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Hemodynamic Effects of Left-Atrial Venous Arterial Extra-Corporeal Membrane Oxygenation (LAVA-ECMO)

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We report a case of a 59-year-old male in post-myocardial infarction cardiogenic shock undergoing left atrial venous arterial extracorporeal membrane oxygenation (LAVA-ECMO) as a bridge to transplantation. The unique feature of this ECMO configuration is use of a single trans-septal cannula to provide biventricular unloading and use of a single arterial access. *ASAIO Journal* 2021; 00;00–00

Key Words: assisted circulation, heart failure, ventricular assist device, cardiovascular physiology

Cardiogenic shock (CS) occurs in 5%–10% of cases of myocardial infarction (MI) and is accompanied by a 30-day mortality as high as 60%.[1,2] Mechanical circulatory support (MCS) devices have been developed and implemented for CS, including veno-arterial extracorporeal membrane oxygenation (VA-ECMO). One disadvantage of peripheral VA-ECMO is insufficient left ventricular (LV) unloading. Arterial pressurization increases LV afterload, end-diastolic filling pressure, wall stress and myocardial oxygen demand.[3] One strategy to provide LV unloading is to use a left atrial cannula to indirectly unload the left ventricle. Left atrial venous arterial ECMO (LAVA-ECMO) utilizes a single cannula (VFEM024, Edwards Lifesciences, Irvine, CA) with a long fenestrated segment (15 cm) 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 (Figure 1).

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Case Report

A 59-year-old man with a history of 3-vessel coronary artery disease with prior bypass surgery presented with an acute inferior MI complicated by cardiogenic shock and unsuccessful revascularization. An emergent Impella CP (Abiomed, Danvers, MA) was inserted; however, the cardiac index remained only 1.2 L/min/m^2. Echocardiography revealed an LV ejection fraction of 30% with severe functional mitral regurgitation. The patient's hospital course was complicated by incessant ventricular tachycardia, escalating vasopressors and inotropes, and worsening invasive hemodynamics prompting MCS escalation with LAVA-ECMO. Trans-septal puncture using intracardiac echocardiography guidance and balloon septostomy facilitated placement of a VFEM024 24Fr cannula (Figure 2 and Supplemental Video 1 *http://links.lww.com/ASAIO/A757*). Anti-Xa were maintained at 0.3–0.7 with unfractionated heparin. LAVA-ECMO decreased the mean pulmonary artery pressure from 38 mm Hg to 10 mm Hg and increased the CI from 1.8 to 5.1 L/min/m^2 (Table 1).

Five days after cannulation, multiple attempts to wean LAVA-ECMO failed. When clamped, the mean pulmonary artery pressure would increase significantly accompanied by cardiac index decrease (Table 1). After two failed weans, the patient was listed for orthotopic heart transplantation and ultimately received a donor heart 11 days after LAVA-ECMO insertion.

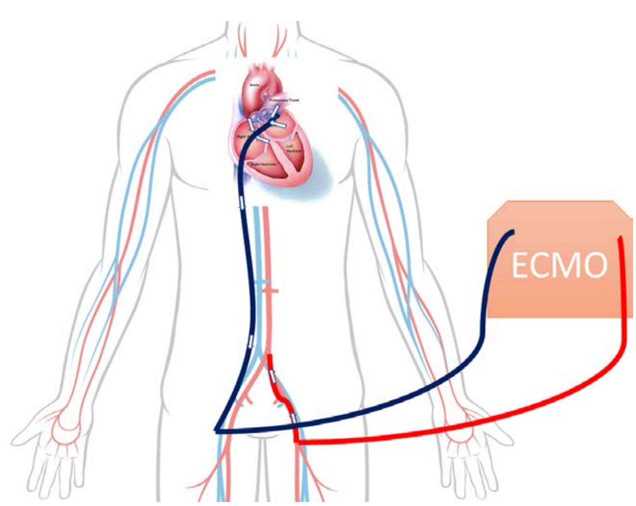

Figure 1. Schematic of the transseptal configuration for LAVA-ECMO. A long cannula that is fenestrated for a length of 30 cm is inserted across the atrial septum from the right femoral vein. This cannula draws blood from the left and right atrium simultaneously takes it through the ECMO circuit to be oxygenated, and then returns the blood to the femoral artery.

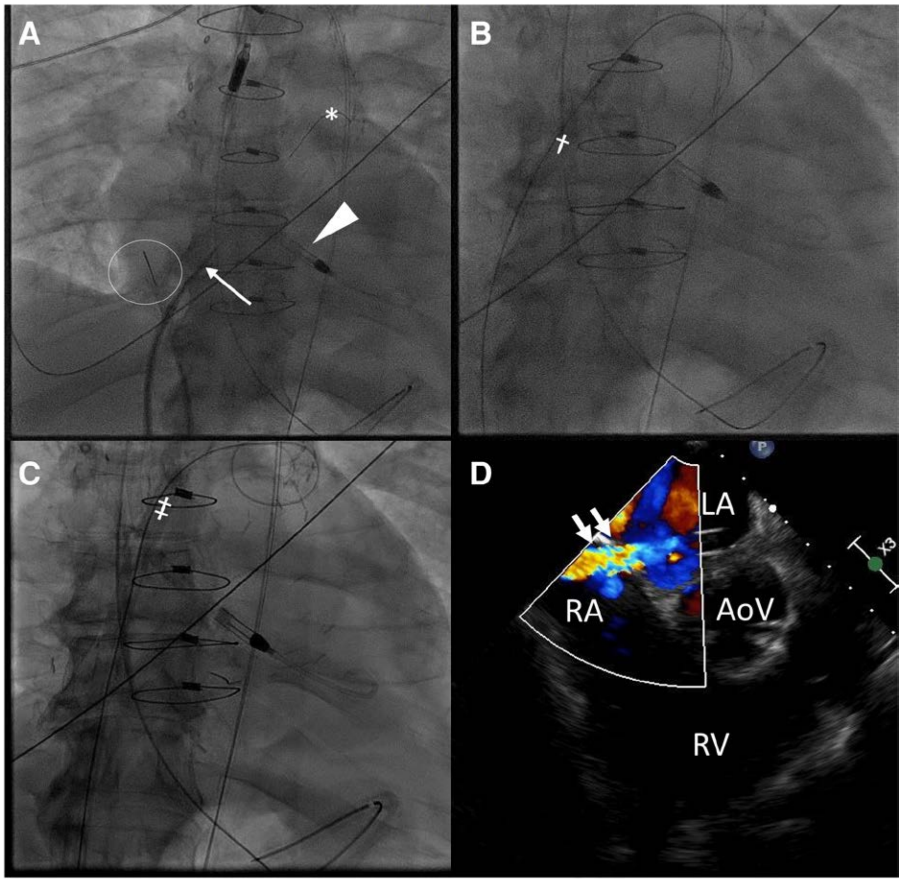

Figure 2. Process of transseptal access and insertion of the VFEM024 cannula across the atrial septum to provide left and right-sided unloading for ECMO. (A) Intracardiac echocardiographic (Circle) guided transseptal puncture using a transseptal crossing system (arrow). A 0.014" Grandslam guidewire (*)provide support for catheter traversal of the interatrial septum. An Impella CP is still supporting the patient. (B) Balloon dilation of the interatrial septum using an 8 × 40 mm Armada peripheral balloon (dagger)(Abbott Vascular, Santa Clara, CA) to facilitate cannula traversal. (C) Insertion of a 24Fr VFEM024 (double dagger) (Edwards Lifesciences, Irvine, CA) across the atrial septum. (D) Transesophageal echocardiography visualizing the transseptal cannula (double arrow) withdrawing blood from both the left and right atrium simultaneously. AoV, aortic valve; LA, left atrium; RA, right atrium; RV, right ventricle

Discussion

This case illustrates the merits of using LAVA-ECMO in biventricular dysfunction. Several key steps improved the likelihood of a good outcome including (1) early recognition of worsening perfusion (2) use of invasive hemodynamics to cater therapy to a patient-specific phenotype (3) early escalation of MCS allowing for biventricular support using single arterial access reducing the risk of vascular access complication.

Ventricular load as demonstrated by an elevated left ventricular end-diastolic pressure is associated with myocardial ischemia, reduced myocardial salvage and increased risk

Table 1. Hemodynamic Characteristics of LAVA-ECMO from the Time of Cannulation, Device Weaning Trials Until Time to Transplantation

	Baseline	Post-LAVA	Day 1	Day 5	Clamp Challenge day 5	Day 6	Day 11
LAVA-ECMO Flow (L/min)	NA	4	4	4	3.5	4	3.5
SvO2 (%)	49.5	77.2	73.9	64.2	74	62.7	61.2
FICK CI (L/min./m^2)	2.09	5.14	4.5	3.3	4.6	3.1	3.3
PCWP	30	22	–	–	–z	–	–
PA systolic (mm Hg)	54	36	33	36	74	33	53
PA diastolic (mm Hg)	25	18	23	19	31	18	25
PA mean (mm Hg)	38	26	27	21	45	23	37
CVP (mm Hg)	12	11	11	5	10	8	10
Hemoglobin (g/dL)	9.2	8.2	8.4	7.8	7.8	7.9	7.3
Platelets (K/uL)	248	204	188	125	125	121	156
BUN (mg/dL)	24	25	21	36	36	36	26
Creatinine (mg/dL)	1.00	1.04	1.09	1.16	1.00	1.00	0.75
Total Bilirubin (mg/dL)	0.5	–	–	–	–	–	0.9

Immediate jump in pulmonary pressures with the LAVA-ECMO circuit clamped and increase in pulmonary artery pressures when the mechanical support is partially weaned to 3.5 L/min of flow (day 11).

Table 2. Comparison of Alternative Mechanical Circulatory Support Strategies for Biventricular Failure when Impella CP is Insufficient

Action	Result	Access	Advantage	Disadvantage
Upgrade to Impella 5.0 or LD (5.5)	Increase of left-sided cardiac output may potentially address biventricular failure depending of degree of right ventricular dysfunction	• Transaxillary (surgical cut down) • Transcaval (Impella 5.0 only)	• Simpler to use one device • Direct LV unloading • Appropriate temporary bridging device	• Requires an arterial access >21 Fr • Hemolysis risk • Catheter instability risk • Will not address right ventricular dysfunction
Addition of venous-arterial ECMO	Unload left and right heart	• 2 large-bore arterial • 1 large-bore venous	• Complete biventricular support • Direct LV unloading • Appropriate temporary bridging device • Technical feasibility reasonable	• Large bore access burden • Hemolysis risk • Catheter instability risk
Upgrade to LAVA-ECMO	Unload left and right heart	• 1 large bore arterial • 1 large bore venous	• Complete biventricular support • Appropriate temporary bridging device • Single large-bore arterial access	• Indirect LV unloading • Transseptal access • Technically more challenging
Urgent BIVAD insertion	Complete left and right-sided support	• Open sternotomy	• Definitive biventricular support • Possible to be ambulatory • Bridging or destination therapy	• Frequently unavailable • Inappropriate for acute decompensation • Long post-operative recovery
Cardiac Transplantation	Definitive treatment for biventricular heart failure	• Open sternotomy	• Definitive treatment	• Rarely available in acute decompensation • Process for transplantation evaluation often long

of mortality. Strategies to reduce ventricular load have correlated with improved outcomes. Russo *et al*. performed a meta-analysis demonstrating the use of LV venting was associated with decreased mortality (OR 0.79 [95%CI 0.72–0.87] $P < 0.00001$), but higher rates of hemolysis.[4] Al-Fares *et al*. performed a meta-analysis demonstrating that LV unloading improved the ability to wean from MCS (OR 0.62 [0.47–0.83] $P = 0.001$); however, survival was similar in both groups.[5] Schrage *et al*. evaluated the use of Impella to provide LV unloading when using VA-ECMO. The investigators showed a mortality reduction with LV unloading when compared to VA-ECMO alone (47% *vs*. 80%, $P < 0.0001$). Importantly; however, the risk of bleeding and access site-related ischemia were significantly higher in those treated with Impella.[6] LAVA-ECMO is ideally suited in such patients as it uses single arterial access and provides biventricular support (Table 2).

Strategies to provide LV unloading include left atrial septostomy[7] and direct left atrial cannulation.[8] Kotani *et al*. reported a 6-year experience in which 12.9% of pediatric patients requiring VA-ECMO underwent left-sided decompression.[8] In this cohort, 70% were decannulated and 52% of patients survived.[8] Our configuration differs by using a single cannula to unload the left and right side of the heart. LAVA-ECMO is limited by the technical expertise required for transseptal puncture and possible need for septal closure post-decannulation. Left-to-right shunting would render pulmonary artery mixed venous readings misleadingly high, complicating management. Furthermore, significant left-to-right shunting could worsen right ventricular failure and tricuspid regurgitation while right-to-left shunting may cause hypoxia. It is unclear if indirect unloading of the ventricle through atrial decompression is more effective than direct ventricular unloading as seen in axial flow pumps (*e.g.,* Impella). While the data shown suggests biventricular unloading is occurring, further hemodynamic studies and continuous wave Doppler interrogation of the trans-septal ECMO flow will be needed to confirm unloading. Finally, there are no dedicated devices for unloading the left and right side of the heart simultaneously and field is in need of properly designed cannulas.

Conclusions

We report the successful use of LAVA-ECMO as a bridge to cardiac transplantation. LAVA-ECMO provides biventricular hemodynamic support using a single arterial access without the need for additional MCS devices. Consideration for the use of LAVA-ECMO should occur in tertiary centers with experienced ECMO programs. Further studies are needed to study the safety and efficacy of such a strategy across a more generalizable population. To our knowledge, this is the first reported case utilizing LAVA-ECMO as a bridge to transplant.

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