LEADING ARTICLE

Extracorporeal life support / membrane oxygenation following paediatric cardiac surgery

Prasad Krishnan, MBBS, MS, MCh, MD

Consultant Cardiac Surgeon, Division of Cardiovascular Surgery, Mayo Clinic, 200, First Street SW, Rochester, MN 55905 ,USA.

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Introduction

Despite technical improvements in congenital heart surgery, mortality as a result of cardiac dysfunction after corrective surgery remains a serious problem. A total of 1 to 5% of these patients will require some form of mechanical support [1-3].

Extracorporeal membrane oxygenation (ECMO) is the most commonly used modality for mechanical support of the failing circulation in children, following heart surgery. Although ECMO is the traditional term associated with this technique, Extracorporeal Life Support (ECLS) is the preferred mnemonic; since in the post cardiac surgical setting, the term "life support" encompasses functions other than "oxygenation", including cardiac and hemodynamic support as well as carbon dioxide elimination.

While in adults with coronary artery disease, pure left ventricular failure is a common cause of heart failure. In children with congenital heart disease additional right ventricular failure, respiratory failure, and pulmonary hypertension often contribute substantially to low cardiac output. In addition, children with myocarditis or dilatated cardiomyopathy (DCM) may also require ECLS, if conservative medical treatment is inadequate.

ECLS provides cardiopulmonary support so that the patient is spared the deleterious effects of high airway pressure, high FiO2, and perfusion impairment secondary to cardiac "pump dysfunction" while "reversible" pathophysiologic processes are allowed to resolve either by spontaneous means or by medical or surgical therapeutic intervention.

Correspondence: Prasad Krishnan, Consultant Cardiac Surgeon, Division of Cardiovascular Surgery, Mayo Clinic, 200, First Street SW, Rochester, MN 55905, USA.

Email: prasad_krishnan@hotmail.com

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Review of the ECLS Organization's Registry Reportin terms of major diagnostic categories demonstrates that pediatric cardiac support (for patients 16years or younger) currently constitutes nearly 30% of total ECLS cases [4]. Since the mid 1980s there has been a steady increase in the proportion of pediatric cardiac cases in comparison to other patient groups This increase reflects both wider use of ECLS to support circulatory failure in children as well as decreased utilization of ECLS for respiratory failure owing to the success of other respiratory support measures such as surfactant administration, high-frequency jet ventilation and nitric oxide. In light of this change in utilization pattern, a greater understanding of the issues that lead to successful support of cardiac patients becomes increasingly important for all tertiary care pediatric cardiac surgical centers.

Indications

Indication for an ECLS is achieved after failing attempts at weaning off from cardiopulmonary bypass (CPB) under pharmacological support or when there is clinical deterioration necessitating resuscitation. The decision to institute the ECMO is made by the cardiovascular surgeon and typically when inotropic support of epinephrine exceeds 0.15 mcg/kg/min, associated with one or more following conditions; systemic ventricular dysfunction with elevated filling pressures (right atrial pressure (RAP) >20 mmHg, left atrial pressure (LAP) >15 mmHg), difficulty with oxygenation and/or ventilation, pulmonary hypertension with right ventricular dysfunction.

Methodology

Cannulation for ECLS is performed either in the operating room or in the intensive care unit. The patient is given 30-100 units/kg of heparin; the activated clotting time is usually maintained between 170 and 200 seconds. On institution of ECLS, inotropic support is weaned to minimal levels to keep mean arterial blood pressures at 50 mm Hg. Flow rates are maintained depending on hemodynamic situation until the SVO2 is 75%. The mean blood pressure range for neonates on ECLS is 40-65 mm Hg. Normothermia is maintained in all patients.

Development of membrane oxygenators were a significant advance during the evolution of cardiopulmonary bypass. Although microporous polypropylene hollow fiber oxygenators are standard devices used for extracorporeal membrane oxygenation (ECMO), they have limitations such as development of plasma leakage. The recent invention of the poly-4-methyl-1-pentene (PMP) diffusion membrane has led to the development of hollow-fibre technology with a true (nonmicroporous) membrane. This has enabled the use of a low-resistance device with all its inherent advantages, without plasma leakage necessitating circuit changeover. This new technology has also enabled the use of a single device for all patient sizes, so we now have an ECLS circuit set up at all times, minimizing the time required for support to be available, potentially improving survivor morbidity. Development of centrifugal pumps and miniaturization have also enabled integration of the oxygenator, heat exchanger and pump into one composite unit.

Management of body systems during ECLS

Pulmonary system

ECLS is used temporarily while awaiting pulmonary recovery. In the classic use ECLS, the typical ventilator settings are FiO2 of 0.30, PIP of 15-25 cm H2O, a positive end-expiratory pressure (PEEP) of 3-5 cm H2O, and intermittent mechanical ventilation (IMV) of 10-20 breaths per minute. Pulmonary hygiene is strict and requires frequent endotracheal suctioning, usually every 4 hours depending on secretions, and a daily chest radiograph.

Cardiovascular system

Systemic perfusion and intravascular volume should be maintained. Volume status can be assessed clinically by urine output and physical signs of perfusion and by measuring the central venous pressure and the mean arterial blood pressure. Cardiac output can be enhanced with minimal doses of inotropic agents. An echocardiogram should be performed to exclude any major residual defects that may require surgical correction other than ECLS

Central nervous system

Central nervous system complications are the most serious and are primarily related to the degree of hypoxia and acidosis. Avoiding paralytic agents and performing regular neurologic examinations are recommended. A head ultrasound should be obtained before beginning ECLS in a neonate. Reevaluation with serial head ultrasounds may be needed on a daily basis, especially after any major event. In patients with seizures or suspected seizures, aggressive treatment is recommended (i.e., phenobarbital).

Renal system

During the first 24-48 hours on ECLS, oliguria and acute tubular necrosis associated with capillary leak and intravascular volume depletion are common because ECLS triggers an acute inflammatory like reaction. The diuretic phase, which usually begins within 48 hours, often is one of the earliest signs of recovery. If oliguria persists for 48-72 hours, diuretics are often required to reduce edema. When renal failure does not improve, hemofiltration or hemodialysis filters may be added to the circuit.

Haematologic considerations

To optimize oxygen delivery, the patient's hemoglobin should be maintained at 12-14 gms% using packed red blood cells (pRBCs). As a result of platelet consumption during ECLS, platelet transfusions are required to maintain platelet counts above 100. ACT should be maintained at 180-240 seconds to avoid bleeding complications.

Infection control

Strict aseptic precautions are required. The presence of infection is monitored by obtaining cultures from the circuit at least once per day. Based on institutional experience, the protocol frequency may vary. Other appropriate cultures (eg, fungal and viral) should be sent as needed.

Fluids, electrolytes, and nutrition

Patients on ECMO require close monitoring of fluids and electrolytes. The high-energy requirements should be met using hyperalimentation techniques. The patient's weight increases in the first 1-3 days on ECLS because of fluid retention.

Medications

- Doses of most inotropic medications, such as dopamine, dobutamine, and epinephrine, usually can and should be decreased once the patient is on ECLS.
- Diuretics, such as furosemide, may be required for mobilization of tissue fluids.
- H2 antagonists are usually administered for a prevention of a gastrointestinal tract bleeding.
- Only minimal sedation with fentanyl, midazolam, or morphine is required after stabilization.
- Phenobarbital can be used if the patient has seizures.
- Antibiotics are given, based on institutional experience.

Complications

Mechanical complications

- Clots in the circuit are the most common mechanical complication. Major clots can cause oxygenator failure, consumption coagulopathy, and pulmonary or systemic emboli.
- Cannula placement can cause damage which causes massive mediastinal bleeding. Dissection of the arterial intima can lead to lethal aortic dissection and result in malperfusion
- Air in the circuit can range from a few bubbles to a complete venous air lock.
  This air can originate in the dislodgement of the venous cannula, a small tear in the membrane, or high partial pressure of oxygen in the blood. A large bolus of air can be fatal.
- Oxygenator failure is defined either as decreased oxygen or carbon dioxide transfer or as presence of consumptive coagulopathy. A failing membrane should be replaced immediately.
- Cracks in the connectors and tube rupture have become less serious problems.
- Pump malfunction may be a manifestation of inadequate venous return to the pump.
- Heat exchanger malfunction can cause severe hypothermia. Failure of the entire circuit, including the oxygen source and oxygen blenders, may occur. The team must be familiar with taking care of these problems by rehearsing these “what-if” situations.

Weaning from ECLS

Readiness to be weaned from ECMO is evaluated by clinical assessment and echocardiography at a reduced pump flow. Before weaning, ventilator support, fluid status, and inotrope and vasodilator treatment are optimised. Pump flow is reduced over 14 hours and the circuit clamped off. Decannulation is performed following a satisfactory 12 hour period on conventional support.

Duration of support

The aim of cardiac ECMO is to profoundly unload the heart and decrease its work, allowing a finite time interval for the myocardium to recover from injury. This period is rarely more than 1421 days in most centres due to cumulative adversity (4)

Results

ECLS after surgical correction of congenital cardiac disease

In a recent report from the Mayo Clinic [5], the weaning rate from ECMO was 68.7%, and the hospital survival was 54.3% which is the range reported by others [6-8]. In the Mayo Clinic report the lowest pH during ECLS treatment was the only predictor of mortality (P = 0.006). This is consistent with a study[9] that showed that the highest lactate level within 48 hours on ECMO predicted death.

The initial policy of offering cardiac ECMO only for biventricular hearts has been changed, as it has become clear that a patient's anatomical diagnosis and operative procedure are imprecise guides to the reversibility of ventricular dysfunction [10]

ECLS for acute fulminant myocarditis

The optimal approach for children presenting with acute, fulminant myocarditis may be to provide mechanical circulatory support (even if required for prolonged periods) in anticipation of eventual ventricular recovery, thereby avoiding transplantation in most of these children. Previous reports have shown the feasibility of this approach with full return of ventricular function in children and young adults with myocarditis after weeks or months of mechanical support [11]. While previously felt to be too complex to provide support during transport, the use of ECLS for the transport of critically ill patients is now routinely performed at some highly specialized centers (12). In this report, all patients survived transport while 78% survived to hospital discharge.

ECLS for perioperative support in Pediatric Cardiac transplantation.

Galantowicz and Stolar (13) reported a multicenter analysis with a 40% success rate in salvaging children who required ECLS in the immediate postoperative period after cardiac transplantation. Other reports with smaller numbers have shown similar results (14). Severe acute rejection episodes after cardiac transplantation may be characterized by rapid deterioration with ECMO providing temporary, life-saving support until anti-rejection therapy becomes effective [13-14].

Summary

While ECLS uses technology that was first developed decades ago, recent advances in technology and better understanding of the pathophysiology have enabled it to retain its status as the mainstay of mechanical circulatory support for children in the acute setting. In fact, new applications for pediatric cardiac ECLS continue to emerge, ensuring its continued importance in this role. It thus constitutes an integral part of any tertiary care center performing pediatric cardiac surgery.

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