ECMO

Extracorporeal Membrane Oxygenation

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Extracorporeal Membrane Oxygenation

Manual for use in Adult Patients

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We dedicate this book
to our patients and their families;
to patients who have survived,
and those who were not so fortunate.
…

P. O. and J. B.

By Anička, aged 4, drawn a few days after being weaned from ECMO.
Published with the consent of her parents.

THANKS

Our thanks go primarily to our colleagues who are involved in ECMO programs. Patient care using ECMO always involves teamwork and requires cooperation, respect and humility, but above all a refusal to be discouraged. ECMO is a treatment method that gives patients the hope that a seemingly impossible situation can be overcome, although, unfortunately, not always…

We also thank our families for understanding why we do this work.

PO, JB, MB, HR

FOREWORD

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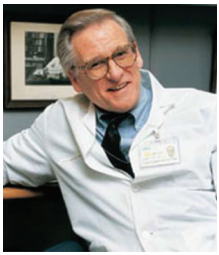

Extracorporeal life support, or ECMO, is the use of mechanical devices to replace heart and/or lung function for days or weeks, leading to recovery or replacement of the failing organ. Although this technology has been in practice for over 30 years, recent advances have led to very rapid growth and application in the last decade. ECMO has been the standard treatment for respiratory failure in newborn infants and children for many years. Recently, this technology has been applied to adult respiratory and cardiac failure throughout the world.

The first edition of this manual was the perfect combination of complex physiology and practical details that every ECMO team needs. It was very helpful for the teams and the patients in the Czech republic. This updated edition which comes also in English will be even more valuable.

The Czech ECMO manual is the essential guidebook for all caregivers on the ECMO team. All of the important topics are covered, from the basic physiology to the practical details of bedside management.

All ECMOlogists are welcomed by ELSO and the worldwide ECMO community.

Robert H Bartlett

PREFACE

In clinical medicine, we face and will continue to face critical, life-threatening conditions that cannot be successfully treated using standard medical techniques. This critical status results from a sequence of largely uncontrollable events, a systemic reaction leading to destabilization of physiological balance and the development of organ dysfunction and failure. Often, the only option is to accept this reality. It is natural, however, to look for ways to bridge the critical state and enable the repair of damaged organ functions, often by methods not yet commonly used. This search acts as an impetus for the development of contemporary healthcare and has led to massive improvements in medicine in recent years.

The introduction of the extracorporeal membrane oxygenation (ECMO) method is a classic example of the refusal to be satisfied with conventional treatments. Certainly, the fact that it is used in patients with severe heart or lung impairment where the probability of death is often 100%, and thus the risk of harm to such patients by using this method is dramatically reduced, has facilitated the development of the technique. However, ECMO is a technically challenging method, and its use inevitably necessitates addressing a number of particular problems that we do not normally encounter in anesthesiology, intensive care, cardiac surgery or cardiac care.

At our institutions in Prague - Na Homolce Hospital, the General University Hospital, and the Institute of Clinical and Experimental Medicine - we have worked intensively on ECMO since 2007 and have experience treating hundreds of patients with ECMO to date. During the introduction of this method into our daily practice, we addressed a whole range of not only clinical but also technical and organizational pitfalls associated with the approach. Our attempts to share this expe-

rience were the motivation for writing this book. The aim was to create a brief guide to use of ECMO in adult patients and to solving the most common problems faced when treating patients with this method.

We believe that this short book will serve as a source of basic information and will help those of you who now, or in the future, decide to use ECMO.

Petr Ostadal
Jan Belohlavek
Martin Balik
Hynek Riha

(We are fully aware that we could not and have not described all the pitfalls of using ECMO. For anyone interested, we will gladly remedy this shortcoming by individual consultations on specific problems. Contact us at: ostadal.petr@gmail.com; jan.belohlavek@vfn.cz.)

CONTENTS

1 INTRODUCTION

Extracorporeal membrane oxygenation (ECMO) is a method of extracorporeal life support (ECLS). The basic principle is extracorporeal blood circulation. Using a blood pump, blood is drained from the patient's vein and passed into the oxygenator, where gas exchange takes place (the blood is enriched with O_2, and CO_2 is removed), and the oxygenated blood returns to the patient's bloodstream.

Suitable candidates for ECMO treatment are patients who have the following:

- respiratory failure with hypoxemia / hypercapnia despite maximum conventional ventilation support
- ventilator-associated lung injury
- progressive cardiogenic shock or cardiogenic shock refractory to conventional treatment
- a combination of respiratory and cardiac failure unresponsive to conventional treatment
- cardiac arrest refractory to standard resuscitation techniques

Selection of the appropriate type of ECMO depends primarily on the patient's overall hemodynamic status. Veno-venous (VV) ECMO is used in isolated lung injury with satisfactory left and right ventricular function, whereas venoarterial (VA) ECMO is administered in cases of combined heart and lung involvement or isolated heart disease. Very occasionally, ECMO is also used in shock states other than cardiogenic shock, such as septic shock.

In this manual, we focus on ECMO with medium or high blood flow and an extracorporeal blood pump. Therefore, we do not discuss low-flow extracorporeal lung support systems (pumpless extracorporeal lung assist - pECLA, low-flow ECMO, or extracorporeal CO_2 removal - eCCO_2R), which are most frequently used for hypercapnia management.

2 VENO-VENOUS (VV) ECMO

VV ECMO uses venous blood intake from the superior and/or inferior vena cava, and after blood gas exchange in the oxygenator, the blood returns to the right atrium. It is used in severe pulmonary disease with preserved heart pump performance. VV ECMO partially or completely replaces gas exchange in the lungs - oxidation and CO_2 removal - thus reducing the need for ventilation support, which in turn lessens the risk of ventilator-induced lung damage. The goal of introducing VV ECMO is usually to bridge the critical period to recovery and, in exceptional cases, to allow lung transplantation.

Patients with clinical indications for VV ECMO primarily include those with acute respiratory distress syndrome (ARDS), typically with bacterial or viral pneumonia, pulmonary damage by inhalation injury, reperfusion edema, pulmonary aspiration and other similar conditions.

2.1 CANNULA INSERTION

For cannulation, we can use separate inflow and outflow cannulas, or a cannula with two lumens, combining venous blood intake and oxygenated blood return in one cannula; this "double-lumen" cannula is usually inserted into the right internal jugular vein (Fig. 2.1). Otherwise, the inflow cannula is usually introduced into the femoral artery with the tip placed in the inferior vena cava just below the right atrium. The outflow cannula is most often introduced into the internal jugular vein with the tip located in the superior vena cava or in the right atrium (Figs. 2.2, 2.3).

The position of the cannula can be checked using ultrasound (transthoracic - subxiphoid view - or transesophageal echocardiography) (Fig. 2.4) or fluoroscopy (X-ray). When using two separate cannulas, a gap of 4-6 cm between the tip

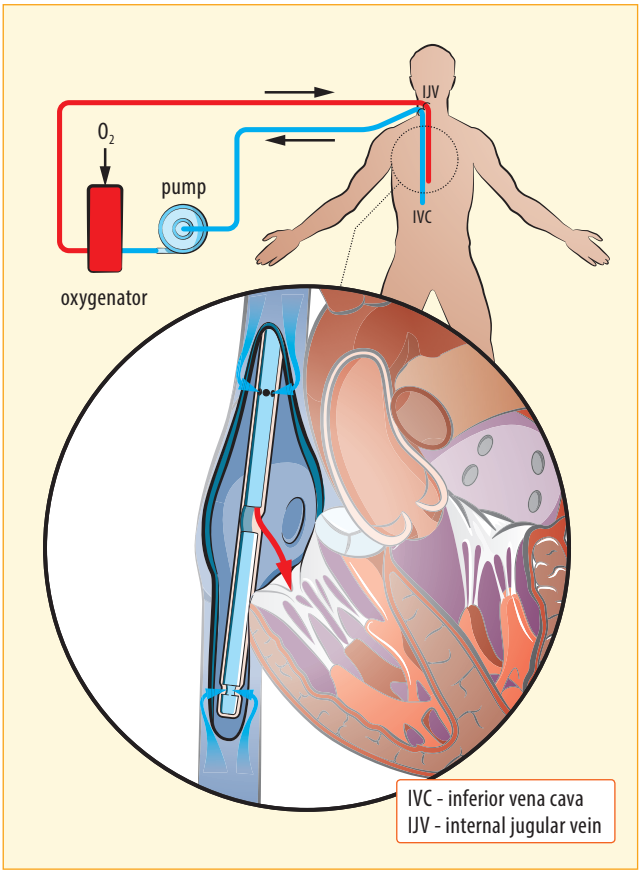

Fig. 2.1 VV ECMO, jugular double-lumen cannula.

of the cannulas is essential to limit oxygenated blood recirculation, and the suction cannula must be placed above the level of the suprahepatic veins or the Eustachian valve to provide sufficient blood flow. When using a double-lumen cannula, it is necessary to place it in such a way that the outflow hole is simultaneously directed against the tricuspid valve in the right atrium.

4 VV ECMO OR VA ECMO?

When considering the risks of using these methods, VV ECMO has a number of advantages over VA ECMO. There are no risks of potentially serious arterial damage and no risk of blood clot embolization or air bubbles entering the systemic circulation. In contrast, there is a risk of pulmonary embolization from the cannula or thrombus formation after cannula extraction, especially in complicated cases and in patients requiring longer-term VV ECMO support. In addition, the VV ECMO modality is a low-pressure circuit, which thus places less stress on the circuit and on the oxygenator than VA ECMO, resulting in a longer lifetime.

The use of VV ECMO is also not associated with more pronounced hemodynamic effects because the blood is drained from and returned to the same part of the circulation, i.e., the increased VV ECMO blood flow does not affect the central venous pressure (CVP); however, the CVP is not a frequently used parameter when considering the drainage effect of the outlet cannula. In contrast, with VA ECMO, the increase in extracorporeal flow reduces the CVP and pulmonary circulation. Preservation of the pulmonary flow in VV ECMO is also likely to allow for the faster recovery of pulmonary parenchyma damage in severe pneumonia and other pulmonary pathologies compared to VA ECMO, where the lymphatic system becomes an important factor in drainage of the parenchyma by decreasing the blood flow through the lungs.

The main advantage of VA ECMO, on the other hand, is complex circulatory and pulmonary support, although at the cost of increased myocardial afterload with a therapeutically reduced preload. When selecting the ECMO modality, we prefer to use VV in all cases where cardiac function has not been severely damaged. If a change occurs in the patient's

condition, for example, a sudden deterioration in cardiac function, an arterial outflow cannula can be introduced and the circuit transferred to the VA ECMO modality, and vice versa - if myocardial function improves, the configuration can be changed to VV. Alternatively, when appropriate, a veno-arterio-venous (VAV) configuration can be used to combine the advantages of both the VV and VA modalities (see Section 11.4).

5 INDICATIONS AND CONTRAINDICATIONS

ECMO is indicated for potentially reversible or otherwise treatable life-threatening conditions affecting the heart or lungs, that are refractory to conventional therapy. There must be a recognized indication for the introduction of ECMO, and the patient must have no absolute contraindications. When considering relative contraindications, the team must also be clear toward which goal the ECMO therapy is being used as a bridge.

5.1 VV ECMO: INDICATIONS

Indications for the introduction of VV ECMO are insufficient blood oxygenation or insufficient CO_2 removal despite intensive ventilation support and/or impending ventilator-induced lung injury, provided, of course, that other causes of pulmonary failure (e.g., high positive fluid balance, undrained pneumothorax, and bronchial tree obstruction) have been ruled out.

For ECMO indications in respiratory failure, the Murray score, which evaluates the oxygenation index, X-ray findings, positive end-expiratory pressure (PEEP), and compliance, is regularly used. If a patient has a total value of ≥ 3, the status is generally considered to be sufficiently serious to justify the initiation of ECMO support.

Murray score:
- paO_2 / FiO_2 (mmHg / oxygen fraction in the range 0-1): ≥ 300 = 0 points; 225-299 = 1 point; 175-224 = 2 points; 100-174 = 3 points; < 100 = 4 points
- chest X-ray: normal = 0 points; 1 point per quadrant with infiltration
- PEEP (cmH_2O): ≤ 5 = 0 points; 6-8 = 1 point; 9-11 = 2 points; 12-14 = 3 points; ≥ 15 = 4 points
- compliance (ml/cmH_2O): ≥ 80 = 0 points; 60-79 = 1 point; 40-59 = 2 points; 20-39 = 3 points and ≤ 19 = 4 points

The total number of points is divided by 4 to give the Murray score. Thus, for example, patients with a paO_2 of 60 mmHg, 100% oxygen, diffused lower lung infiltrates, a PEEP of 12 cmH_2O and a compliance of 19 ml/cmH_2O (breath volume of 440 ml at peak inspiratory pressure of 35 cmH_2O), the sum of points is 4 + 2 + 3 + 4 = 13, giving a Murray score of 3.25.

If we wish to simplify the indication, we can consider the introduction of VV ECMO based on the following values:
- paO_2 / FiO_2 < 60-80
  or
- paO_2 / FiO_2 < 100 and $paCO_2$ > 100 mmHg for more than 1 hour

The Murray score cannot be used for patients with hypercapnic respiratory failure, and VV ECMO indication is considered in these cases mainly on the basis of progressive acid-base imbalance with a pH ≤ 7.2, assuming, of course, that conventional ventilation failure and other causes of pulmonary failure (e.g., pneumothorax, airway obstruction, reversible / correctable bronchospasm) have been eliminated.

5.2 VV ECMO: CLINICAL CONDITIONS ELIGIBLE FOR IMPLANTATION

Common:
- severe pneumonia (bacterial and viral; Fig. 5.1)
- ARDS
- pulmonary contusion

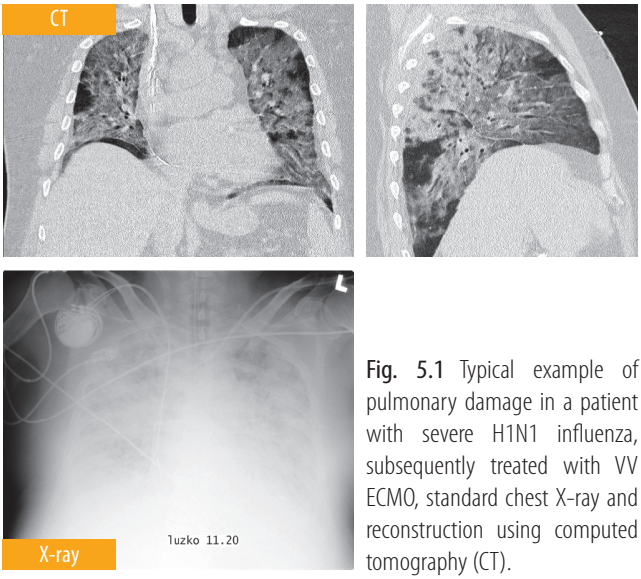

Fig. 5.1 Typical example of pulmonary damage in a patient with severe H1N1 influenza, subsequently treated with VV ECMO, standard chest X-ray and reconstruction using computed tomography (CT).

- barotrauma, bronchopleural fistula
- acute graft failure after lung transplantation

Less common:
- pulmonary alveolar proteinosis
- inhalation of toxic gases
- status asthmaticus
- obstruction of the airway - as a bridge to a specific bronchological therapy
- aspiration

5.3 VV ECMO: CONTRAINDICATIONS

Absolute:
- severe brain damage
- irreversible lung damage
- severe heart failure, cardiogenic shock
- severe pulmonary hypertension (mPAP > 50 mmHg)

- cardiac arrest
- advanced-stage incurable disease (e.g., malignancy, AIDS)
- patients in whom it has been decided to withhold therapy

Relative:
- age > 75 years
- obesity with a BMI over 40 kg/m^2
- aggressive artificial lung ventilation ≥ 7 days
- advanced liver disease
- trauma with extensive bleeding
- multiorgan failure
- hemorrhagic diathesis and severe thrombocytopenia

5.4 VA ECMO: INDICATIONS

5.4.1 Cardiogenic shock

Cardiogenic shock refractory to standard treatment is indicated for ECMO, when, despite the administration of sufficient doses of inotropes and vasopressors (and support with an intra-aortic balloon pump or other devices in selected indications), organ perfusion remains poor (decreased cerebral and tissue oxygenation below 50%, decrease in diuresis below 30 ml/h, increased lactate, $SvO_2 < 55\%$, signs of encephalopathy, cardiac index < 2.2 L/min/m^2).

DEPOMPENSATION OF CHRONIC HEART FAILURE

For cardiogenic shock in decompensated chronic heart failure, VA ECMO is indicated in the following cases:
- if the goal is as a bridge to recovery
- as a bridge to intervention, while at the same time, prior consent to the intervention by a specialist once the patient's condition has improved has been granted or is expected
- if neither of the above is viable, the patient must meet the criteria for inclusion in the transplant program. In the case of borderline findings, it is advisable to consult the transplantation center prior to implementing support and to request prior approval for inclusion in the transplantation program.

DE NOVO ACUTE HEART FAILURE

For cardiogenic shock in de novo acute heart failure, VA ECMO is indicated in the following cases:

- as a bridge to recovery (in myocarditis, acute myocardial infarction)
- as a bridge to intervention (in arrhythmic storms, MI with mechanical complications), while at the same time, prior consent to the intervention by a specialist once the patient's condition has improved has been granted or is expected
- if neither of the above apply, the patient must have no known conditions excluding them from the transplantation program. In borderline cases, it is advisable to consult the transplantation center prior to implementing the support and to request prior approval for inclusion in the transplantation program.

5.4.2 Cardiac arrest

The introduction of ECMO is indicated in cardiac arrest (in this context, the term ECPR - extracorporeal cardiopulmonary resuscitation - is often used) under the following conditions:

- refractory cardiac arrest with failure to restore blood circulation after at least 10 minutes of standard resuscitation procedures
- the cardiac arrest was witnessed, and cardiopulmonary resuscitation was immediately initiated
- resuscitation was initiated and is continuing without unnecessary interruptions
- no terminal disease
- preliminary bedside laboratory results do not exceed extreme values (lactate > 21 mmol/L, pH < 6.7, SvO_2 < 8% - according to one large cohort study, no one with such values has survived).
- some centers insist on a shockable initial rhythm (ventricular fibrillation or ventricular tachycardia). The prognosis of ECPR with a nonshockable rhythm is generally very poor.

5.4.3 Arrhythmic storm

In refractory arrhythmic storms or sustained refractory hemodynamically significant ventricular tachycardia, the use of VA ECMO is indicated if a hemodynamically effective rhythm cannot be maintained with the use of standard pharmacological and nonpharmacological treatments.

5.4.4 VA ECMO and cardiac surgery

Perioperatively, the introduction of an ECMO system in cardiac surgery patients is indicated if the patient cannot be disconnected from cardiopulmonary bypass due to low cardiac output using conventional pharmacological or nonpharmacological support, if there is a potentially reversible perioperative failure of the left or right ventricle, or if there are other complications with reasonable expectation of recovery or of transfer to another support system (e.g., in the case of complex cardiac surgery with a long cross-clamp time or extended cold ischemia time during transplantation). VA ECMO is also indicated preventatively in patients in a critical condition requiring subsequent surgical correction to stabilize organ function (e.g., acute rupture of the ventricular wall in patients with myocardial infarction and developing cardiogenic shock). In such cases, VA ECMO is introduced preoperatively, and after stabilization, the patient undergoes surgery. ECMO can also be used in early postoperative care.

5.4.5 Support during high-risk interventions

The use of VA ECMO can be considered a preventative measure in a planned intervention with a high risk of iatrogenic cardiac arrest or severe circulatory failure with the risk of ischemic tissue damage (e.g., transcatheter aortic valve implantation - TAVI, complicated PCI or electroanatomic mapping and the ablation of hemodynamically intolerable ventricular tachycardia in patients with severe left ventricular dysfunction, when the introduction of VA ECMO enables the ablation to take place even during arrhythmia, which would otherwise lead to rapid circulatory collapse).