Journal of The Cardiovascular Thoracic Anaesthesia and Intensive Care Society

GKDA Derg 2024;30(2):53-59
Doi: 10.14744/GKDAD.2024.17048

REVIEW

Importance of Echocardiography in Patients Supported by Extracorporeal Membrane Oxygenation

Türkan Kudsioğlu

[1]**Department of Anesthesiology and Reanimation, University of Health Sciences, Dr. Siyami Ersek Thoracic and Cardiovascular Surgery Training and Research Hospital, İstanbul, Türkiye**

ABSTRACT

ECMO is a mechanical support system applied in cases of severe heart and/or lung failure unresponsive to all treatments. The use of ECMO is increasing. Technological advancements in ECMO systems (oxygenator, pump, cannula systems, and cannulation techniques), careful patient selection, and the use of echocardiography (ECHO) contribute to improving survival rates. Additionally, the establishment of ECMO teams and increased experience in this field have also enhanced its applications. Knowledge of ECMO indications and contraindications, technical and intraoperative anesthesia management, and potential complications necessitates collaborative implementation in the operating room, intensive care unit, or during the e-CPR process. This review emphasizes the importance and guidance of transthoracic and transesophageal echocardiography (TTE and TEE) in peripheral or central ECMO applications, including ECMO cannulation, hemodynamic monitoring, and separation processes.

Keywords: Cardiac surgery, echocardiography, extracorporeal membrane oxygenation, intensive care

Please cite this article as: "Kudsioğlu T. Importance of Echocardiography in Patients Supported by Extracorporeal Membrane Oxygenation. GKDA Derg 2024;30(2):53-59".

Introduction

ECMO therapy includes veno-venous (VV) ECMO for damaged lungs, short-term cardiac support, and veno-arterial (VA) ECMO as a bridge to transplantation. ECMO indications and contraindications are defined in the "Extracorporeal Life Support Organization (ELSO)" guidelines.[1]

VV ECMO Indications:

- Hypoxic respiratory failure (such as ARDS),
- Mortality risk exceeding 50% (PaO_2/FiO_2<150, FiO_2>0.9, or Murray score 2–3) and mortality risk exceeding 80% (PaO_2/FiO_2<80, FiO_2>0.9, or Murray Score 3–4),
- Hypercapnia and acidosis despite adequate mechanical ventilation support (plateau airway pressure>30 cm H_2O),
- As a bridge to lung transplantation or post-transplantation,
- In cases of respiratory collapse despite optimal conventional therapy.

VA ECMO Indications:

- ECMO may be applied with an intra-aortic balloon pump (IABP) in reversible cardiogenic shock despite optimal medical therapy,
- In post-cardiotomy cases,
- Cardiac arrest: Following the latest American Heart Association (AHA) guidelines for CPR,
- As a bridge to transplantation or ventricular assist devices.

Contraindications:

- Serious neurological damage, intracranial hemorrhage, inoperable malignancy, severe immunosuppression, irreversible multi-organ failure, or poor prognosis for chronic diseases,
- Aortic dissection and severe aortic insufficiency,
- Partial contraindication in patients with prolonged ventilation therapy under high airway pressure in ARDS,
- In patients with prolonged cardiac arrest, not candidates for VAD or transplantation, and suboptimal CPR,

Address for correspondence: Türkan Kudsioğlu, MD. Sağlık Bilimleri Üniversitesi, Dr. Siyami Ersek Göğüs Kalp ve Damar Cerrahisi Eğitim ve Araştırma Hastanesi, Anesteziyoloji ve Reanimasyon Kliniği, İstanbul, Türkiye

Phone: +90 216 542 46 13 **E-mail:** turkancoruh@gmail.com

Submitted: May 28, 2024 **Accepted:** May 29, 2024 **Available Online:** June 10, 2024

The Cardiovascular Thoracic Anaesthesia and Intensive Care - Available online at www.gkdaybd.org

- In elderly patients: Controversial, but can be used with advancements in technology and reduced complications,
- Partial contraindication in patients with obesity or contraindication to anticoagulation.

VV ECMO: Both inlet and outlet cannulas are placed into a systemic vein. It does not directly support cardiovascular function but facilitates the return of oxygenated blood to the lungs. Oxygenated blood from the outlet cannula mixes with systemic venous blood in the pulmonary artery and returns from the lungs. SaO_2 is provided by ECMO flow, determined by pulmonary residual function, the systemic venous return of the patient, systemic venous blood oxygen saturation (SvO_2), and the degree of recirculation. An SaO_2 above 85% is considered successful with minimal or even no pulmonary function (Table 1).[2]

VA ECMO: Used in the treatment of temporary cardiogenic shock or cardiopulmonary failure. Similar to the standard cardiopulmonary pump (CPB), it takes blood from the venous system via the inlet cannula and delivers it to the arterial system after oxygenation through the outlet cannula. The systemic arterial blood flow equals the ECMO circulation flow plus the flow generated by the left ventricle. Inadequate left ventricular ejection fraction (EF) results in SaO_2 being solely dependent on ECMO outlet cannula flow (Table 1).[2]

Cannulation Strategies: Cannulations are performed percutaneously and surgically. Percutaneous cannulation is a less invasive technique. The cannula site and vessel diameter are evaluated using USG and ECHO (Table 2).[2] The most common cannulation in adults for peripheral ECMO is femoro-femoral. Other approaches include the axillary artery and carotid artery. A general rule in cannula selection is that the diameter of the cannula should not exceed two-thirds of the vessel diameter. Optimal ECMO cannula position is determined by ECHO. In peripheral VV-ECMO, the femoral vein/jugular vein and femoral vein are typically used (Fig. 1). In peripheral VA ECMO, the inlet cannula is advanced through the femoral vein to the inferior vena cava and right atrium (mid-portion) (Fig. 1d).[3,4] The other cannula is advanced from the femoral artery to the aortic valve. After air removal, the cannulas are connected to the ECMO circuit. It is the fastest application for bridging to heart transplantation or left ventricular mechanical support devices. Surgically recommended cannulation is femoral or axillary.

Central Cannulation in VA-ECMO: A larger inlet cannula is placed into the right atrium, and an outlet cannula is placed into the ascending aorta. Flow is antegrade, and upper body hypoxia should be avoided. Central ECMO is applied in patients who cannot be weaned from CPB after cardiac surgery.[2,5]

Anesthetic Approach: The aim of anesthesia management in ECMO monitoring is to maintain cardiac and pulmonary balance. The patient is clinically monitored using advanced hemodynamic monitoring and ECHO.

Complications: Complications such as bleeding, hemolysis, thromboembolic events, limb ischemia, mechanical failure (oxygenator, cannula, and device thrombosis), rarer intracerebral hemorrhage, circuit disconnection, decannulation, and air embolism can occur.

In ECMO application, TTE and TEE ECHO are crucial for indicating ECMO, verifying cannula positions, and guiding ECMO decannulation. They provide hemodynamic monitoring, facilitate the detection of complications, and demonstrate cardiac functions during separation (Table 2).[4,5]

Pre-ECMO ECHO: The indication for ECMO and the decision between VV or VA ECMO are made based on etiology and comprehensive ECHO findings (Table 2). Systolic functions of the right (RV) and left (LV) ventricles, EF, regional wall motion abnormalities, and valve functions should be assessed, and the presence of PFO (Patent Foramen Ovale) should be checked (Figs. 2, 3).[5,6]

RV failure signs include RV dilation, resulting in the interventricular septum causing the LV to take on a D-shaped appearance with an eccentricity index greater than 1 (Fig. 4), and significant tricuspid regurgitation (TR) (Fig. 3b). RV systolic functions are evaluated using tricuspid annular plane systolic excursion (TAPSE) (normal>16), right ventricle FAC (fractional area change) (normal %35–60) (Fig. 3a), and tricuspid annular systolic peak velocity (S') measured using tissue Doppler imaging. Pulmonary artery systolic pressure is calculated from the TR jet using the simplified Bernoulli equation, which equals the right ventricular systolic pressure (Fig. 3b). Tricuspid valve pathologies should be evaluated; tricuspid stenosis can jeopardize the flow of oxygenated blood from the right atrium (RA) to the RV, while tricuspid regurgitation increases left atrial (LA) pressure and can lead to right-to-left shunting and hypoxia during ECMO separation, especially in the presence of ASD or PFO. Congenital variations such as Chiari network and persistent left superior vena cava (LPVCS) are evaluated in RA. LPVCS dilates the coronary sinus and may cause problems during cannulation. Pericardial fluid should be examined, particularly in cases of heart failure.[4,6]

LV failure signs include LV size, global and regional functions. LV wall thickness, LA dilation, chronic LA, and LVDP elevation are indicative. Global LV systolic function is evaluated using EF via the modified Simpson method (Fig. 2). EF is less than 20% in severe systolic dysfunction and is an indication for VA ECMO. When assessing the aortic valve, if aortic regurgitation (AR) is present during VA ECMO, it leads to an increase in LV afterload and dilation, resulting in pulmonary edema. Myocardial oxygen consumption and wall tension increase, and the risk of subendocardial ischemia develops. Additionally, aortic dissection is a contraindication for VA ECMO. Significant mitral regurgitation can lead to pulmonary edema.[7]

Table 1. VA ECMO and VV ECMO features

ECMO	V-A	V-V
Patient	There is/is no respiratory failure with HF	Hypoxic patient with cardiovascular component
	Inotrope or IABP unresponsiveness	O_2 problem resistant to conventional treatment
		High CO, often due to sepsis or infection
Cardiac effect	Reduces preload	RV Right afterlod may be reduced or not affected
	Increases afterload	With hyperoxia, PVR decreases and CO improves
	Pulse pressure: Reduces	
	LV blood desaturates	
	RV Right afterlod may decrease or not affect	
	With hyperoxia, PVR decreases and CO improves	
Circuit	Parallel	Series
Flow/target	3 L/m^2/min, SvO_2 >70%.	60–80 ml/kg/min
Circulation	Partial/ Full	Non-direct support
Condition	Cardiogenic shock (ACS, refractory arrhythmia, myocarditis, pulmonary embolism, sepsis, drug toxicity, isolated cardiac trauma, acute anaphylaxis)	ARDS (severe bacterial or viral pneumonia, aspiration syndrome, pulmonary alveolar proteins)
	Post cardiotomy	In the perioperative period of lung transplantation
	After heart transplant	Lung hyperinflammation: status astmaticus
	Chronic cardiomyopathy	Pulmonary hemorrhage, or diffuse hemorrhage
	High risk initiatives also for support	
	Bridge to transplantation	

VA: Veno-arterial; ECMO: Extracorporeal Membrane Oxygenation; VV: Veno-venous; HF: Heart failure; IABP: Intraortic balloon pump; O_2: Oxygen; CO: Cardiac output; RV: Right ventricle; LV: Left ventricle; PVR: Pulmonary vascular resistance; SvO_2: Oxygen saturation; ACS: Acute Coronary Syndrome; ARDS: Acute Respıratory Dıstress Syndrome.

Table 2. ECHO (TTE/TEE) evaluation before ECMO application

TTE/TEE	Left ventricle	Right ventricle
Morphology	Size, wall thickness	RV end diastolic area/LV end diastolic area
		Triangular shape versus rounded shape of apex,
		RV wall thickness
Systolic function	EF (Simpson's method) or FAC	TAPSE, TDI at tricuspid annulus, S wave
	Wall motion abnormalities	FAC
	S wave at mitral annulus	PWD through PV (acceleration time / biphasic pattern)
	Velocity time integral in LVOT	
Diastolic	Diastolic function E/A ratio	E/A trans-tricuspid flow
Function	E/e' ratio at mitral annulus	regurgitation Estimation of RVSP
	Left atrium	**Right atrium**
	Size and volume	Size and volume
		Dilated coronary sinus
		Chiari network
Valves	Diagnosis and quantification of aortic/mitral/ tricuspid regurgitation/stenosis	
Interventricular septum	Presence of paradoxical septum	
	Eccentricity index	
Interatrial Septum	PFO CFD ± bubble study	
IVC/SVC	Size and respiratory variation	
Vascular	Thrombosis/stenosis/aortic dissection/severe atheroma	

ECHO: Echocardiography; TTE: Transthoracic echocardiography; TEE: Transesophageal echocardiography; ECMO: Extracorporeal Membrane Oxygenation; RV: Right ventricle; LV: Left ventricle; EF: Ejection fraction; FAC: Fractional area change; TAPSE: Tricuspid annular plane systolic excursion; TDI: Tissue Doppler Image; PWD: Pulse Wave Doppler; LVOT: Left Ventricular Outflow Tract; RVSP: Right Ventricular Systolic Pressure; PFO: Patent Foramen Ovale; CFD: Color Fow doppler; IVC: Inferior Vena Cava; SVC: Central Venous Pressure.

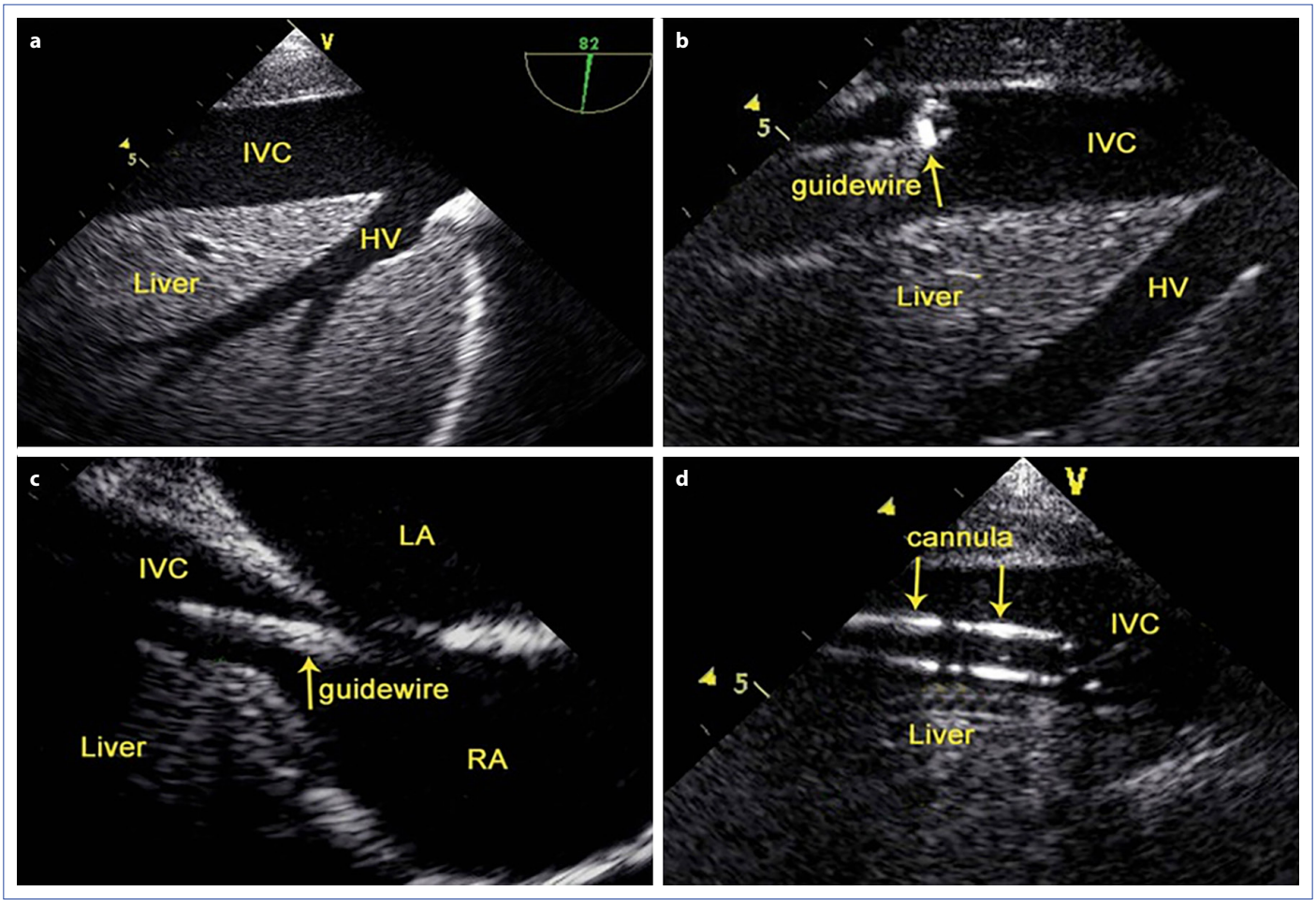

Figure 1. TEE-Guided Cannulation of the Inferior Vena Cava: **(a)** the intrahepatic IVC view; **(b)** TEE shows the guidewire in the IVC; **(c)** TEE shows the guidewire in the RA; **(d)** TEE shows the cannula in the IVC. HV hepatic vein, IVC inferior vena cava, LA left atrium, LV left ventricle, RA right atrium.

IVC: Inferior Vena Cava; LA: Left atrium; RA: Right atrium; TEE: Transesophageal echocardiography; HV: Hepatic vein; LV: Left ventricle.

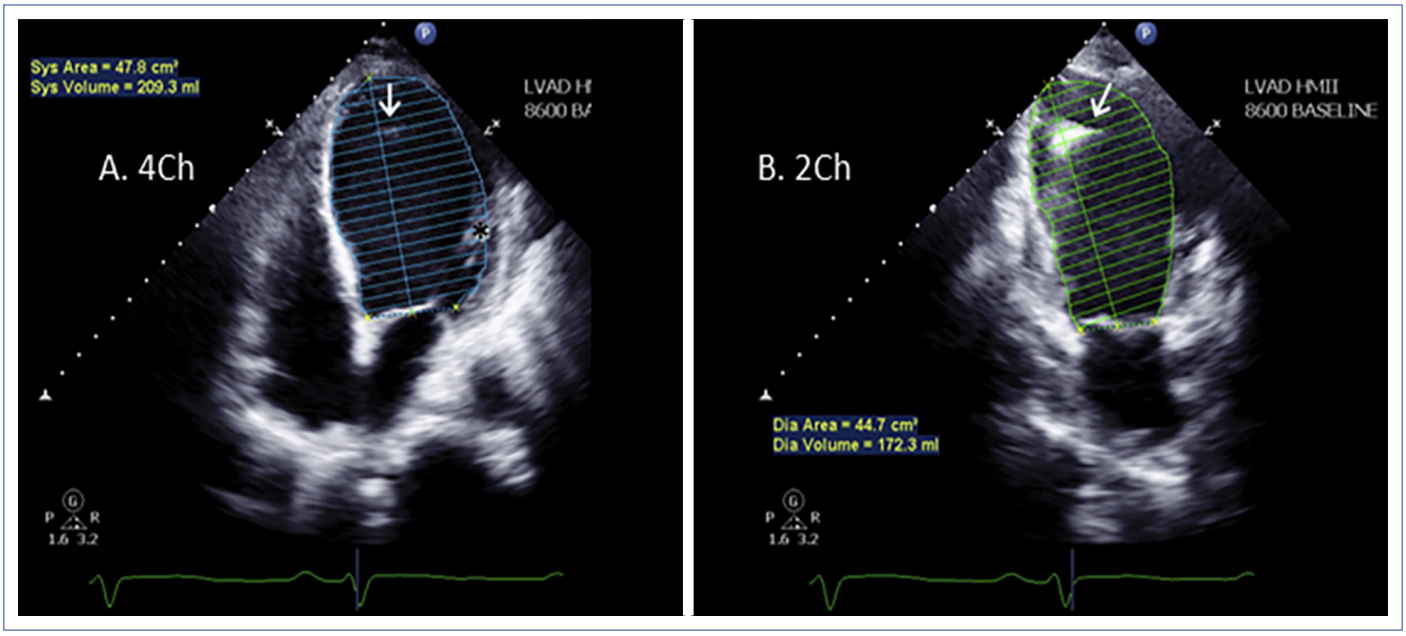

Figure 2. TTE view; LV Functions are evaluated with EF (Simpson's method's).

LVAD: Left ventricle anterior diameter; TTE: Transthoracic echocardiography; LV: Left ventricle; EF: Ejection fraction; Ch: For chamber.

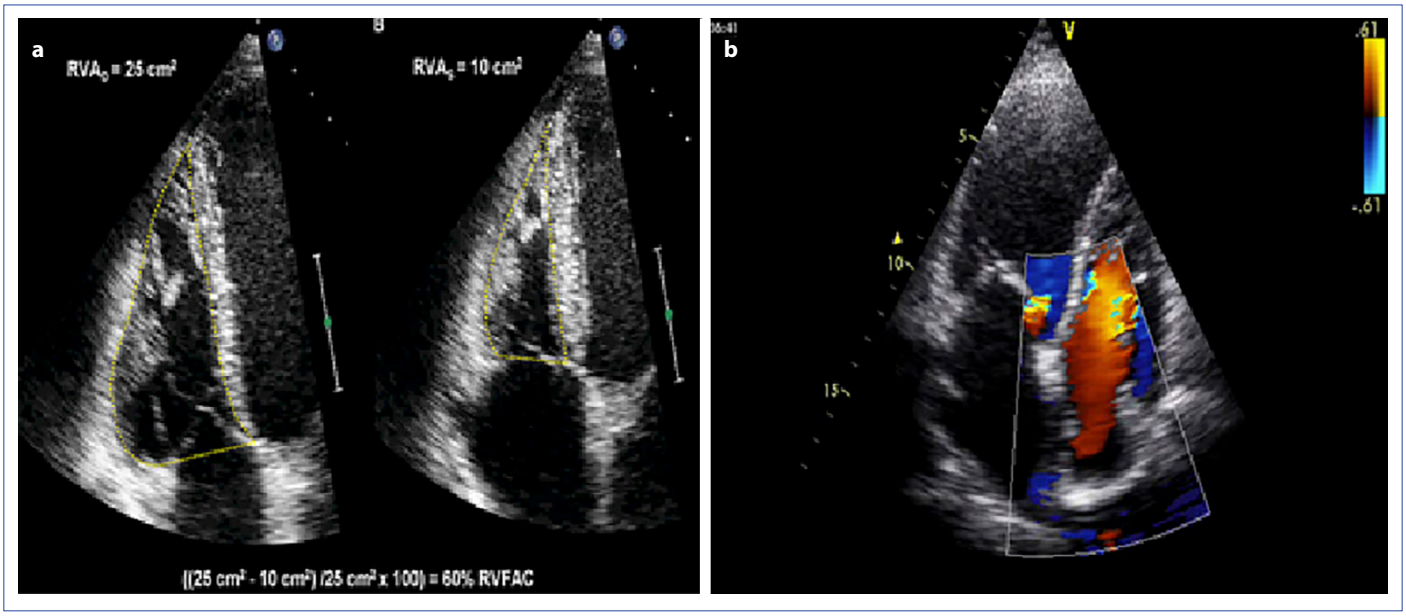

Figure 3. TTE (Apical 4 Ch view). **(a)** Right ventricle, FAC (fractional area change); EDA (End diastolic Area)-ESA (End systolic Area)/EDA, (Normal 35-60%). **(b)** Tricuspid regurgitation, RVSP (Right ventricle Systolic Pressure)=SPAP (Systolic Pulmonary Arteial Pressure): 4VTR2+RAP
RVA: Right Ventricular Area; TTE: Transthoracic echocardiography; 4VTR2+RAP: 4(Tricuspid Regurgitant Velocity)2+Right Atrial Pressure.

During ECMO, ECHO: In VV ECMO, it reduces PVR and corrects RV functions and respiratory data in patients undergoing VV ECMO. However, RV failure may not immediately improve, and VA ECMO may be required when LV functions begin to deteriorate. During ECMO support, because drainage of blood from the RA to the RV and the pressure gradient between the RV and RA may change, RV systolic pressure and TR may not be accurately evaluated. If the inlet cannula is too proximal to the right atrium and close to the outlet cannula, hypoxia may result from recirculation. Malposition is corrected by ECHO.[7,8]

In VA ECMO, cardiac hemodynamics and ECMO response are monitored daily using ECHO, as other methods (thermodilution technique, pulse contour analysis method) are not reliable for assessing cardiac output. RV and LV sizes are monitored for the adequacy of cardiac emptying. Additionally, the opening of the aortic valve is crucial. In peripheral VA ECMO, retrograde aortic blood flow is affected by left ventricular stroke volume. Closure of the aortic valve will lead to LV distension and hence thrombosis (SEC image). If aortic valve insufficiency is present, increased afterload AR may lead to LV distension, myocardial ischemia, and pulmonary edema. In this case, LV decompression under TEE ECHO guidance is required. Several methods have been described: surgical approach with minimal invasive thoracotomy (from LV apex or LA vent application), percutaneous approaches via pulmonary artery or aortic valve, placement of the Impella® device peripherally, or septostomy can be performed. Monitoring biventricular functions with ECHO allows early detection of recovery (Table 3).[9,10]

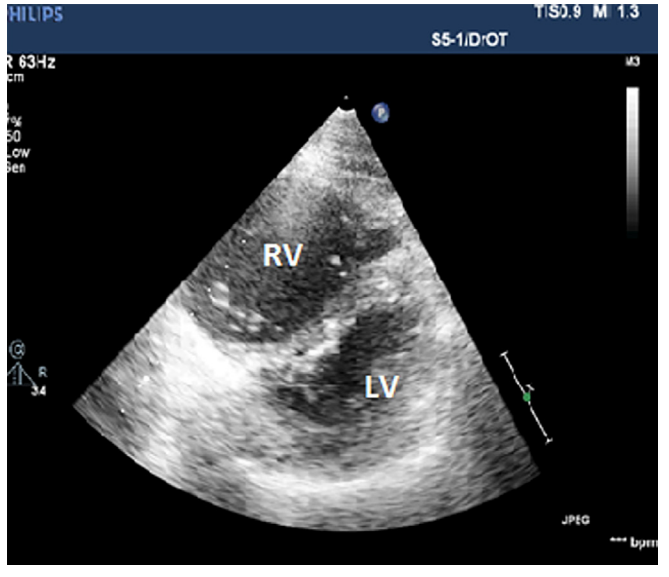

Figure 4. TEE (Transgastric short axes viev; interventriküler septum, LV creating a D-shaped LV with an eccentricity index greater than 1).
TTE: Transthoracic echocardiography; RV: Right ventricle; LV: Left ventricle.

ECMO Complications: It may occur especially due to situations such as decreased ECMO flow, intracatheter thrombosis, or displacement of the bicaval double lumen venous cannula (Fig. 5). This condition can lead to severe hypoxia and must be corrected with ECHO. Pericardial effusion and tamponade may develop due to bleeding. If sufficient images cannot be obtained with transthoracic echocardiography (TTE), transesophageal echocardiography (TEE) can be performed (Table 4).[6–8]

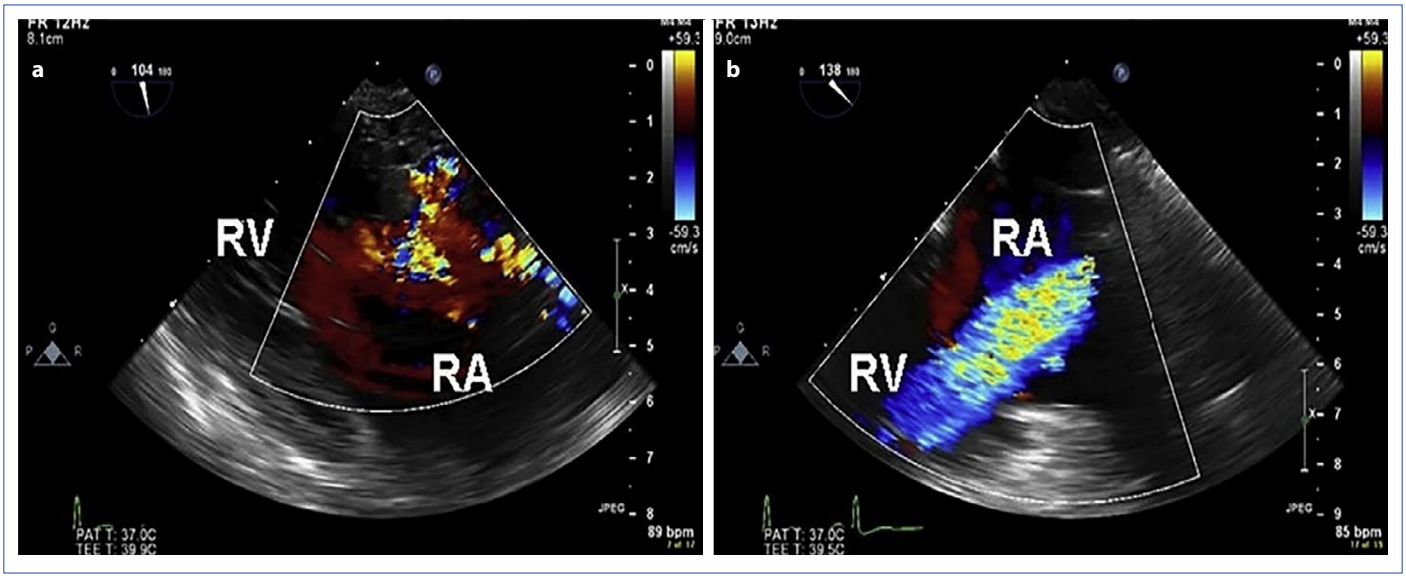

Figure 5. (a) TEE (Transgastric right ventricle inflow view - turbulent outflow towards the posterior leaflet. **(b)** After the cannula position is corrected; ME modified BC (Mid eosophageal bicaval view - laminar flow TV corrected correctly.

TTE: Transthoracic echocardiography; ME: Mid Eesophageal; RV: Right ventricle; RA: Right Atrium.

Table 3. Evaluation of response to ECMO treatment with ECHO

	Status	ECHO
Peripheral VA ECMO	<Preload (< blood flow) >Afterload	LV distension/ECHO contrast
	Severe LV dysfunction and MR	AV not opening
Peripheral VV ECMO	LV preload does not change >Mixvenous SO_2	Improvement of LV function
	Improvement of O_2 circulation	

ECMO: Extracorporeal Membrane Oxygenation; ECHO: Echocardiography; VA: Veno-arterial ; LV: Left ventricle; MR: Mitral regurgitation; AV: Aortic valve; VV: Veno-venous; Mixvenous SO_2: Mixvenous oxygen saturation; O_2: Oxygen.

Table 4. Evaluation of complications developing in ECMO treatment with ECHO

Tamponade	Heart filling and functions are checked
	Pericardial effusion may be difficult to identify as significant
	Hemodynamics may not necessarily be affected
Thrombosis and	Cannula flow is checked
Vascular occlusion	Important for weaning from ECMO
Cannula malposition	SVC syndrome or thrombosis?
	Thrombus may remain after cannula removal
	Cannula site position is checked with TTE

ECMO: Extracorporeal Membrane Oxygenation; ECHO: Echocardiography; SVC: Central Venous Pressure; TTE: Transthoracic echocardiography.

Weaning ECMO: The arterial wave must be pulsatile and hemodynamic, clinical, and echocardiographic findings must be stable. There is no need to reduce ECMO flow during the weaning process from VV ECMO support. However, it is important to reduce gas flow in the ECMO circuit and regulate it according to oxygenation and ventilation. Right ventricular (RV) functions should be evaluated with ECHO. This process may cause hypercapnia, RV failure, pulmonary hypertension, and reopening of the patent foramen ovale (PFO) (Table 5).[11]

Table 5. Weaning from ECMO is managed with ECHO and also with PAC (if a pulmonary artery catheter is inserted)

Cardiac recovery	Left ventricular EF 35–40%
	LVOT velocity-time integral >10 cm
	If there is no left ventricular dilatation
	If there is no tamponade

ECMO: Extracorporeal Membrane Oxygenation; ECHO: Echocardiography; PAC: Pulmonary Artery Catheter; EF: Ejection fraction; LVOT: Left ventricular outflow tract.

During the weaning process from VA ECMO, weaning from ECMO occurs by reducing the flow in 0.5 to 1.0 L/min increments according to cardiac recovery and without dropping the flow below 1 to 2 L/min to avoid circuit thrombosis. In this process, with continuous TEE ECHO and minimal ECMO support, the aortic velocity-time integral must be greater than 10 cm, the EF must be at least 25% above, the systolic pressure at the lateral annulus of the mitral valve (with tissue Doppler imaging) must be greater than 6 cm/sec. S wave velocity (Sa) can predict successful separation.[12]

As a result, ECMO is a team effort at every stage. Advanced monitoring with guidelines and especially ECHO plays a critical role in ECMO monitoring, and this process should be carried out under ECHO guidance.

Disclosures

Conflict of Interest: All authors declared no conflict of interest.

Use of AI for Writing Assistance: Not declared.

Financial Disclosure: The authors declared that this study has received no financial support.

Peer-review: Externally peer-reviewed.

References

1. Tonna JE, Abrams D, Brodie D, Greenwood JC, Rubio Mateo-Sidron JA, Usman A, et al. Management of adult patients supported with Venovenous Extracorporeal Membrane Oxygenation (VV ECMO): Guideline from the Extracorporeal Life Support Organization (ELSO). ASAIO J 2021;67:601–10.
2. Lorusso R, Shekar K, MacLaren G, Schmidt M, Pellegrino V, Meyns B, et al. ELSO interim guidelines for venoarterial extracorporeal membrane oxygenation in adult cardiac patients. ASAIO J 2021;67:827–44.
3. Cha S, Kostibas MP. Echocardiographic and Point-of-Care Ultrasonography (POCUS) guidance in the management of the ECMO patient. J Clin Med 2024;13:2630.
4. Platts DG, Sedgwick JF, Burstow DJ, Mullany DV, Fraser JF. The role of echocardiography in the management of patients supported by extracorporeal membrane oxygenation. J Am Soc Echocardiogr 2012;25:131–41.
5. Lorusso R, Whitman G, Milojevic M, Raffa G, McMullan DM, Boeken U, et al. 2020 EACTS/ELSO/STS/AATS expert consensus on post-cardiotomy extracorporeal life support in adult patients. Eur J Cardiothorac Surg 2021;59:12–53.
6. Douflé G, Roscoe A, Billia F, Fan E. Echocardiography for adult patients supported with extracorporeal membrane oxygenation. Crit Care 2015;19:326.
7. Martin-Villen L, Martin-Bermudez R, Perez-Chomon H, Fuset Cabanes MP. Role of ultrasound in the critical ill patient with ECMO. Med Intensiva (Engl Ed) 2024;48:46–55.
8. Prager R, Bowdridge J, Pratte M, Cheng J, McInnes MD, Arntfield R. Indications, clinical impact, and complications of critical care transesophageal echocardiography: A scoping review. J Intensive Care Med 2023;38:245–72.
9. Hussey PT, von Mering G, Nanda NC, Ahmed MI, Addis DR. Echocardiography for extracorporeal membrane oxygenation. Echocardiography 2022;39:339–70.
10. Kapoor PM. Echocardiography in extracorporeal membrane oxygenation. Ann Card Anaesth 2017;20:S1–3.
11. McCarthy C, Fletcher N. Transoesophageal echocardiography in cardiac anaesthesia. Anaesth Intensive Care 2021;22:223–31.
12. Cavarocchi NC, Pitcher HT, Yang Q, Karbowski P, Miessau J, Hastings HM, et al. Weaning of extracorporeal membrane oxygenation using continuous hemodynamic transesophageal echocardiography. J Thorac Cardiovasc Surg 2013;146:1474–9.