Intensive Care Med
https://doi.org/10.1007/s00134-024-07659-2

EDITORIAL

My echo checklist in venoarterial ECMO patients

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Transthoracic echocardiography is an essential tool for the management of venoarterial extracorporeal membrane oxygenation (VA-ECMO) [1–4]. Its ease of access makes it ideally suited for routine daily bedside assessments, which are essential for adjusting ECMO flow, detecting ECMO-related complications, evaluating the need for venting devices, and monitoring patient recovery. If transthoracic imaging is not feasible or the images are suboptimal, a transesophageal echocardiography should be performed.

We aimed to propose a systematic echocardiographic approach using a nine-point checklist to address the key challenges faced by physicians managing VA-ECMO patients.

Is the drainage cannula well positioned?

The optimal position for the drainage cannula tip is within the right atrium (RA) (supplementary video 1a). If positioned within the inferior vena cava (IVC), the IVC walls may be suctioned, impeding blood drainage (supplementary video 1b). When located within the superior vena cava, ECMO flow typically remains unaffected. However, if the cannula tip contacts cardiac structures, such as the interatrial septum, it can lead to inadequate drainage, endothelial injury, and potential thrombus formation (supplementary video 1c). Perforation or reopening of a patent foramen ovale may redirect oxygenated blood from the left atrium (LA) to the return cannula (supplementary video 1d, 1e), reducing left ventricular (LV) preload and ejection.

The return cannula tip on echocardiography is often difficult to visualize, except for the right atrium-pulmonary artery (RA-PA) double-lumen cannula, which reinfuses blood into the pulmonary artery (supplementary video 1f, 1g). If the tip of the device is improperly positioned below the pulmonary valve (supplementary video 1h, 1i), the right ventricle (RV) may not be adequately supported, risking overload, which could result in dilation and tricuspid regurgitation.

Assessment of drainage insufficiency

Drainage insufficiency is characterized by chattering of the ECMO lines, accompanied by a rapid and transient drop in ECMO flow. This typically occurs when the multistage drainage cannula suctions against the walls of the IVC or RA. A subcostal view should be employed to:

(1) Verify the position of the drainage cannula tip (if located within the IVC, it should be advanced into the RA; see Fig. 1, point 1).
(2) Confirm the absence of significant pericardial effusion that could cause tamponade (see Fig. 1, point 6).
(3) Ensure that there is adequate space between the IVC walls and the cannula, as a virtual space may indicate the need for fluid administration (supplementary video 2).

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Additionally, pneumothorax and abdominal hypertension should be excluded as potential causes. In cases of line chattering, reducing the revolutions per minute (RPM) of the pump, followed by a cautious, gradual increase, can mitigate line suction and restore ECMO flow. If this is insufficient for the patient's needs, fluid administration is necessary before increasing RPM and ECMO flow.

How much is the aortic velocity time integral and which ECMO flow is necessary?

ECMO flow should be tailored to meet patient's metabolic demand and provide adequate cardiac and circulatory support. The ECMO flow setting should consider residual stroke volume (assessed by left ventricular outflow tract velocity time integral, LVOT VTI), aortic valve opening and intracardiac thrombotic risk (Fig. 1, see point 4), mean arterial pressure, vasopressor needs, lactate level/clearance and clinical signs of organ hypoperfusion (i.e., skin mottling, urine output, neurologic status).

High ECMO flow (3–4 liters per minute, LPM) is necessary for severe hemodynamic instability with high vasoactive drugs doses, elevated lactate and poor residual ejection (LVTO VTI < 5 cm). Lower ECMO flow (2–3 LPM) suffices for stabilized patients with residual LV ejection. Evaluating left ventricular ejection fraction (LVEF) and LVOT VTI should be done daily from ECMO initiation to recovery (electronic supplementary material, ESM, video 3a, and Image 1) [3, 4].

Is the aortic valve still opening: is there a high risk of left ventricle or aortic root thrombosis?

In severe cases with very low residual cardiac ejection, especially with high ECMO flow (leading to decreased preload and increased afterload), the aortic valve may remain closed (supplementary video 4a).

This can cause blood stagnation (supplementary video 4b) and thrombus formation within the LV (supplementary video 4c, and 4e) or the aortic root (supplementary video 4d). Keeping LV ejection and aortic valve opening is then a major concern that can be achieved through: (1) reducing the ECMO flow, provided that circulatory support is sufficient; (2) inotropic support; (3) LV unloading

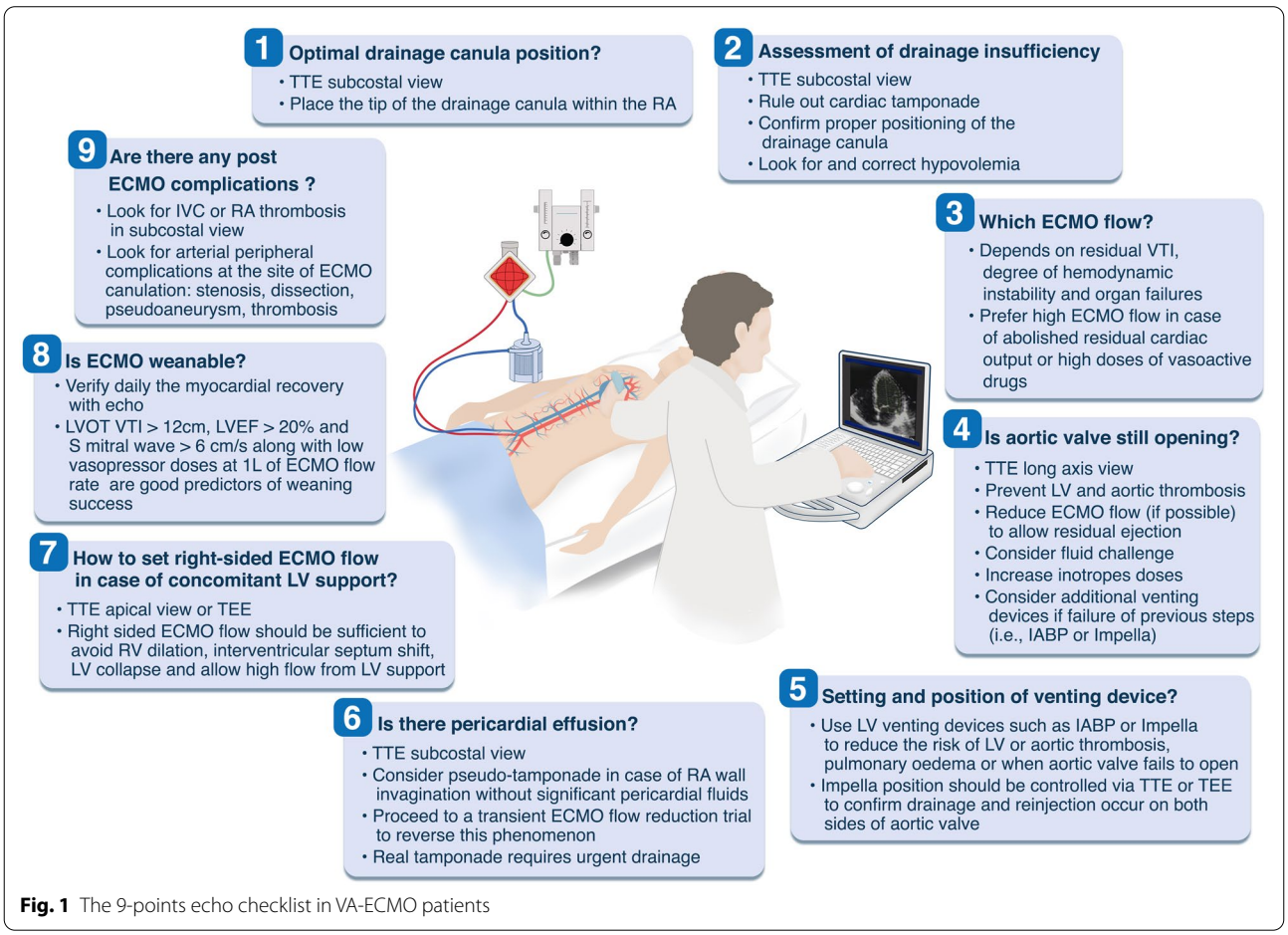

Fig. 1 The 9-points echo checklist in VA-ECMO patients

with intra-aortic balloon pump (IABP) (supplementary videos 4f, and 4g); (4) fluid challenge.

Note that patients on VA-ECMO with atrioseptostomy or trans-septal LA drainage cannula may have worsened LV ejection due to a marked decreased in LV preload [5].

If the aortic valve remains closed, consider direct venting for example with microaxial flow pump such as Impella® to prevent LV thrombus formation.

Position and setting of the venting device?

Unloading strategies are increasingly used in VA-ECMO patients [6, 7]. The IABP decreases LV afterload and aids residual LV ejection, promotes aortic valve opening, decreases the risk of pulmonary edema and may reduce mortality [8, 9]. The supplementary video 5a demonstrates aortic valve opening with the IABP activated after several unassisted cycles. The positioning of the IABP can be assessed using a supra sternal transthoracic echocardiography (TTE) view, showing the tip of the IABP at the origin of the left subclavian artery. The Impella® device also reduces LV end-diastolic volume and pressure and lowers the risk of pulmonary edema and intracardiac or intra-aortic thrombus [8–10]. The supplementary video 5b and Image 2 show a properly positioned Impella with the inlet 3–4 cm below the aortic valve annulus within the LV. Color Doppler aliasing confirms blood return into the ascending aorta (supplementary video 5c). If positioned too deeply within the LV, blood is reinjected into the LV (ESM, Image 3, and videos 5d, 5e), providing no support and increasing the risk of LV distension and pulmonary edema.

Is there pericardial effusion, and if yes, is there tamponade?

Assessing pericardial effusion and its impact in VA-ECMO patients is challenging. RA collapse observed on echocardiography may be due to suction from the drainage cannula or a compressive pericardial effusion. The presence of IVC dilation and concurrent RV collapse can help differentiate true tamponade (supplementary video 6a) requiring drainage, from ECMO-induced pseudo-tamponade. In complex cases, clinicians may perform a transient reduction in ECMO flow to determine if the tamponade-like appearance resolves (supplementary videos 6b, 6c) [11].

Settings of right-sided ECMO when combined with left ventricular support?

Some patients may require both right-sided ECMO (RA-PA circuit) and LV support, such as those with a RA-PA double-lumen cannula for severe RV failure following left ventricular assist device (LVAD) implantation, or patients with peripheral VA-ECMO related complications (cardiac akinesia and high risk of cardiac thrombosis, severe cannula site infection) switched to double central ECMO with both RA-PA and LV-aortic artery (AA) circuits. In these cases, insufficient right-sided ECMO flow can lead to RV dilation (supplementary video 7a), leftward shift of the interventricular septum, LV collapse due to LV support suction (supplementary video 7b), and intraventricular obstruction (supplementary video 7c), resulting in left-sided low-flow. The right-sided ECMO flow should be increased (potentially requiring a fluid challenge) to achieve a neutral position of the interventricular septum and restore left-sided adequate flow (supplementary video 7d).

Does my patient still need ECMO support?

To predict successful weaning in stabilized ECMO patients, several echo-guided algorithms were described [12–16]. In our practice, we conduct a weaning trial that combines clinical hemodynamic assessment with Doppler echocardiographic evaluation during a brief reduction of the ECMO flow rate to 1 L/min for 5–10 min (supplementary videos 8a and 8b and Images 4–5). Patients who remain hemodynamically stable at this reduced ECMO flow, while receiving low doses of vasopressors or inotropes, and who demonstrate a LVOT VTI of $\geq$ 12 cm, LVEF $\geq$ 20%, and S mitral wave $\geq$ 6 cm/s have high chances of being successfully weaned [13, 15]. Of note, this prediction can also be achieved through evaluation of the ventricular interdependence or of the RV systolic function and coupling to the pulmonary circulation [12, 16].

After ECMO removal, are there any ECMO-related complications?

Vascular complications at the site of peripheral ECMO insertion are common and can include thrombus formation, pseudoaneurysm, stenosis, or dissection. Thrombus within the IVC may appear as the "phantom of the cannula" (supplementary video 9a) or as a thrombus attached to the IVC walls (supplementary video 9b). This condition poses a risk for pulmonary embolism and necessitates anticoagulation therapy. Thrombus within the RA is less frequently observed (supplementary video 9b). Arterial pseudoaneurysm at the cannulation site can also be detected using echo-Doppler imaging (supplementary videos 9c and 9d).

Take-home message

Doppler echocardiography, in conjunction with clinical evaluation and sometimes with, pulmonary artery catheter hemodynamic assessment, is essential to guide clinicians in the real-time management of critically ill patients throughout the entire course of VA-ECMO. A systematic daily evaluation of various aspects of cardiac function and potential complications is crucial for enhancing VA-ECMO monitoring and preventing adverse outcomes.

Supplementary Information
The online version contains supplementary material available at https://doi.org/10.1007/s00134-024-07659-2.

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Declarations

Conflicts of interest
AC reports receiving grant support and lecture fees from Maquet and Baxter. All other authors declare that they have no conflict of interest, no funding or financial support.

Ethical standards
This paper was written in accordance to ethical guidelines.

Publisher's Note

Received: 10 July 2024 Accepted: 12 September 2024
Published online: 25 October 2024

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