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Left atrial decompression during veno-arterial extracorporeal membrane oxygenation using a single multi-stage drainage cannula with a transseptal approach: Clinical significance and medical management of LAVA ECMO

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Abstract

Extracorporeal Membrane Oxygenation (ECMO) is a life-support treatment used in critically ill patients that temporarily acts as the heart and lungs. It is used in numerous clinical scenarios where the patient's heart and/or lungs are too sick to work on their own. With ECMO, a patient's blood is removed from the body and pumped through an artificial lung, where oxygen is added and carbon dioxide is removed. There are two types of ECMO support: VV ECMO and VA ECMO. VV ECMO is used when a patient's lungs need additional support, and VA ECMO is used when a patient's heart and lungs need additional support. Although ECMO therapy can be life-saving, it is a supportive therapy, not a disease-modifying treatment. There are numerous techniques and strategies used to implement ECMO, all in which come with their own risks, complications, and possible emergencies. Cannulation strategy is determined by a multitude of factors, such as materials available, patient presentation, concurrent venous/arterial access, specific patient anatomy, clinical diagnosis, provider training, etc. One major complication specific to VA ECMO is left ventricular overload, which can create a lethal cascade of issues for a patient receiving this mode of support. This manuscript will discuss the products and materials needed, cannulation techniques, configurations, and clinical significance of left atrial veno-arterial extracorporeal membrane oxygenation (LAVA ECMO). We will focus on clinical scenarios that allow for LAVA ECMO and unique considerations for this complex cannulation strategy. Additionally, we will address the use of LAVA ECMO in patients where traditional left atrial venting and decompression techniques are contraindicated. Finally, current data pertaining to patient outcomes related to the use of LAVA ECMO will be discussed in length, giving a synopsis of the benefits of using a single multi-stage drainage cannula with a transseptal approach for left atrial decompression in VA ECMO

Keywords: Extracorporeal Membrane Oxygenation; Venoarterial Extracorporeal Membrane Oxygenation; Extracorporeal Life Support; Mechanical Circulatory Support; Left Ventricular Offloading; Cardiogenic Shock

1. Introduction

The primary objective of this manuscript is to provide a comprehensive review of left ventricular offloading techniques in patients receiving peripheral VA ECMO support in the case of cardiac or circulatory failure. We will explore clinical scenarios where patients can be salvaged using left atrial veno-arterial extracorporeal membrane oxygenation and its superiority to traditional offloading techniques as well as the benefits of using a single multi-stage drainage cannula with a transseptal approach for left-sided cardiac decompression.

2. What is VA ECMO?

VA ECMO is used when a patient needs temporary mechanical circulatory support for the heart. This mode of ECMO provides oxygen-rich blood to the body when the heart is too weak or compromised to do this alone. In more detail, VA

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ECMO provides the patient with oxygenated, or arterialized, blood flow to the systemic circulation in acute and severe cardiac or circulatory failure (Fresiello et al., 2024). VA ECMO enables complete and immediate cardiopulmonary support in the setting of cardiogenic shock and cardiac arrest. It consists of a centrifugal pump capable of propelling up to 8 L/min of blood through the body, a hollow fiber artificial lung that adds oxygen and removes carbon dioxide called an oxygenator, and venous drainage and arterial return cannulas (Tsangaris et al., 2021).

The preferred approach for percutaneous VA ECMO is femoral artery and vein cannulation. In an adult, the tip of an 18-28 Fr cannula draining deoxygenated venous blood is positioned in the mid right atrium (RA) or the superior vena cava-RA junction. After passing through the 'membrane lung,' oxygenated blood is returned to the systemic circulation via a 15-19 Fr arterial cannula with its tip typically positioned in the iliac artery (Tsangaris et al., 2021). It has been described clinically and experimentally that VA ECMO can increase left ventricular mechanical loading. In this context, it is often suggested that the retrograde infusion of VA ECMO-derived blood into the aorta importantly dictates left ventricular overload. This phenomenon is encountered in peripherally cannulated VA ECMO which is the most commonly used technique (Fresiello et al., 2024).

VA ECMO retrograde blood flow can increase aortic root and left ventricular pressure, increase LVEDP, and decrease stroke volume (Jong et al., 2022). This leads us to discuss left ventricular offloading. When LVEDP exceeds 25mmHg, it can deteriorate LV systolic function and decrease antegrade stroke volume. This phenomenon is known as LV overload. LV overload is a critical condition that can cause severe pulmonary edema, refractory ventricular arrythmia, and significant LV stasis (Jong et al., 2022). This complication is one that needs to be identified quickly and intervention is absolutely necessary. LV overload can be identified through bedside echo and LV offloading will need to be implemented.

3. LV Offloading: Who, When, and Why?

Peripheral VA ECMO is limited by the significant increase in afterload because of retrograde aortic flow. Approximately 30-70% of patients treated with VA ECMO develop increased afterload, which is associated with increased mortality. LV unloading in these patients has been associated with a higher rate of recovery or bridge to advanced therapies, more successful weaning from VA ECMO, and lower in-hospital mortality (Ezad et al., 2023). A higher preload may increase left ventricular end-diastolic volume (LVEDV), that should in turn increase stroke volume via the Frank-Starling mechanism. The ability to increase stroke volume by increasing LVEDV is known as the preload reserve, if this is exhausted the LV becomes sensitive to increased afterload particularly in the context of limited contractile reserve (Ezad et al., 2023). The goal of LV unloading is to promote LV recovery, even in those without apparent complication. LV venting in contrast refers to a reduction in left ventricular end diastolic pressure (LVEDP) with the goal of reducing pulmonary congestion, not all patients will therefore require venting in the absence of elevated LVEDP but may still benefit from unloading (Ezad et al., 2023).

Multiple techniques have been proposed to offload the left ventricle (LV) in patients on VA ECMO, including a pigtail catheter in the LV or pulmonary artery, atrial septostomy, and simultaneous mechanical circulatory support such as the intra-aortic balloon pump (IABP) or a percutaneous left ventricular assist device like the Impella. The IABP has remained the most used modality of LV decompression studied in literature because of its ubiquitous availability, ease of insertion, relatively small arteriotomy, theoretical benefit of diastolic augmentation and therefor coronary perfusion, and lastly, the ease of maintenance in the cardiac intensive care unit" (Bansal et al., 2022). The IABP is placed in a standard position in the descending aorta, with deflation in systole decreasing afterload during LV ejection and promoting forward flow through the aortic valve, while inflation in diastole improves coronary blood flow. The IABP provides less unloading compared to an Impella (Ezad et al., 2023).

Even though the IABP is the most used LV offloading device, literature and practice has shown the Impella to be superior. The Impella CP is used for LV unloading, a configuration referred to as ECPELLA. The Impella is usually inserted percutaneously via the contralateral femoral artery to the ECMO outflow cannula, though surgical implantation via the axillary artery and percutaneous transcaval insertion can be considered ECPELLA has been shown to reduce PCWP, improve pulmonary flow by reducing right ventricular afterload, and reduce LV dimensions (Ezad et al., 2023). The combined use of VA ECMO with the Impella percutaneous ventricular assist device (pVAD) or IABP have allowed the medical team to efficiently offload the LV when peripheral ECMO is used, but not every patient is a candidate for these devices.

4. Problems with Traditional LV Venting

There are certain clinical situations where the use of an Impella or IABP are contraindicated therapies. Contraindications to the use of pLVADs such as Impella include mechanical aortic valve replacement, severe aortic regurgitation, LV thrombus, and peripheral vascular disease. Unfortunately, these are common comorbidities in patients suffering cardiac or circulatory failure. Left ventricular thrombus is a potentially life-threatening condition with significant risk of catastrophic embolic events.

Patients with biventricular thrombi can be salvaged by utilizing an advanced cannulation strategy referred to as left atrial venoarterial extracorporeal membrane oxygenation (LAVA ECMO). LAVA ECMO has been described where a multistage venous drainage cannula is placed in the left atrium via transseptal puncture. This allows simultaneous bi-atrial drainage thereby unloading the right and left ventricles, with a reduction of PCWP demonstrated. This approach is particularly helpful in patients with LV thrombus or unilateral peripheral vascular disease that precludes a second large-bore femoral arterial access since the Impella CP device requires large bore access (14 Fr), as well as anticoagulation delivered directly through the device purge solution. The LAVA approach may be the preferred choice in patients with severe aortic stenosis or a mechanical aortic valve replacement, where transaortic device placement is contraindicated (Ezad et al., 2023).

5. Materials Needed

LAVA ECMO utilizes a single cannula (VFEM024, Edwards Lifesciences) with a long fenestrated segment decompressing both the left and right atria. The cannula is inserted using femoral venous access, necessitating transseptal puncture and enabling biventricular support while minimizing arterial access (Singh-Kucukarslan et al., 2021). Having specialty cannulas such as the single multistage drainage cannula needed for LAVA cannulation readily available could be a reason the LAVA technique is not more widely utilized. Transthoracic and transesophageal echocardiography allow to collect detailed anatomical and functional information on the heart's condition. During VA ECMO, echocardiographic investigation should therefore be performed by experienced operators as part of the daily routine and whenever the clinical situation requires it (Fresiello et al., 2024). Having echo available for LAVA cannulation is another reason this technique may not be used as commonly as other offloading techniques.

6. Cannulation Techniques

Percutaneous transseptal venting has a good unloading effect and can reverse LV overload within a few minutes. To prevent LV overload after ECMO activation, some operators insert the ECMO venous cannula to the left atrium (LA) through the fossa ovalis (FO) after atrial septectomy (Jong et al., 2022). Physiologically, the venous draining cannula which passes through the inter-atrial septum and into the left atrium reduces the left ventricular end diastolic volume and pressure, helping to reduce preload as well as left ventricular distension. The volume removed from the drainage cannula is added to the ejection fraction of the left heart through the arterial cannula, thus improving tissue perfusion (Lamastra et al., 2023).

However, the LAVA venous cannula should be inserted in the LA before ECMO activation; LAVA can only be a preventive therapy. Compared with conventional VA-ECMO, in the LAVA mode, more time is required to perform atrial septectomy before venous cannulation. This may be the reason that LAVA-ECMO has not been widely utilized. Therefore, balloon atrial septectomy (BAS) is conducted to create a small atrial septal defect (ASD) in the FO and advance the original ECMO venous cannula (VC) to the LA while VA-ECMO is being conducted. This technique renders LAVA-mode ECMO not only as a preventive treatment but also as a rescue therapy (Jong et al., 2022).

7. Benefits of LAVA-ECMO

Unlike the placement of an IABP or an Impella, which operate on a separate mechanical circuit, LAVA ECMO mitigates the need for additional arterial cannulation. As such, the risk of limb ischemia is reduced. Another advantage of this configuration is that LAVA ECMO allows left-sided decompression at the onset of ECMO initiation (Dulnuan, et al., 2022). When initiating a second device like the IABP or Impella, the patient may experience LV overload during the time between device placements. This is especially true when high ECMO support is needed, which increases the retrograde flow and leads to LV distention much quicker. Also, compared with conventional VA ECMO offloading, LAVA ECMO has a better unload effect (Jong et al., 2022). With the use of a single multistage drainage cannula, more LV offloading can be achieved when compared to an IABP or Impella. This is particularly helpful in cases where high ECMO flow is needed, or severe cardiogenic shock is present.

8. Risks of LAVA-ECMO

Compared with conventional VA ECMO, in the LAVA mode, more time is required to perform atrial septectomy before venous cannulation. This may be the reason that LAVA ECMO has not been widely utilized. In the clinical scenarios involving eCPR or rapidly deteriorating cardiogenic shock, VA ECMO is implemented as quickly as possible. These situations would not be ideal for the use of LAVA ECMO due to the time requirement needed for the atrial septectomy and additional resources that would need to be readily available.

LAVA ECMO requires a transseptal percutaneous cannulation. As with any procedure involving transseptal catheterization, there is the potential of developing a persistent iatrogenic atrial septal defect (ASD) as a complication following this cannulation strategy. It has been shown that larger catheter sizes and more manipulation across the interatrial septum may be associated with an increased incidence of IASD. Since LAVA ECMO is such a new and under-studied cannulation strategy, the clinical significance of persistent IASD following transseptal venting is unknown (Dulnuan et al., 2022). Although an ASD could be repaired through a small minimally invasive procedure, additional procedures increase risk of complication.

9. Conclusion

LAVA ECMO is a cost-effective and convenient procedure for hemodynamic support in patients with high-stage cardiogenic shock. Because of the offloading effect, LAVA ECMO is suitable for patients with risk factors for LV dilation. LAVA ECMO is also a great offloading technique for patients in which traditional LV offloading with additional mechanical circulatory support devices such as IABP and Impella are contraindicated. LAVA ECMO is a relatively new therapy that is still being developed and studied but can be a life-saving treatment modality for many patients on VA ECMO experiencing advanced cardiac or circulatory failure.

Advanced therapies such as complex cannulation strategies require an established ECMO program. Clinical support, unit-based protocols, and ample resources have been proven to help achieve optimal patient outcomes in the ECMO patient population. Having a clear understanding of the vision for the ECMO program is a critical component. With the appropriate foundation in place, LAVA ECMO can ultimately be a technique used more commonly in high-functioning ECMO centers and become a standard practice in LV offloading for patients on VA ECMO.

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Authors short Biography

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