Veno-Arterial ECMO in Severe Acute Right Ventricular Failure with Pulmonary Obstructive Hemodynamic Pattern

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ABSTRACT: Extracorporeal membrane oxygenation (ECMO) is an effective rescue method for severe respiratory and cardiac failure. Right ventricular (RV) failure with cardiogenic shock is a critical condition with generally poor prognosis unless aggressive therapeutical measures are undertaken. Authors report on their initial experience with ECMO support in severe RV failure with cardiogenic shock caused by an obstructive hemodynamic pattern. Four patients with cardiogenic shock due to severe RV failure related to pulmonary arterial hypertension (2 patients), congenital heart disease with Eisenmenger physiology (1 subject) and massive pulmonary embolism (1 patient) were supported with emergency veno-arterial ECMO. ECMO circuit was instituted using peripheral cannulation in all subjects. Immediate hemodynamic and ventilatory improvement was observed in all patients. The mean support duration was 11 days (range 5–16 days), 2 (50%) patients were successfully weaned off ECMO and survived to hospital discharge. The other 2 patients were considered by mutual consensus to have irreversible organ damage, the ECMO support was withdrawn and the patients died. Bleeding complications were the main complications observed.

As per initial experience, veno-arterial ECMO allows bypassing of the pulmonary bed, therefore, relieves the RV pressure overload and does not cause further elevation of the pulmonary pressures in contrary to RV assist devices. This aggressive management approach requires further clinical evaluation in order to establish its definite role in critical RV failure.

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Extracorporeal membrane oxygenation (ECMO) has been successfully used in patients with severe respiratory and/or cardiac failure[1–3] and can be initiated in an urgent setting including imminent or actual cardiac arrest.[4,5] In addition, patients on ECMO can be transported for further diagnostic or therapeutic procedures.[6] In ventilatory and/or severe right ventricular (RV) failure, the use of ECMO has been previously described in the following conditions: during the intra- and postoperative period in bilateral lung transplantation,[7] pulmonary endarterectomy,[8] in massive pulmonary embolism[9–11] as a bridge to embolectomy or resolution with thrombolysis and in severely decompensated pulmonary arterial hypertension as a bridge to urgent lung transplantation.[12] The authors report on their initial experience with ECMO support in RV failure and cardiogenic shock.

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Methods

From January 2008 until the end of December 2009, 4 out of 23 consecutive patients treated at our institution since the ECMO team establishment were indicated to ECMO support for severe RV failure. Their hospitalization courses were assessed in a retrospective analysis by chart review.

Device used. The ECMO circuit consisted of a Maquet console (*Maquet Cardiopulmonary AG, Hirrlingen, Germany*) or Medtronic 550 Bio-Console (*Medtronic Perfusion Systems, Brooklyn Park, Minnesota*) with adapter, and Rotaflow RF 32 centrifugal pump with Quadrox PLS hollow fibre BIOLINE® coated membrane oxygenator (*Maquet Cardiopulmonary AG, Hirrlingen, Germany*), Maquet PLS tubing set and a mechanical gas blender (*Sechrist, Anaheim, California*). Edwards cannulae (*Fem-Flex Cannulae, Edwards Lifesciences Research Medical Inc., Midvale, Utah*) were introduced percutaneously using a standard Seldinger technique after repeated dilatations of the femoral artery and vein. The venous inflow cannula was inserted via the femoral vein into the inferior vena cava (IVC) just below the right atrium (the tip position checked by echocardiography) and the arterial outflow cannula was placed into the femoral artery. Constant circuit/patient temperature was regulated by the oxygenator heater unit HU 35 (*Maquet Cardiopulmonary AG, Hirrlingen, Germany*). All patients were anticoagulated with heparin to reach an aPTT of 2–3 times normal unless contraindicated due to bleeding. The circuit and the console function were regularly checked by perfusionists.

Patients. Out of 23 patients treated in our center since the ECMO team establishment, 4 patients were diagnosed with cardiogenic shock due to severe RV failure. This was related to pulmonary arterial hypertension (PAH) in 2 patients, to massive

Table 1. A timeline of selected hemodynamic and metabolic parameters in patient #1. Note severely depressed cardiac index and SvO_2 before extracorporeal membrane oxygenation (ECMO) was implanted (19:30) and improvement in SvO_2, lactate and diuresis on running ECMO.

	Before ECMO			On ECMO
Time	12:54	15:14	17:20	20:00
SpO_2 (%)	94	93	91	98
CVP (mmHg)	14	13	15	12
HR (s^{-1})	107	108	120	100
MPAP (mmHg)	57	57	59	59
PAW	20	20		
Lactate (mmol/l)			**3.3**	**1.5**
SvO_2 (%)	**48.2**		**23.9**	**67.5**
paO_2 (mmHg)	98		71.3	130
pCO_2 (mmHg)	22.6		14	27.7
pH	7.37		7.44	7.4
BE	-8.1		-12.3	-6.1
MAP (mmHg)	72	75	74	90
CO (l/min)	2.6	2,3	2.5	2.5
CI (l/min/m²)	**1.2**	**1,1**	**1.2**	**1.2**
PVRI (dyn.sec/cm⁵/m²)	2,458	2,778	3,039	968
SVRI (dyn.sec/cm⁵/m²)	3,853	4,656	3,748	5,318
Time	12–13:00	15–16:00	17–18:00	20–21:00
Diuresis (ml/hour)	**15**	**25**	**8**	**1,000**

pulmonary embolism with imminent cardiovascular collapse in another, and congenital heart disease with Eisenmenger physiology in the final patient. They were supported with emergency percutaneous veno-arterial (VA) ECMO. Immediate hemodynamic and ventilatory improvement was observed in all of the patients. The mean duration of the support was 11 days (range 5–16 days); 2 (50%) patients were successfully weaned off ECMO and survived to hospital discharge. By mutual consensus, the other 2 patients were considered to have irreversible multiple organ damage and the ECMO support was terminated after multidisciplinary team discussion.

Patient 1. *A 42-year-old male with a 2-month history of progressive dyspnea on exertion was admitted after having suffered 2 syncopal episodes with respiratory insufficiency and hemodynamic instability. Severe pulmonary arterial hypertension (PAH) (mean pressure 73 mmHg) was confirmed and pulmonary embolism excluded. The patient was started on inhaled iloprost and noninvasive mechanical ventilation, however, his clinical status progressed further to cardiogenic shock with CI of 1.2 L/min/M² and severe hypotension despite inotropic support and vasopressor therapy, and he became anuric and drowsy. Urgent VA ECMO was started, resulting in prompt restoration of full consciousness and renal recovery. Table 1 shows the selected hemodynamic and metabolic parameters before and after ECMO initiation. Specific pharmacotherapy with intravenous epoprostenol and oral sildenafil was initiated. The patient developed a self-resolving episode of pulmonary edema (evidenced by chest X-ray and asymptomatic on ECMO), sepsis of unknown origin and an episode of ECMO circuit-related bleeding. Pericardiocentesis for pericardial effusion related to PAH was performed on ECMO day 12. The patient was put on the highly-urgent waiting list for lung transplantation, however, a donor organ was not available during the following 3 weeks. While on ECMO, the patient's clinical condition gradually improved, and after 16 days, ECMO was successfully weaned off and he was discharged in New York Heart Association (NYHA) class II status on continued specific pharmacotherapy for PAH. Unfortunately, he suffered sudden cardiac death 3 months following his discharge while still on the waiting list for lung transplantation as a non-urgent candidate.*

Patient 2. *A 57-year-old female with known familiar PAH (mean pulmonary pressure 75 mmHg), NYHA class III and coronary artery disease (CAD) with 50% proximal left anterior descending artery stenosis was admitted because of general deterioration of her clinical condition with low cardiac output resulting from RV failure and respiratory insufficiency. She was treated using noninvasive mechanical ventilation, levosimendan, intravenous epoprostenol and oral sildenafil. However, her clinical status progressed further to cardiogenic shock with severe RV pressure overload (tricuspid gradient of 97 mmHg, thus an estimated RV systolic pressure of 110–120 mmHg with concurrent systemic blood pressure of 70/40 mmHg on high-dose vasopressors), and she was urgently started on VA ECMO. Despite temporary improvement, multiple organ dysfunction with predominant respiratory insufficiency progressed and intubation with mechanical ventilation was required. The patient developed a coagulation disorder with profound thrombocytopenia and generalized bleeding. After 13 days of support, we decided by mutual consensus to withdraw ECMO and the patient died. In this patient we observed dynamic left ventricular (LV) function changes, most likely related to the ECMO flow-dependent LV afterload changes (see Figure 1 and corresponding videos: Video #1 – Before ECMO [http://blip.tv/file/3856099]; Video #2: ECMO 5.3 L/min [http://blip.tv/file/3856229]; Video #3: ECMO 2.5 L/min [http://blip.tv/file/856726]; Video #4: after terminal weaning from ECMO) [http://blip.tv/file/3856879], with CAD and silent myocardial ischemia possibly contributing to this phenomenon.*

Patient 3. *A 51-year-old male with a history of pulmonary endarterectomy performed for chronic thromboembolic pulmonary hypertension was readmitted 1 year later for a new episode of major pulmonary embolism with an extensive mobile right-heart thrombus (Figure 2), RV dilatation (55 mm in an apical view) and severe systolic dysfunction with tricuspid anular plane systolic excursions (TAPSE) of 6 mm. Surgery was not indicated and systemic thrombolysis with bed-side ECMO was started. Thirty five minutes after initiation of a regular dose of 100 mg r-tPA, the thrombus dislodged and ventilatory and hemodynamic collapse ensued. While receiving bag-mask ventilation and bolus doses of norepinephrine, femoral VA ECMO was urgently initiated with immediate hemodynamic and ventilatory improvement on the ECMO flow of about 2.5–3 L/min. Thrombolysis was completed, however, pulmonary angiography performed on the next day revealed occlusion of the right pulmonary artery branch and surgical pulmonary embolectomy was performed. Despite maximal inotropic therapy, the attempts to*

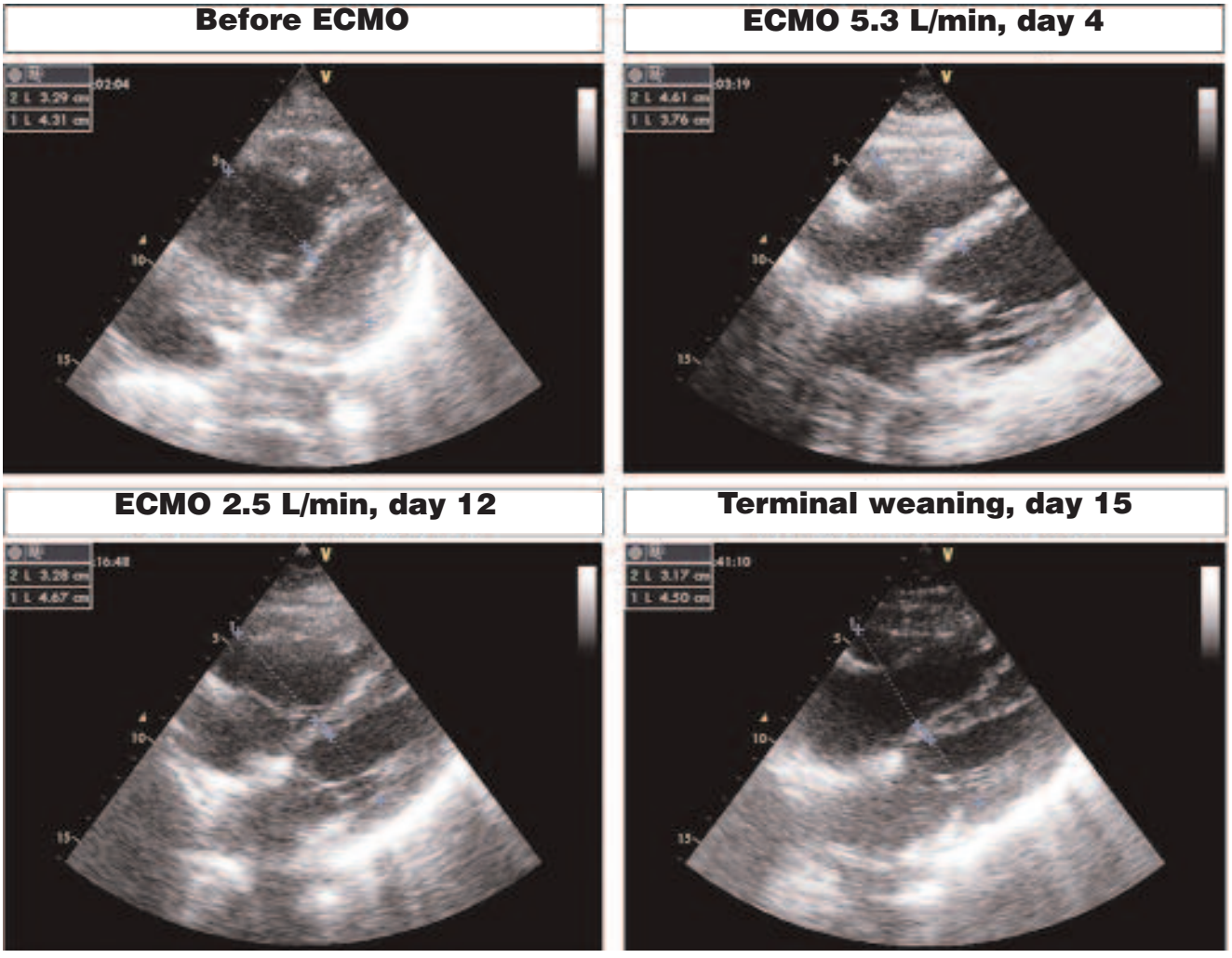

Figure 1. *Subxiphoidal 4-chamber view demonstrating right ventricular (RV) and left ventricular (LV) diameters before extracorporeal membrane oxygenation (ECMO) initiation (43 vs. 33 mm, respectively), during ECMO flow of 5.3 L/min on day 4 (38 vs. 46 mm, respectively), on lower ECMO flow of 2.5 L/min on day 12 (47 vs. 33 mm, respectively) and finally, after ECMO terminal weaning just before the patient died (45 vs. 32 mm). Note marked LV dilatation on high ECMO flow in contrast to almost normalized "baseline" pattern on lower ECMO flow of 2.5 L/min and after ECMO weaning. Changes of LV diameter and function are also demonstrated on corresponding video sequences 1–4.*

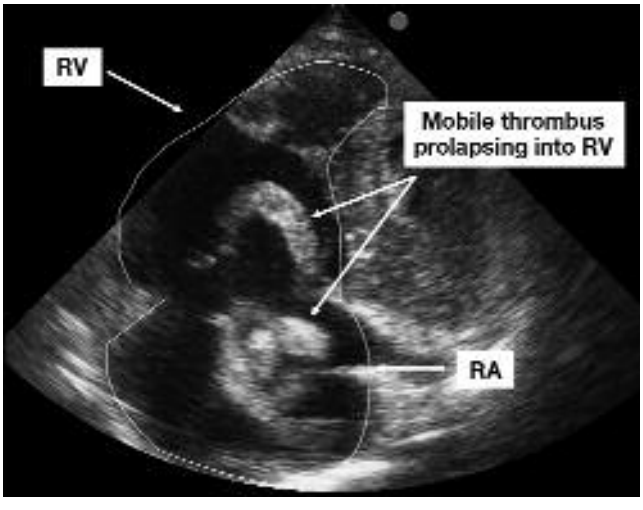

Figure 2. *Dilated right ventricle (RV) and right atrium (RA) with extensive mobile thrombus prolapsing from RA to RV.*

wean the patient off the cardiopulmonary bypass were unsuccessful due to continued RV failure, and the ECMO was restarted again and continued postoperatively for 4 more days. The patient was given a reduced protamine dose for heparin reversal at the end of surgery to allow for chest closing. After being weaned from ECMO, the patient was successfully extubated and discharged home 2 weeks later.

Patient 4. *A 42-year-old female with congenital heart disease, an uncorrected atrial septal defect with Eisenmenger physiology, with severe pulmonary hypertension, a mean PA pressure of 65 mmHg, chronic polyglobulia and respiratory insufficiency suffered two episodes of cardiac arrest with successful cardiopulmonary resuscitation. Several days later, she developed bronchial bleeding with further progression of respiratory insufficiency. The ECMO support was urgently started for another episode of massive bronchial hemorrhage while the patient was intermittently resuscitated. Despite temporary stabilization, further bleeding episodes into her lungs and also around the ECMO cannulas occurred. After 12 days and by mutual consensus, the ECMO support was terminated and the patient died.*

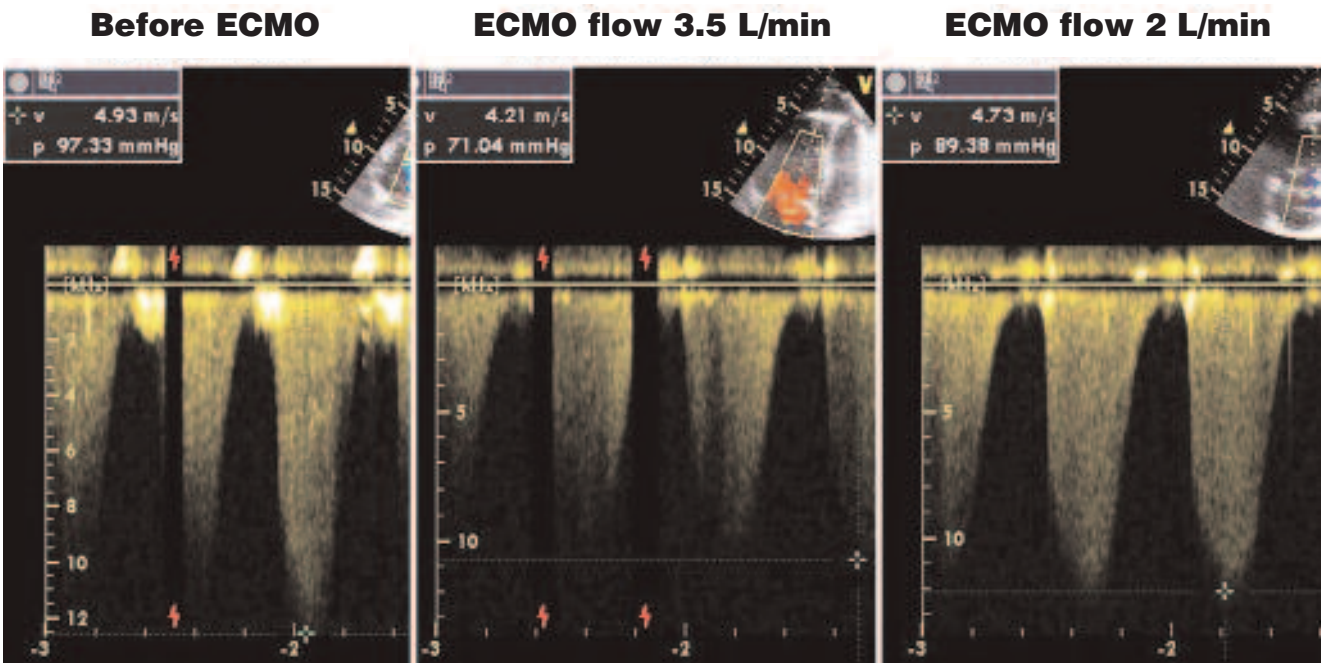

Figure 3. *Tricuspid regurgitation gradients in a patient with severe pulmonary arterial hypertension supported with extracorporeal membrane oxygenation (ECMO) (Patient #1). Note a dynamic pattern of right sided pressures dependent on ECMO flow and unloading of the right ventricle.*

Discussion

Severe pulmonary hypertension as well as massive pulmonary embolism complicated by RV failure and cardiogenic shock have poor prognoses[13,14] unless aggressive therapeutic measures are instituted. Both conditions, characterized by pulmonary flow "obstructive" pattern, require either restoration of adequate blood flow by vasodilatation (*i.e.,* specific pharmacotherapy in PAH) or urgent thrombolysis or embolectomy in pulmonary embolism. However, in hemodynamically unstable patients, these therapeutic interventions cannot be initiated due to logistic reasons, or are not immediately sufficiently effective. Therefore, mechanical support in patients with life-threatening RV failure is essential. In such cases, use of the right ventricular assist device (RVAD) has been described.[12,15] However, in both of these reports, use of the RVAD support in severe pulmonary hypertension resulted in even further elevation of the PA pressure to suprasystemic values, to severe lung bleeding in one of the cases, and in death in the other case despite temporary hemodynamic improvement. Replacing the RVAD by ECMO in a recent report stabilized hemodynamics, and lung bleeding stopped.[12] Berman and colleagues[16] have commented that VA ECMO may be the optimal strategy in RV failure cases resulting from pressure overload caused by pulmonary obstruction. RVAD will not allow increased blood flow through an obstructed pulmonary bed and may increase the risk of pressure-related lung injury, while left-sided cardiac filling remains low. On the contrary, use of the VA ECMO will decompress the RV, decrease the PA pressure (Figure 3), increase left-sided pressures and facilitate preservation and recovery of end-organ function.[12,16]

It is worth mentioning that retrograde ECMO flow may increase the LV afterload and thus possibly result in LV overload.[17–19] Considering that the LV is chronically underloaded in patients with long-term PAH and acutely underloaded in pulmonary embolism, the sudden overload associated with VA ECMO initiation might cause LV failure, especially in clinical scenarios with "full" ECMO flow. Possible solutions for these concerns include either surgical central cannulation for ECMO (via the right atrium and ascending aorta) or peripheral cannulation via the right subclavian artery, however, these techniques are technically demanding with an additional risk of bleeding. In one experimental study in subjects with severe cardiopulmonary dysfunction requiring high-flow bypass, subclavian artery perfusion was considered to be more effective than femoral artery perfusion in achieving diastolic augmentation, thus enhancing myocardial oxygen balance.[20]

As mentioned above, in one of our patients (Patient #2) we documented dynamic LV dilatation and failure dependent on ECMO flow that was very likely caused by retrograde flow-related LV afterload changes.

Limitations. Our report encompasses only a small patient group, the data were analyzed retrospectively, and due to the emergent nature of these cases, complete hemodynamic data are not available for all patients.

Conclusion

Based on our initial experience, VA ECMO may be considered a reasonable approach to provide mechanical support in cases of severe RV failure and obstructive pulmonary hemodynamics. This approach does not cause further PA pressure elevation that may be observed with the use of a RVAD. Close monitoring of LV function is required. If LV failure develops, subclavian artery or central cannulation should be considered. This aggressive management deserves further clinical evaluation, in order to establish its definitive role in critical RV failure.

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