

Conversion from Extracorporeal Membrane Oxygenation to Total Cardiopulmonary Bypass: A Simplified Method

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Abstract: Pediatric patients who have preoperative hemodynamic instability or postoperative cardiac decompensation may frequently require the use of extracorporeal membrane oxygenation (ECMO) for stabilization of cardiac and respiratory function. While ECMO can be a therapeutic treatment for the congenital pediatric patient, it does not allow the additional functions of a complete cardiopulmonary bypass (CPB) circuit should subsequent surgical revision in the operating room be required. This paper will discuss our approach to converting the ECMO circuit to total cardiopulmonary bypass al-

lowing the use of cardioplegia, cardiotomy suction, and modified ultrafiltration. This technique allows the conversion to CPB without ceasing support to the critically ill patient or exposing them to additional blood products or surface area in the priming of a new extracorporeal circuit. In addition, this circuit design allows for the resumption of ECMO support utilizing the same circuit if the patient necessitates it. **Keywords:** extracorporeal membrane oxygenation, cardiopulmonary bypass, cardiac arrest. *JECT, 2003;35:196-199*

In many children with congenital heart defects, myocardial function can be abnormal either from preoperative underlying disease or postoperatively from the effects of surgical repair with cardiopulmonary bypass (CPB). Many mechanical assist devices have met with success in the adult population; however, options for infants and children have been limited. Intra-aortic balloon pumps (IABP) and ventricular assist devices (VAD) have been used with some success in the pediatric population (1-4). However, limitations to both of these devices exist for neonatal and pediatric patients. IABP, while assisting the left heart and coronary circulation, is not effective in right heart failure and the use of a VAD in infants can be limited by the patient's smaller anatomical size.

Extracorporeal membrane oxygenation (ECMO), a treatment that can support respiratory and cardiac function, may prove to be the optimal treatment for severe myocardial dysfunction (5,6). ECMO can be therapeutic preoperatively for unstable patients waiting for surgical repair or for postoperative surgical complications such as sudden cardiac arrest. ECMO for postoperative complications can allow the patient to be stabilized, re-evaluated, and if necessary, brought back to the operating room for subsequent surgical revision. Although the ECMO circuit

provides respiratory and cardiac support for the patient, it does not allow the additional functions of a complete CPB circuit such as cardioplegia, modified ultrafiltration (MUF), left-ventricular vent, and cardiotomy suction. This report describes our technique of conversion from a conventional ECMO to total CPB without ceasing support to the patients or exposing them to a new extracorporeal circuit.

DESCRIPTION

Since August 2000, three patients were placed on ECMO following complications from their initial surgery or for preoperative hemodynamic stabilization. These patients were then brought back to the operating room for subsequent surgical revision of their cardiac anatomy. Table 1 denotes the preoperative diagnosis, date of ECMO initiation, and termination, surgical revisions and outcome for each patient. Each ECMO pump consisted of a Stöckert SIII Modular roller pump (Cobe Cardiovascular, Arvada, CO) with pressure control monitors/regulators for the venous bladder and silicone membrane. A silicone membrane and stainless steel heat exchanger (Medtronic, Minneapolis, MN) was used along with 1/4-inch Tygon tubing (Saint-Gobain Performance Plastics Corporation, Akron, OH) for the pump raceway. A CDI 500 blood gas monitor (Terumo Cardiovascular, Ann Arbor, MI) supplied continuous blood gases for the ECMO circuit (Figure 1). Each ECMO circuit was primed with Plasmalyte-A, washed red blood cells, 25% mannitol (1.0

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Table 1. ECMO/CPB patients.

	Patient 1	Patient 2	Patient 3
Preoperative diagnosis	TOF, absent PV syndrome, respiratory failure, tracheomalacia	Tricuspid atresia, Ebstein's anomaly lymphangiectasia	HLH, TAPVR, coarctation of aorta, s/p Stage I Norwood
ECMO initiation	8/22/00	9/5/00	10/14/00; 12/5/00
Surgical revision	8/24/00	9/8/00; 9/9/00	10/16/00; 12/7/00; 12/12/00
Surgical procedure	Repair TOF, VSD closure, RVOT reconstruction w/homograft	Ligation PDA, central shunt, reduction RA (reduce ASD size); shunt revision lung biopsy	Revision central shunt (10/16), revision of central shunt (12/7/00), thrombectomy and revision of central shunt (12/12/00)
ECMO termination	8/24/00	9/24/00	10/16/00; 12/12/00
Patient outcome	Discharged to home	Patient expired	Patient expired

ECMO: Extracorporeal Membrane Oxygenation; CPB: Cardiopulmonary Bypass; TOF: Tetralogy of Fallot; PV: Pulmonary Valve; VSD: Ventricular Septal Defect; RVOT: Right Ventricular Outflow Tract; PDA: Patent Ductus Arteriosus; RA: Right Atrium; ASD: Atrial Septal Defect; HLH: Hypoplastic Left Heart; TAPVR: Total Anomalous Pulmonary Venous Return.

gm/kg not to exceed 12.5 gm), 25% albumin (1 gm/kg not to exceed 25 gm), 50 mL of sodium bicarbonate (1mEq/mL), 300 U of heparin sulfate (1000 U/mL), and 125 mg calcium chloride (100 mg/mL). Following ECMO initiation, the patients were stabilized and subsequently assessed for any surgical revisions that were necessary. The patients were then transported to the operating room where the ECMO circuit was modified to sustain full cardiopulmonary bypass.

Once in the operating room, the bridge of the ECMO circuit was divided to provide a venous portion and an arterial portion (Figures 2,3). In each case, an integrated Lilliput 1 hardshell oxygenator (Cobe Cardiovascular, Arvada, CO) was incorporated into the venous portion of the ECMO bridge. The venous reservoir/cardiotomy portion was used to provide additional venous return and cardiotomy/vent return. The membrane and heat-exchanging portion of the Lilliput was excluded from the circuit. The ECMO silicone oxygenator and heat exchanger continued to supply oxygenation and temperature control for the patient. Additional venous return was provided by passing

off a sterile, primed, 1/4-inch venous line from the field and connecting it to the venous inlet of the Lilliput.

The arterial portion of the bridge was "Y"ed with a 1/4 connector to include a second arterial line, if necessary, and a blood cardioplegia line. In instances where deep hypothermic circulatory arrest was used, new arterial canulae was placed in the aorta and connected to the CPB arterial line. A dual-headed roller pump provided 2:1 blood cardioplegia. The roller head containing the blood cardioplegia line, once flushed of all cardioplegic solution, was also used for modified ultrafiltration (MUF). A separate heater/cooler was connected to the cardioplegia device to provide cold cardioplegia and warm blood during MUF. Two additional pump heads were integrated and connected to the cardiotomy portion of the Lilliput for cardiotomy and vent return. Figures 4 and 5 illustrate the completed ECMO/CPB circuit. In each case, the patients were systemically heparinized with 300 IU/kg of heparin sulfate. This allowed the complete use of cardiopulmonary bypass, including the availability of cardioplegia and MUF, if needed. Subsequent to the surgical revision, the

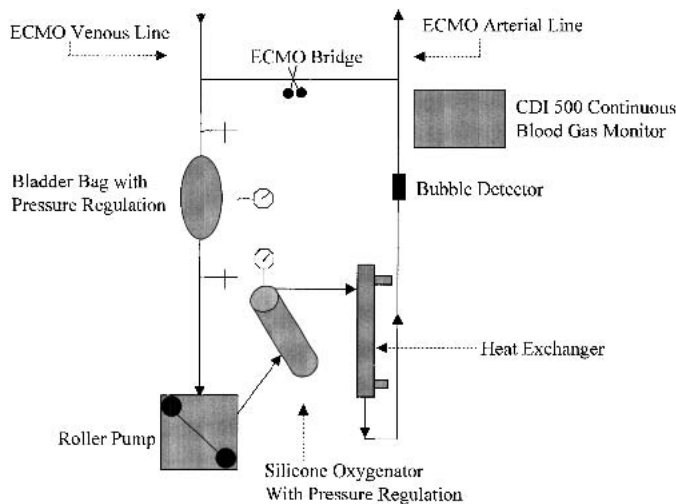


Figure 1. Diagram of ECMO circuit. ECMO: Extracorporeal Membrane Oxygenation.

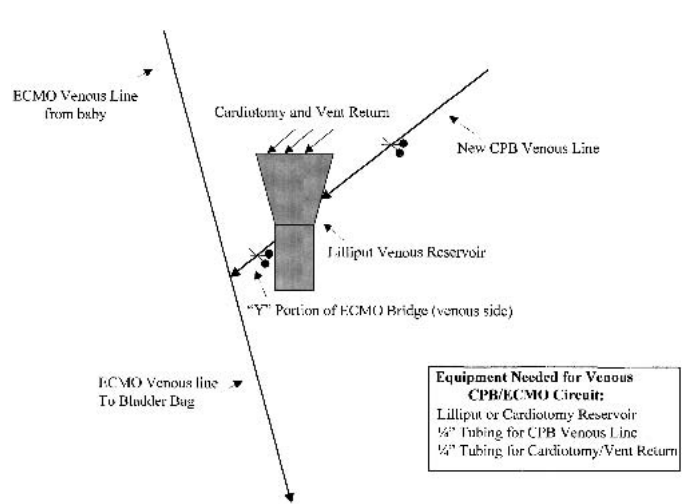


Figure 2. Venous portion ECMO/CPB circuit. ECMO: Extracorporeal Membrane Oxygenation; CPB: Cardiopulmonary Bypass.

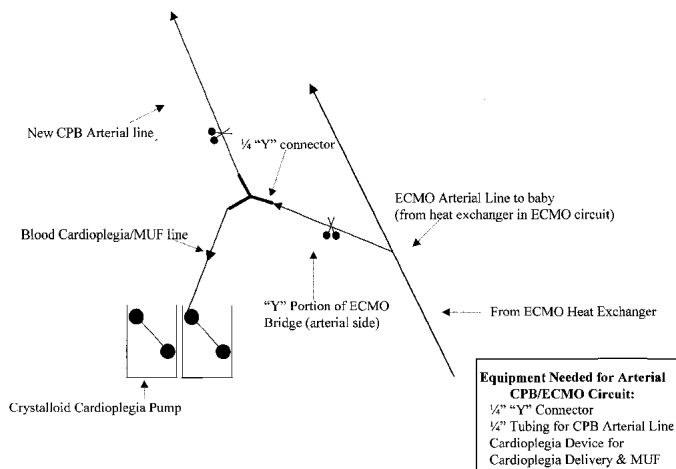


Figure 3. Arterial portion ECMO/CPB circuit. ECMO: Extracorporeal Membrane Oxygenation; CPB: Cardiopulmonary Bypass; MUF: Modified Ultrafiltration.

patient could be maintained on ECMO with the same circuit if necessary and transported back to the intensive care unit. In these cases, the bridge of the ECMO circuit was resecured with a 1/4 connector, and the extra equipment necessary for complete CPB was removed.

DISCUSSION

At Children’s Hospital of Illinois, the use of ECMO is the device of choice for children who are in need of respiratory or mechanical cardiac support who are not responsive to traditional ventilatory and pharmacologic therapies. In cases of sudden cardiopulmonary decompensation, such as these three infants (< 3 kg), complete cardiac function and respiratory function can be supported with ECMO. It is understood that ECMO cannot be expected to treat any underlying cardiac or pulmonary dis-



Figure 5. Photograph of completed ECMO/CPB circuit.

ease, but it can provide a period of physiologic support during which options for treatment can be ascertained.

The initial experience for the ECMO patient who required additional surgical intervention prompted us to construct a system that would provide a rapid form of mechanical cardiopulmonary support in the event of acute cardiovascular collapse, but also a system that could be easily converted to provide full CPB support similar to our conventional system.

During the design of this system several key issues were addressed. First, attempts to minimize patient trauma are at the forefront of this system design. This began with minimizing the time from CPR to ECMO support by keeping an ECMO pump ready in the pediatric intensive care unit (PICU). It is noted that the time from cardiac arrest to the institution of ECMO is critical, and several papers have documented the importance of time during a sudden cardiac arrest period to when the infant is stabilized on ECMO (7).

Second, we clearly recognized the deleterious effects that could occur from multiple exposures to systems (ECMO to CPB back to ECMO). This system reduces the use of blood products, thereby reducing volume exposure, foreign surface area, and the subsequent inflammatory response that can ensue. Finally, this setup has provided a system that physicians, perfusionists, and nurses are comfortable with in the intensive care unit and in the operating room. In retrospect, we have recognized that a simple cardiotomy reservoir could be used in place of the Lilliput hardshell integrated oxygenator, contributing to additional cost savings for the patient.

Although ECMO has traditionally been used for respiratory support in neonatal patients with such diseases as pulmonary hypertension, meconium aspiration, and congenital diaphragmatic hernia, we feel that it can be successfully used for patients who experience sudden cardiac decompensation. Several centers have supported the use

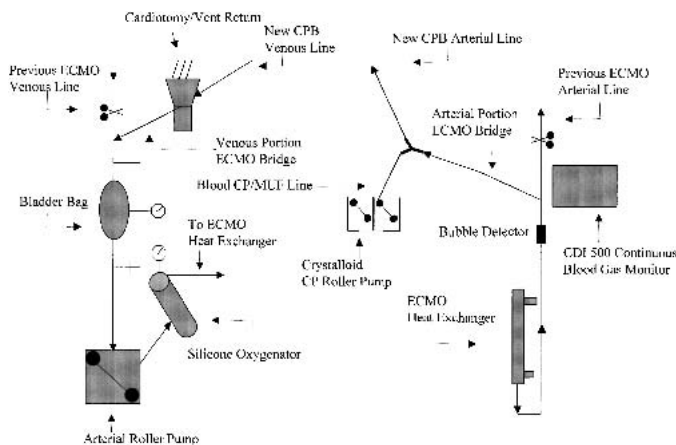


Figure 4. Diagram of completed ECMO/CPB circuit. ECMO: Extracorporeal Membrane Oxygenation; CPB: Cardiopulmonary Bypass; CP: Cardioplegia; MUF: Modified Ultrafiltration.

of ECMO in pediatric patients for sudden cardiac arrest situations (8,9).

Finally, recognizing that this manuscript is focused on a method for converting ECMO to total CPB, patient outcomes cannot be totally disregarded. Results from the most recent Extracorporeal Life Support Organization (ELSO) registry find favorable outcomes for infants treated for respiratory disease (10). However, in cases where infants received pre-ECMO CPR the outcomes are traditionally not as optimistic (10,11). The most recent international Extracorporeal Life Support Organization (ELSO) registry reported survival for neonatal and pediatric patients who underwent Extracorporeal Cardiopulmonary Resuscitation (ECPR) and survived extracorporeal life support (ECLS) at 58 and 44%, respectively. However, only 40% of the neonatal and 37% of the pediatric ECPR patients survived to discharge or transfer (10). Although all of the patients who required ECPR at our institution were successfully weaned, only one survived to be discharged to home.

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