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Case report

Pulmonary artery cannulation during venovenous extracorporeal membrane oxygenation: An alternative to manage refractory hypoxemia and right ventricular dysfunction

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ABSTRACT

Venovenous extracorporeal membrane oxygenation (ECMO) has become a rescue therapy for acute respiratory distress syndrome (ARDS) secondary to COVID-19 for patients who are refractory to conventional therapy. However, this therapy comes with complications, and alternative cannulation strategies are needed to overcome these difficulties. In this article, we present a case of venovenous ECMO presenting with refractory hypoxemia and right ventricular dysfunction, which were corrected by cannulating the pulmonary artery. This situation is rarely reported in literature and may constitute an alternative for managing these patients.

1. Introduction

The Extracorporeal Life Support Organization, World Health Organization, and Surviving Sepsis Campaign Guidelines recommend considering venovenous (VV) extracorporeal membrane oxygenation (ECMO) in specialized centers as a rescue maneuver in patients with COVID-19, acute respiratory distress syndrome (ARDS), and severe hypoxemia despite optimal medical treatment, including prone position ventilation and nitrous oxide [1]. VV ECMO is a modified cardiopulmonary bypass that provides gas exchange to ensure systemic oxygenation and sustain the cardiopulmonary function of the patient [2]. The in-hospital mortality reported in COVID-19 patients receiving ECMO is 37.1% [3]. Complications occurring during VV ECMO include sepsis, acute renal failure, multiorgan failure, and cannulation-related and central nervous system complications [4]. The major determinants of peripheral oxygen saturation during VV ECMO are pump flow, degree of recirculation, systemic venous return, hemoglobin concentration, and residual lung function. Sometimes, patients develop refractory hypoxemia during VV ECMO despite transfusion therapy, administration of neuromuscular blocking agents and sedatives, therapeutic hypothermia, and prone ventilation [5]. Cardiac failure, particularly right ventricular dysfunction (RVD), is commonly encountered in moderate-to-severe ARDS in COVID-19, with a prevalence rate ranging from 13% to 51% and is one of the major determinants of mortality [6]. VV ECMO reverses hypoxemia, hypercapnia, and acidemia, resulting in reduced pulmonary vasoconstriction, pulmonary artery pressure, and right ventricular afterload, with subsequent improvement in right ventricular systolic function. However, RVD can persist during ECMO, worsening outcomes [7]. As such, aside from vasoactive drugs, other treatments, such as switching to veno-arterial configuration or using a right ventricular assist device (RVAD), have been reported [8]. In the present case, we describe a patient who developed refractory hypoxemia and RVD during

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ECMO that was satisfactorily managed with colocation of the return cannula directed to the pulmonary artery.

2. Case presentation

A 13-year-old child was admitted to the emergency department with a history of dyspnea, dry cough, and fever. He has tachypnea and hypoxemia ($SatO_2$ 60%). He was positive for his real-time reverse transcription polymerase chain reaction test for SARS-CoV-2 RNA. A chest computed tomography (CT) scan showed COVID-19 reporting and data system (CO-RADS) 5 classification and a severity index of 25 points. During admission, the patient required invasive mechanical ventilation with high inspired oxygen fraction levels and positive end-expiratory pressure titration, neuromuscular blockade, and prone ventilation. Despite these therapeutic maneuvers, the patient still had refractory hypoxemia ($SatO_2$ 80%) and hypercapnia, aside from remaining outside the lung protective ventilation goals. Our center was consulted to initiate therapy with VV-ECMO. A double cannulation strategy with a femoro-jugular configuration was performed. A 23 French extraction venous cannula (Medtronic plc., Minneapolis, MN, USA) was inserted through the right femoral vein (FV) directed toward the inferior vena cava (IVC), and a 21 French arterial return cannula (Medtronic plc., Minneapolis, MN, USA) was inserted through the right internal jugular vein (YV) into the right atrium directed toward the tricuspid valve (Fig. 1). We reached a $SatO_2$ greater than 90%, resolved hypercapnia, and achieved lung-protective ventilation goals. During ECMO, the patient had an excessively increased negative pressure of the circuit, with decreased blood flow during VV ECMO and hypoxemia. Hence, a second 23 French venous extraction cannula (Medtronic plc., Minneapolis, MN, USA) was placed through the left FV, directed toward the IVC. His negative pressure levels in the circuit, ECMO blood flow, and oxygenation improved. Throughout the admission, the patient presented with poor pulmonary recovery and refractory hypoxemia despite support with VV ECMO, which prolonged extracorporeal therapy and a need to change the oxygenator multiple times. Prone ventilation, therapeutic hypothermia, beta-blockers (to decrease the patient's oxygen consumption) were also used; all of which showed poor response, especially while the patient was awake. Additionally, a recirculation percentage of 25% was documented; therefore, blood extraction flow was reduced to limit recirculation. Moreover, the patient developed shock, with decreased blood pressure and central venous saturation as well as increased central venous pressure and lactate levels; Thus, a transthoracic echocardiogram was performed, documenting right ventricular dilatation and dysfunction (Fig. 2A). For this reason, inotropic therapy (levosimendan 0.1 μg/kg/min) was started, with a partial response, and was then suspended because the patient developed atrial tachycardia with hemodynamic instability. Given the presence of RVD and refractory hypoxemia, the ECMO configuration was changed to the V-pulmonary artery (V-PA), placing the return cannula in the PA to: (1) improve the patient's refractory hypoxemia by injecting oxygenated blood directly into the pulmonary artery, thereby reducing the degree of recirculation and the venous mixture; and (2) assist the right ventricle by decreasing its pressure and volume load to improve the right ventricular function. The patient was transferred to the hemodynamics department for the procedure. Before starting, the configuration of the VV ECMO was changed from femoro-jugular to femoro-femoral to maintain extracorporeal assistance while the cannula was changed through the right internal YV. A hydrophilic metal wire guide was introduced through the previous return cannula and advanced to the PA under fluoroscopic guidance (Fig. 3A). Then, over the guide, a 5 French multipurpose catheter was advanced (Fig. 3B), through which a Lunderquist extra-stiff wire guide (Cook Medical LLC., Bloomington, IN, USA) (Fig. 3C) was introduced. Then, a 19 French venous cannula (Medtronic plc., Minneapolis, MN, USA) was advanced to the right branch of the PA (Fig. 3D). Afterwards, the patient's systemic oxygenation improved (increase in arterial oxygen content, partial pressure of

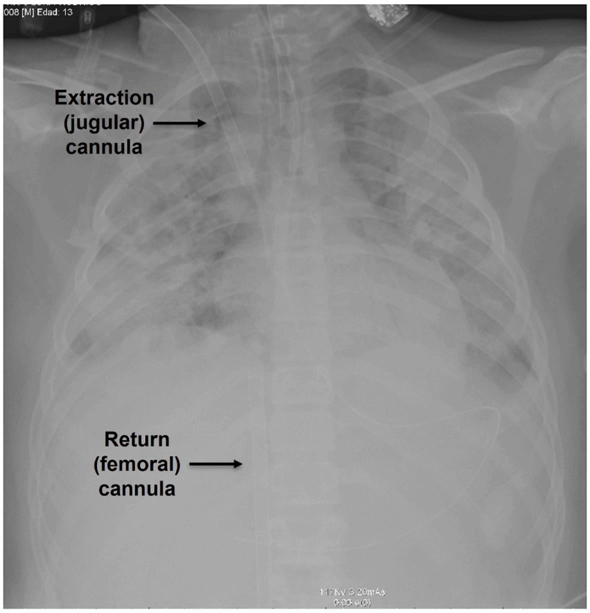

Fig. 1. Chest X-ray showing the extraction (femoral) and return (jugular) cannulas.

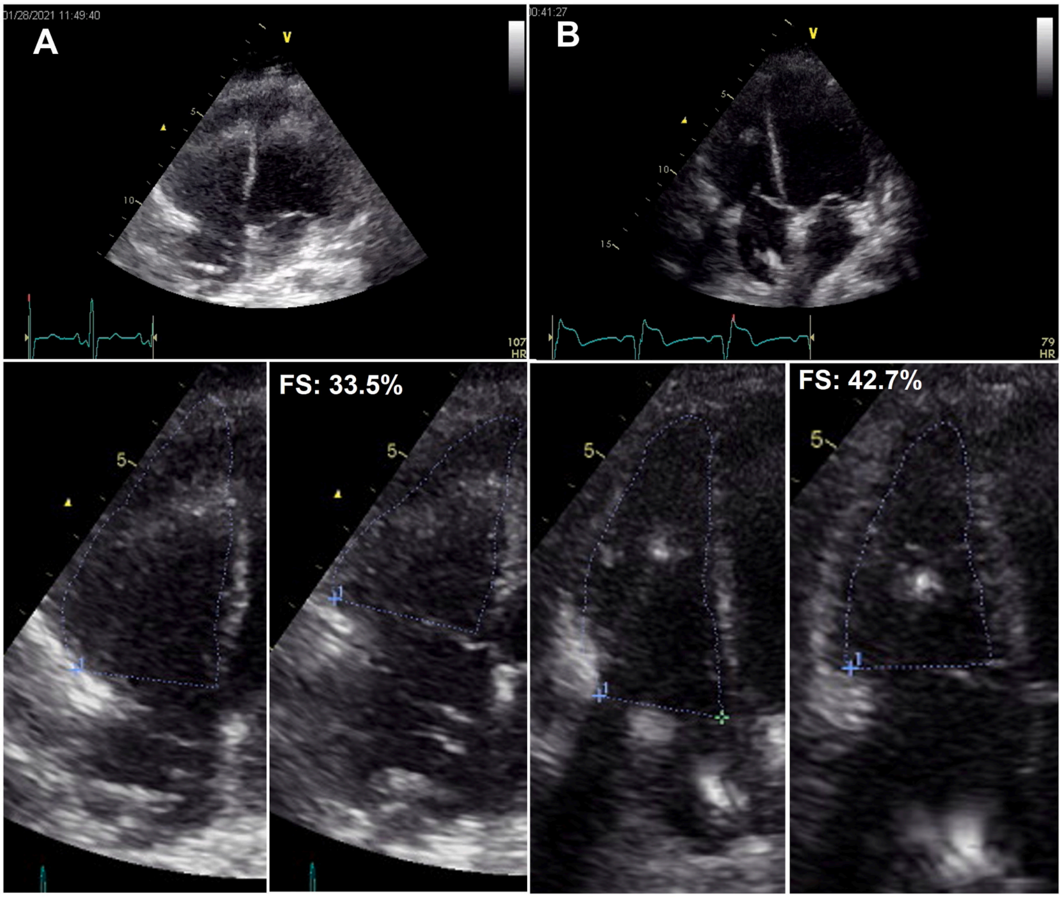

Fig. 2. Transthoracic echocardiogram, apical 4-chamber view. **A:** RV dilatation, with a RV/LV ratio >1 and fractional shortening (FS) of 33.5% (normal ≥35%), confirming RV dilatation and dysfunction. **B:** RV/LV ratio <1 and FS of 42.7%, confirming improving of the RV systolic function. RV: Right ventricle, LV: left ventricle.

oxygen, venous oxygen saturation, arterial oxygen saturation, and cardiac output) and a reduction in the percentage of recirculation and oxygen consumption were noted **(Table 1)**. The diameter of the right ventricle was decreased, and his functional parameters improved (Fig. 2B), with no subsequent requirements for inotropes and maintenance of serum lactate levels below 2 mmol/L.

3. Discussion

3.1. Clinical discussion

Although VV ECMO is increasingly being used in patients with ARDS-associated COVID-19 refractory to conventional treatment, it is a complex therapy that requires a multidisciplinary team. They must address various complications and situations that compromise the life of the patient during the course of treatment. In this case, two scenarios prompted a change in the configuration to V-PA ECMO: (1) the presence of refractory hypoxemia, which was attributed to poor pulmonary recovery; and recirculation, which was generated when a percentage of the oxygenated blood injected by the return cannula was suctioned by the extraction cannula. This prevented the complete passage of oxygenated blood to the right cavities and toward the systemic circulation. There is always some degree of recirculation, but it is acceptable when less than 10% [5]; a situation that could not be reversed in this patient because of the usual maneuvers; and (2) the development of RVD. Despite correcting gas exchange and implementing the least damaging ventilatory parameters with VV ECMO, different mechanisms can affect the right ventricle during extracorporeal therapy, such as pulmonary vascular dysregulation, microvascular thrombosis, atelectasis (whereby extra-alveolar vessel resistance increases), and continuous non-pulsatile flow (especially in cases of prolonged support), as was the case in this patient [7]. Changing the configuration of the extracorporeal therapy by placing the return cannula toward the PA improved the patient's clinical condition for two main reasons: (1) by injecting oxygenated blood directly into the PA, the degree of recirculation was significantly reduced, thereby improving the systemic oxygenation of the patient, as shown in Table 1; and (2) mechanical right ventricular unloading in the context of severe acute respiratory failure combined with extracorporeal oxygenation allows the application of lung and right ventricular protective ventilation. It is important to mention that this strategy has not been classically reported to manage refractory hypoxemia.

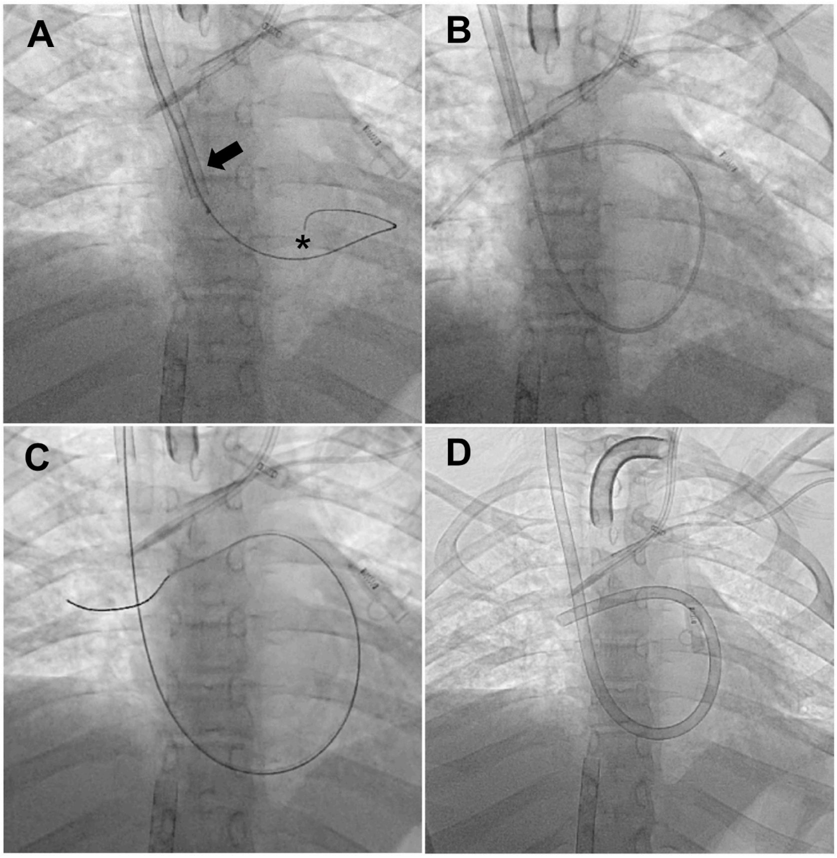

Fig. 3. A: The hydrophilic metal wire guide (asterisk) was introduced through the return cannula (arrow). **B:** A multipurpose catheter was advanced over the hydrophilic guide toward the pulmonary artery. **C:** An extra-stiff wire guide was introduced through the catheter. **D:** A venous cannula was advanced to the right branch of the pulmonary artery over the guide (final position).

Table 1
Gas exchange and systemic oxygenation evaluation before and after cannulation of the pulmonary artery.

Parameter	VV ECMO	V-PA ECMO
CaO_2 (mL/dL)	11.2	13.3
CvO_2 (mL/dL)	9.04	10.1
$avDO_2$ (mL/dL)	2.16	2.2
DO_2 (mL/min)	850	606
VO_2 (mL/min)	182	144
DO_2/VO_2 ratio	4.6/1	4.2/1
Lactate (mmol/L)	2.7	1.1
Oxigenator O_2 delivery (mL/dL)	4.06	3.6
SvO_2 (%)	64	78
ECMO blood flow (L/min)	4.5	4.5
Cardiac output (L/min)	4.9	5.4
Native venous flow (L/min)	0.4	0.9
Recirculation (%)	25	14
PaO_2 (mmHg)	57	78
$SatO_2$ (%)	88	96

VV: venovenous, **V-PA:** veno-pulmonary arterial, **CaO_2:** arterial oxygen content, **CvO_2:** venous oxygen content, **$avDO_2$:** arterial-venous oxygen difference, **DO_2:** oxygen delivery, **VO_2:** oxygen consumption, **SvO_2:** venous oxygen saturation, **PaO_2:** partial pressure of oxygen, **$SatO_2$:** arterial oxygen saturation.
* Oxygen fraction of the ECMO was set to 1.0 (100%) to carry out the gasometric measurements in both cases.

3.2. Brief review of literature

Using RVAD during VV ECMO therapy has recently been evaluated. In one study, the authors used percutaneous RVAD with an oxygenator to support 40 patients with COVID-19 lung and right ventricular injury using a 29 or 31 Fr Protek-Duo right atrium to PA TandemHeart cannula (CardiacAssist Inc., Pittsburgh, PA, USA). Survival to hospital discharge was 73%, although it is unclear whether the outcome benefit can be attributed to mechanical support or the combination of ECMO, early rehabilitation, and pharmacological care [8]. A small retrospective analysis found that using percutaneous RVAD at the time of ECMO initiation may improve mortality in patients with severe COVID-19 lung injury [9]. However, RVADs are expensive and often inaccessible to developing countries. Complications described during cannulation of the PA include extrinsic compression of the right coronary artery [10] and the risk of perforation. In our case, PA cannulation was performed with a conventional extracorporeal circulation venous cannula; therefore, this strategy can be applied in centers with limited resources or where the usual cannulation devices for right ventricular assistance are not available or are scarce, a particularly relevant situation during the pandemic.

4. Conclusions

- Refractory hypoxemia and right ventricular dysfunction can occur during VV ECMO.
- Placing the return cannula in the PA improved oxygenation and right ventricular function.
- This technique can be performed using conventional extracorporeal circulation venous cannulas in the catheterization laboratory under fluoroscopic guidance.

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CRediT roles

GRV: original idea, supervision, review; PCL: conceptualization, image acquisition, writing the original draft, review, and editing; DMS: original idea, conceptualization, image acquisition, writing the original draft, review, and editing; ELD: image acquisition; FDS: supervision and review.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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