The Venoarterial Extracorporeal Membrane Oxygenation Weaning Checklist

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Venoarterial extracorporeal membrane oxygenation (vaECMO) is a well-established treatment option for severe cardiogenic shock of various etiologies. Although trials have explored weaning strategies, a brief and conclusive overview is lacking. We present the different aspects of weaning and provide an evidence- and experienced-based guide for clinicians managing patients under vaECMO in the preweaning, weaning, and postweaning phases. (A&A Practice. 2020;14:e01199.)

GLOSSARY

3D = 3 dimensional; **ACT** = activated clotting time; **CI** = cardiac index; **ECMO** = extracorporeal membrane oxygenation; **Fio_2** = fraction of inspired oxygen; **ICU** = intensive care unit; **LV** = left ventricle; **LVEF** = left ventricular ejection fraction; **MAP** = mean arterial pressure; **mPAP** = mean pulmonary arterial pressure; **Pao_2** = partial pressure of arterial oxygen; **PCRTO** = pump-controlled retrograde trial off; **PEEP** = positive end-expiratory pressure; **ROTEM** = rotational thromboelastometry; **RV** = right ventricle; **RVEF** = right ventricular ejection fraction; **Sao_2** = arterial oxygen saturation; **Svo_2** = mixed venous oxygen saturation; **TDSa** = tissue Doppler lateral mitral annulus peak systolic velocity; **TEE** = transesophageal echocardiography; **TTE** = transthoracic echocardiography; **UFH** = unfractionated heparin; **vaECMO** = venoarterial extracorporeal membrane oxygenation; **VTI** = velocity time integral; **vvECMO** = venovenous extracorporeal membrane oxygenation

Venoarterial extracorporeal membrane oxygenation (vaECMO) is a well-established treatment for severe cardiogenic shock of various etiologies[1] and is indicated as a bridge-to-recovery or a bridge-to-bridge concept until a definitive treatment strategy can be defined.[2]

Depending on the etiology of heart failure, the duration of vaECMO support varies from days to weeks.[1] When parameters indicating cardiac and pulmonary recovery are reached, a weaning attempt is made. Successful weaning from vaECMO is defined as removal of the device without further requirement for mechanical circulatory support over the next 30 days due to refractory (or recurrent) cardiogenic shock.[3]

Likely due to patients' heterogeneity and the variation in experience, reported success rates for weaning vary between 24% and 69%, with in-hospital mortality rates as high as 65%.[4] The lack of a standardized accepted weaning protocol might further impact weaning success. A brief and conclusive checklist is currently lacking. After having summarized current guidelines of the Extracorporeal Life Support Organization and all PubMed results for the search "vaECMO AND weaning," we developed at our center (>100 vaECMOs per year) the evidence-based weaning protocol describe below.

PREWEANING

General Considerations

vaECMO flow of 50–70 mL/kg/min (4–6 L/min) with gas exchange is usually sufficient to support end-organ recovery. Extracorporeal membrane gas exchange is typically mandatory in classic vaECMO to avoid a high-output-like venoarterial fistula-like functional bypass with potentially severe arterial desaturation in settings without gas exchange. Protective mechanical ventilation is mandatory in patients with vaECMO and includes low tidal volumes of 3–5 mL/kg, ventilation rates <8/min, positive end-expiratory pressure (PEEP) <8 cm H_2O, and fraction of inspired oxygen (Fio_2) <0.40.[1]

Flow reduction is performed every 12–24 hours, aiming at the lowest flows that provide adequate support with minimal vasoactive agents. This stepdown strategy is to be stopped when mean arterial pressure (MAP) falls to <60 mm Hg. Echocardiographic evaluation is performed every 24 hours, preferably with transesophageal echocardiography (TEE).[1,4,5] Reduction of "ECMO flow to a minimum" and "pump-controlled retrograde trial off" are 2 possible stepdown strategies (Supplemental Digital Content, Table, http://links.lww.com/AACR/A304) in the preweaning phase.

Myocardial recovery, stable hemodynamics, and sufficient pulmonary function must be present[4] to consider vaECMO weaning after 72 hours of support[4] (earlier in

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cases of intoxications).[5] Therefore, continuous monitoring of peripheral (preferably in the right arm) and pulmonary artery pressures is recommended.[1,6] Lactate concentrations are measured regularly to monitor end-organ perfusion and metabolism,[7] and routine platelet counts >80,000/μL must be targeted. A recent survey revealed large global practice variations in anticoagulation management in ECMO patients.[8] We use unfractionated heparin (UFH) aiming at activated clotting time (ACT) >180 seconds.[6]

Parameters Predicting Successful Weaning From ECMO

Hemodynamics are considered stable with a MAP >60 mm Hg and pulsatile arterial waveforms (aortic valve opening) as a sign of myocardial recovery[1] for ≥24 hours without significant vasoactive pharmacological support.[4] Increasing pulsatility and pulsatile pressures of >10 mm Hg are associated with weaning success,[9] and stable hemodynamics contributing to a physiological homeostasis are reflected in normal liver function and normal pH and lactate concentrations.[3,4]

Normalized lactate concentrations <2.4 mmol/L within the first 12 hours of vaECMO support are associated with higher rates of weaning success,[7] while neither recovery of renal function[6] nor cardiac biomarkers predict weaning success in vaECMO patients.[5]

While weaning protocols are described mostly using transthoracic echocardiography (TTE), hemodynamics are to be correlated with left ventricular (LV) and right ventricular (RV) function by TTE or TEE[10] with minimal ECMO support. LV ejection fraction (LVEF) >20%–25%, aortic velocity time integral (VTI) >10 cm, tissue Doppler lateral mitral annulus peak systolic velocity (TDSa) >6 cm/s, and less than moderate aortic regurgitation are associated with weaning success.[5] While poor RV function is generally associated with decreased weaning success, 3-dimensional (3D) RV ejection fraction (RVEF) >24.6% predicts weaning success.[1,4,5,11] Measuring RV strain is a reliable alternative in settings where 3D technology is not available. If neither 3D RV nor strain analysis is available, classical measures of RV function are considered. In any case, RVEF is evaluated during reduction of ECMO flow and during volume administration while avoiding systemic hypotension.[12] Tricuspid annular plane systolic excursion,[11] tricuspid regurgitation,[11] and indices of LV filling pressure[3] do not correlate with weaning success.

Vasoactive pharmacological support is kept at the lowest concentrations possible before weaning initiation. With severely reduced LVEF (<25%) or persistent low cardiac output, 0.1 and 0.2 μg/kg/min levosimendan administered 24 hours before weaning initiation may increase weaning success, reduce need of inotropic support after weaning, and decrease in-hospital mortality,[13] but current evidence is not sufficient to unrestrictedly justify the high costs. Milrinone at 0.1 and 0.75 μg/kg/min[13] appears to be a feasible alternative.[14] Nitric oxide at 20 ppm may be beneficial if there is impaired RV function or pulmonary hypertension.[14]

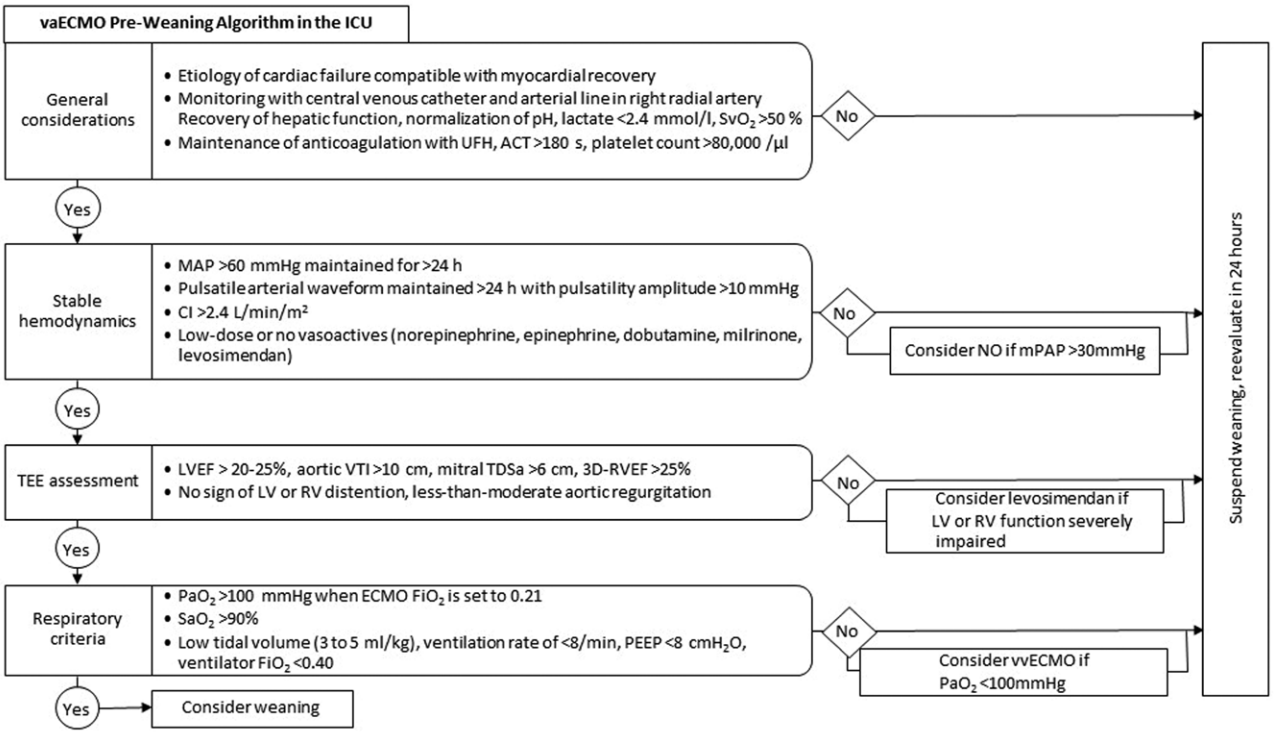

Figure 1. vaECMO preweaning checklist in the intensive care unit. 3D indicates 3 dimensional; ACT, activated clotting time; CI, cardiac index; ECMO, extracorporeal membrane oxygenation; Fio_2, fraction of inspired oxygen; ICU, intensive care unit; LV, left ventricle; LVEF, left ventricular ejection fraction; MAP, mean arterial pressure; mPAP, mean pulmonary arterial pressure; Pao_2, partial oxygen pressure of arterial oxygen; PEEP, positive end-expiratory pressure; RV, right ventricle; RVEF, right ventricular ejection fraction; Sao_2, arterial oxygen saturation; Svo_2, mixed venous oxygen saturation; TDSa, tissue Doppler lateral mitral annulus peak systolic velocity; TEE, transesophageal echocardiography; UFH, unfractionated heparin; vaECMO, venoarterial extracorporeal membrane oxygenation; VTI, velocity time integral; vvECMO, venovenous extracorporeal membrane oxygenation.

Although protective ventilation aims at avoiding pulmonary complications, some patients may develop pulmonary failure, especially after prolonged vaECMO support. In cases of respiratory failure, and if the ratio of partial pressure of arterial oxygen (Pao_2)/Fio_2 is <100 mm Hg with ECMO gas flow set at 21%, a stepdown approach using venovenous ECMO is an option. Figure 1 displays our vaECMO preweaning checklist based on current evidence and our experience.

WEANING AND DISCONTINUATION TRIALS

Actual weaning with discontinuation takes place in the operating room with the patient under total intravenous anesthesia. The American College of Cardiology proposes a graduated decrease in flow at the rate of 1 L/h, over a period of 3–4 hours.[1] Mixed venous oxygen saturation (Svo_2) and arterial oxygen saturation (Sao_2) are maintained at >65% and >90%, respectively, at an ECMO flow rate of <1.5 L/min.[1] Native heart or lung function is typically adequate to discontinue vaECMO when support is <25% of total cardiac output.

Vasoactive agents are limited to low doses of norepinephrine, and if necessary, low doses of epinephrine or dobutamine.[4] Anticoagulation therapy with UFH is continued, aiming at ACTs >180 seconds postweaning to avoid deep vein thrombosis.[15] Platelets are maintained at >80,000/μL, and regular whole blood viscoelastic point-of-care testing includes thromboelastography or rotational thromboelastometry.[6,12]

During weaning, vasoactive pharmacological agents and volume administration are continuously adjusted according to hemodynamics. At idle ECMO flow, the MAP must be stable at >50 mm Hg, with arterial wave amplitudes >10 mm Hg, cardiac index (CI) >2.4 L/min/m^2, Svo_2 >60%, Sao_2 >90%, Pao_2 >100 mm Hg, and lactate <2.4 mmol/L. LVEF must be >20%–25%, aortic VTI >10 cm, and TDSa >6 cm/s.[1,4] There must be no worsening of biventricular dilation and less than moderate aortic regurgitation.[1,4] RV preload and right heart function cannot be sufficiently tested at idle flow.

Discontinuation trials are performed during the weaning process to either stop or significantly reduce ECMO circulation and to assess cardiac function before decannulation. The Supplemental Digital Content, Table, http://links.lww.com/AACR/A304, provides an overview of strategies commonly used in discontinuation trials. The selected strategy is defined before the start of the weaning process.

Before the weaning or discontinuation trial begins, the patient is placed on full ventilator support and low-dose inotropes are started as needed. Hemodynamic, echocardiographic, metabolic, and gas exchange parameters are assessed regularly. If they are satisfactory, decannulation is performed and protamine is administered. Figure 2 displays

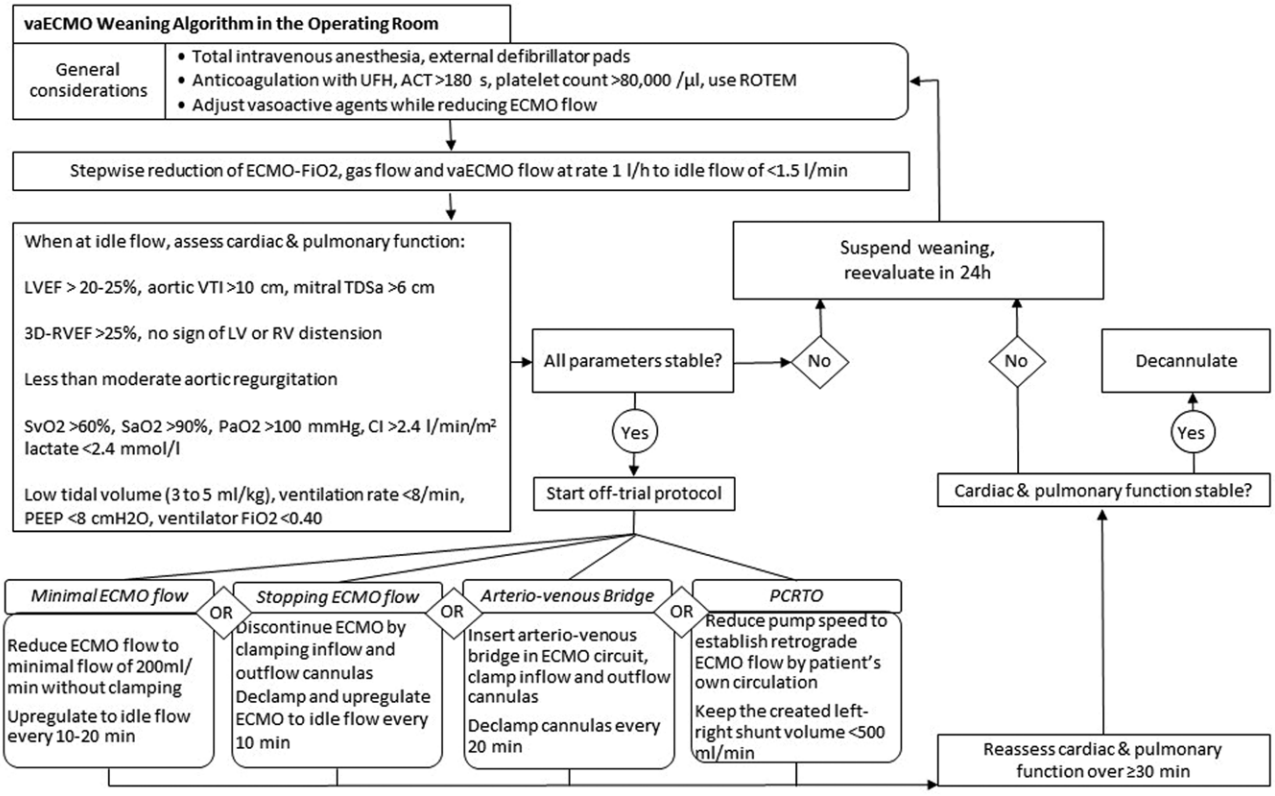

Figure 2. vaECMO weaning checklist in the operating room. ACT indicates activated clotting time; CI, cardiac index; ECMO, extracorporeal membrane oxygenation; Fio_2, fraction of inspired oxygen; ICU, intensive care unit; LV, left ventricle; LVEF, left ventricular ejection fraction; MAP, mean arterial pressure; Pao_2, partial oxygen pressure of arterial oxygen; PCRTO, pump-controlled retrograde trial off; PEEP, positive end-expiratory pressure; ROTEM, rotational thromboelastometry; RV, right ventricle; RVEF, right ventricular ejection fraction; Sao_2, arterial oxygen saturation; Svo_2, mixed venous oxygen saturation; TDSa, tissue Doppler lateral mitral annulus peak systolic velocity; UFH, unfractionated heparin; vaECMO, venoarterial extracorporeal membrane oxygenation; VTI, velocity time integral.

Table. Hemodynamic and Metabolic Conditions Warranting Stopping a Weaning Attempt

Maximal vasoactive support without possibilities of further increase
LVEF <20%–25%
CI < 2.4 L/min/m^2
MAP <50 mm Hg
Pulse pressure amplitude <10 mm Hg
Svo_2 <50%
Sao_2 <90 %
Lactate >2.4 mmol/L
PEEP >12 cm H_2O
Fio_2 >0.5

Abbreviations: CI, cardiac index; Fio_2, fraction of inspired oxygen; LVEF, left ventricular ejection fraction; MAP, mean arterial pressure; PEEP, positive end-expiratory pressure; Sao_2, arterial oxygen saturation; Svo_2, mixed venous oxygen saturation.

our vaECMO weaning checklist based on current evidence and our experience.

WEANING FAILURE

If hemodynamic, respiratory, and metabolic parameters differ from minimum requirements at any stage, weaning attempts are stopped and vaECMO support reestablished. Weaning must be aborted and ECMO returned to full flow if the pharmacological vasoactive support is high, LVEF remains <20%–25%, pulsed pressure amplitude is <10 mm Hg, or MAP <50 mm Hg is present. Furthermore, weaning must be aborted when CI remains <2.2–2.4 L/min/m^2, Svo_2 <50% or Sao_2 <90%, at a PEEP of >12 cm H_2O, and Fio_2 >0.5 or when lactate concentrations are >2.4 mmol/L. The patient's physiology is optimized, and a future weaning attempt is planned for a minimum of 24–48 hours at the earliest. The Table summarizes reasons to abort the weaning attempt.

CONCLUSIONS

Weaning from vaECMO is a multistage procedure that requires careful planning. Continuous assessment of hemodynamic, respiratory, and metabolic parameters is required. We recommend development of an institutional checklist. Our version is based on current evidence and, while not validated, may serve as a guide for successful weaning from vaECMO.

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