was successfully weaned from ECMO

without hypoxia or hemodynamic instability with supportive treatment that included 5 μ g/kg/min dobutamine, 3 μ g/min norepinephrine and 1.2 U/h vasopressin.

After ECMO removal, hemostasis was again attempted and finally achieved. Respiration was maintained with standard ventilation. The total operating time was 631 minutes, with anesthesia duration of 770 minutes, CPB duration of 321 minutes, and ECMO duration of 196 minutes. Regarding blood components, a total of 56 RBC units, 62 Fresh Frozen Plasma (FFP) units, and 80 platelet component units were administered. The bleeding volume was 20,000 ml, with a urine output of 5000 ml, CPB balance of 15000 ml, and fluid balance of 13900 ml.

The patient was subsequently transferred to an Intensive Care Unit (ICU), where a postoperative chest X-ray indicated severe bilateral lung edema (**Figure 1**). After 2 hours, the patient awoke without any neurological issues. No significant bleeding occurred from her chest tube. Because she had suffered from severe edema, additional diuretics were administered. After her arrival at the ICU, a tidal volume of 350 ml was achieved with PIP and PEEP settings of 28 and 8 cm H₂O, respectively, and oxygenation was maintained with 80% oxygen. Her lung function improved over time, and she was extubated 2 days later after all edema had resolved.

Discussion

We have described our experience with a case of severe obstructive lung injury after CPB that could not be ventilated using standard management. The first impression was acute bronchospasm because left lung remained inflated, with little deflation. However, another possible diagnosis of pulmonary edema was made simultaneously because copious amounts of a red-colored secretion appeared from the bronchial tube.

Non-cardiogenic pulmonary edema has been reported to occur in $<1\%$ of all cardiac surgeries; despite this low incidence, it is

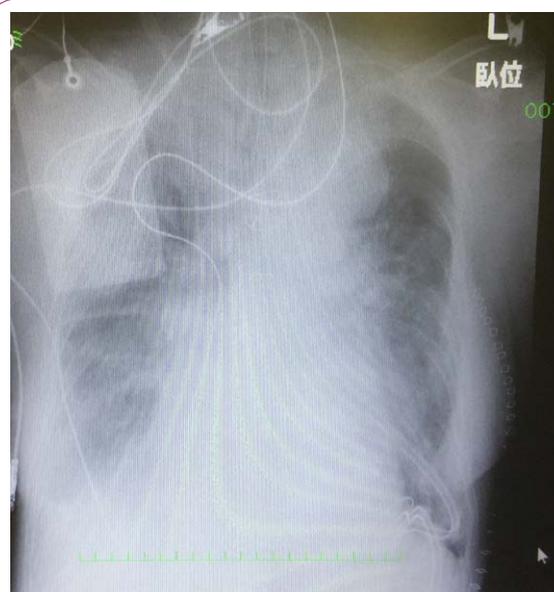


Figure 1 Severe lung edema is apparent on a chest x-ray.

associated with high mortality rates of 30-50% [3]. Pulmonary edema in the present case, which would have been non-cardiogenic, could have caused severe obstruction if it impacted the small airways. The hyper-permeability experienced by this patient while on CPB could have led to severe lung injury.

Notably, protamine and FFP have been reported as leading causes of non-cardiogenic pulmonary edema [4,5]. However, at the time of edema development, the patient had not received either agent and had only been administered 10 units of RBC. Furthermore, in the present case, severe adhesion prevented the insertion of a left-side cardiac venting system; this might have increased the pulmonary artery pressure, especially in the presence of retro-cerebral circulation, possibly leading to pulmonary edema.

Standard treatment was impossible in the present case. The patient could not be weaned from CPB because of respiratory failure and consequent hemodynamic instability, as well as hyper-permeability and bleeding. However, continued CPB no longer seemed a good option in terms of hemostasis and vascular permeability. We noted that a previous study reported the achievement of effective support with VV ECMO [6]. ECMO can be used to maintain oxygenation and circulation and, at least for short-term treatment, does not require the use of heparin in heparin-bonded circuits [7]. As a result, hemostasis would likely be better with ECMO than with CPB. We noted that after the patient was transferred to ECMO and received protamine and blood components, hemostasis did improve. Despite the reason

for poor homeostasis (e.g., thrombocytopenia, disseminated intravascular coagulation, hyperfibrinolysis, or acquired von Willebrand syndrome), ECMO aggregates hemostatic factors in the absence of heparin [8].

Notably, it remained difficult to achieve hemostasis with ECMO. However, during a 3-hour period on ECMO, the patient gradually responded to treatments for pulmonary edema and could be weaned from ECMO, after which hemostasis was finally achieved with additional efforts. Upon ICU admission, chest x-ray revealed lung edema that was not accompanied by heart failure. The reason this edema could not easily be determined, and red blood cell transfusion, hyper-permeability, and elevated pulmonary artery pressure associated with retro-cerebral perfusion that was not drained by the left-side venting system were all considered possible causes. Regardless, VA ECMO was a life-saving option from which the patient was weaned after aggressive treatment and ultimately achieved hemostasis.

In summary, this case involved obstructive respiratory failure due to non-pulmonary edema following CPB, a very rare and catastrophe situation that was initially difficult to distinguish from acute bronchospasm. For this patient, temporary VA ECMO was a life-saving option that allowed us to administer protamine and permitted lung function recovery. However, as it is difficult to achieve hemostasis while on ECMO, it is important to wean patients as soon as possible.

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