EXTRACORPOREAL MEMBRANE OXYGENATION IN PEDIATRIC PATIENTS

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Extracorporeal membrane oxygenation (ECMO) is the use of cardiopulmonary bypass pumping for prolonged periods of time to support individuals who have undergone acute pulmonary failure. Although the greatest experience with this technique has been in neonates, its use is increasing in both older children and adults. Although the basics are the same for both groups, non-neonatal ECMO differs in the size of the circuit, the length of run, the rate of complications, and the rate of survival. It is an important, evolving procedure, and surgical technologists need to understand the procedure in order to assist with the cannulation.

In this article, our team's experience to date at both the University of Chicago Medical Center and the Ochsner Clinic is reviewed.

The first successful use of ECMO was reported in 1972 in an adult with adult respiratory distress syndrome (ARDS). Subsequent studies on ECMO in adults with ARDS showed a 10% survival rate for patients treated with ECMO and an 8% survival rate for those treated with conventional therapy.[1] This study is thought to be misleading as most of these patients had irreversible lung disease at initiation of ECMO and remained on highly damaging levels of oxygen and ventilatory support throughout their ECMO course.[2] The first successful application of ECMO in a newborn was in a baby with meconium aspiration syndrome (MAS) at the University of California, Irvine, in 1975. Consequently, attention was turned to ECMO in neonates who have a greater capacity for pulmonary healing. Survival in the first series of 45 newborns was 55%.[3,4] After increasing experience with neonates, attention turned once again to the use of ECMO in the older pediatric population.

From 1983 to the present, this ECMO team has had a total of 210 patients on ECMO at either the Ochsner Foundation Hospital or the University of Chicago Medical Center. Survival for neonates is 80%; however, the overall survival in our series of 210 patients is 74%. Twenty-eight of these patients were beyond the neonatal age when they underwent ECMO for respiratory failure. Although survival is lower for these older patients, their overall survival was 54%. The most important differences between pediatric and neonatal ECMO are that pediatric patients on the average have a longer course on ECMO, a higher rate of complications, and a lower rate of survival.

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Selection Criteria for Pediatric ECMO

The selection of pediatric patients for ECMO is difficult. Historically, the most reliable indicators of respiratory failure leading to death in neonates have been the alveolar-arterial oxygen difference, $(A\text{-}a)DO_2$, and oxygenation index, which is calculated by the following formula:

$$OI = MAP \times FiO_2 \times 100/PaO_2$$

where MAP = mean airway pressure, FiO_2 = fraction of inspired oxygen, and PaO_2 = arterial oxygen tension.

However, neither of these parameters have been either retrospectively or prospectively shown to predict with high accuracy a fatal outcome for older children. For completeness, $(A\text{-}a)DO_2$ and OI as indications for neonatal ECMO are listed below:

(1) an $(A\text{-}a)DO_2 > 610$ for 8 hours or 600 for 12 hours
(2) an $OI > 40$

In addition, acute deterioration, barotrauma, failure to respond to maximal ventilatory therapy, and cardiac arrest have all been used as entry criteria for pediatric ECMO. None of these has proved routinely reliable as a predictor of outcome for the majority of patients. All of these parameters as ECMO entry criteria are listed, along with survival incidence in Table 1. Currently, pediatric patients who are on maximal ventilatory support for no more than 10 to 14 days, fail to show improvement, and are believed to have reversible lung disease should be considered strongly for

Table 1. Criteria for Pediatric ECMO*

Criteria	Number	Survival
Oxygen index	30 (11.9%)	47%
$(A\text{-}a)DO_2$	10 (3.9%)	50%
Acute deterioration	28 (11.9%)	39%
Barotrauma	42 (16.6%)	52%
Failure to respond	125 (49.4%)	43%
Cardiac arrest	4 (1.6%)	0
Shunt > 30%	1 (0.4%)	0
Others	13 (5.1%)	62%

*ECMO Registry, July 1991, University of Michigan, Ann Arbor, Michigan

ECMO. All of the consulting services involved in the patient's care should agree that the outcome would be dismal without ECMO.

The most common diagnostic indications for pediatric ECMO are viral pneumonia (33.6%), ARDS (28%), and aspiration (10.7%).[5] However, many children are considered for ECMO without an exact diagnosis for their respiratory failure. It has been proposed that an open lung biopsy on patients prior to ECMO will often establish the diagnosis and help identify the presence of irreversible lung disease. The amount of fibrosis seen microscopically in the biopsy specimen should be directly proportional to the irreversibility of the lung disease. Performing a lung biopsy immediately prior to ECMO has significant risk for bleeding complications since patients are systemically anticoagulated for ECMO. Currently there is no consensus on whether this should be done in all patients prior to the initiation of ECMO.

ECMO Techniques

There are currently two methods of ECMO that differ only in the method of vascular access, venovenous and venoarterial. Venoarterial ECMO is accomplished by cannulating a vein (usually the internal jugular vein) from which deoxygenated blood is withdrawn, and an artery (usually the common carotid artery), through which oxygenated blood is returned to the body. This type of ECMO not only accomplishes the task of respiratory gas exchange but also provides cardiac support. Another method is venovenous ECMO in which two large veins are cannulated. Deoxygenated blood is removed from one vein, and oxygenated blood is returned via the other vein. This can also be done by cannulating one vein with a double lumen catheter, one lumen for withdrawal of blood and one lumen for return of blood to the circulation. One important difference between venovenous and venoarterial ECMO is that venovenous ECMO does not provide any support of cardiac function. It returns oxygenated blood to the venous system, leaving the heart to pump the blood to the body.

As of July 1991, there were a total of 5,415 ECMO cases nationwide. Of these, 253 were pediatric cases, with 218 (86%) being venoarterial and 25 (10%) being venovenous. There were 10 cases (4%) of venovenous ECMO that had to be converted to venoarterial. The survival rates of these groups were 46%, 40%, and 40%, respectively.[5]

Circuit Components

The ECMO circuit is diagrammed in Figure 1. The main components of the ECMO circuit are the servoregulated roller pump, membrane oxygenator, and heat exchanger. These are connected by polyvinylchloride tubing and connectors of varying size. Of special note is the tubing that connects the bladder to the oxygenator, which is called the raceway. The size of the tubing and connector is chosen based on the rate of flow that will be going through the circuit. The larger the patient, the greater the flow will need to be. The size of the oxygenator is graded by how much flow can pass through it and exit with the blood 95% saturated. This flow must be at least equal to the patient's cardiac output. The sizes are based on the surface area of the membrane across which gas exchange occurs. For neonates, a 0.4-m² to 0.8-m² oxygenator is used, for children a 1.5-m² to 2.5-m² oxygenator, and for adults a 3.5-m² to 4.5-m² oxygenator. Table 2 shows the recommended tubing, raceway, and oxygenators for various sized patients. After assembly of the circuit, it is primed first with crystal-

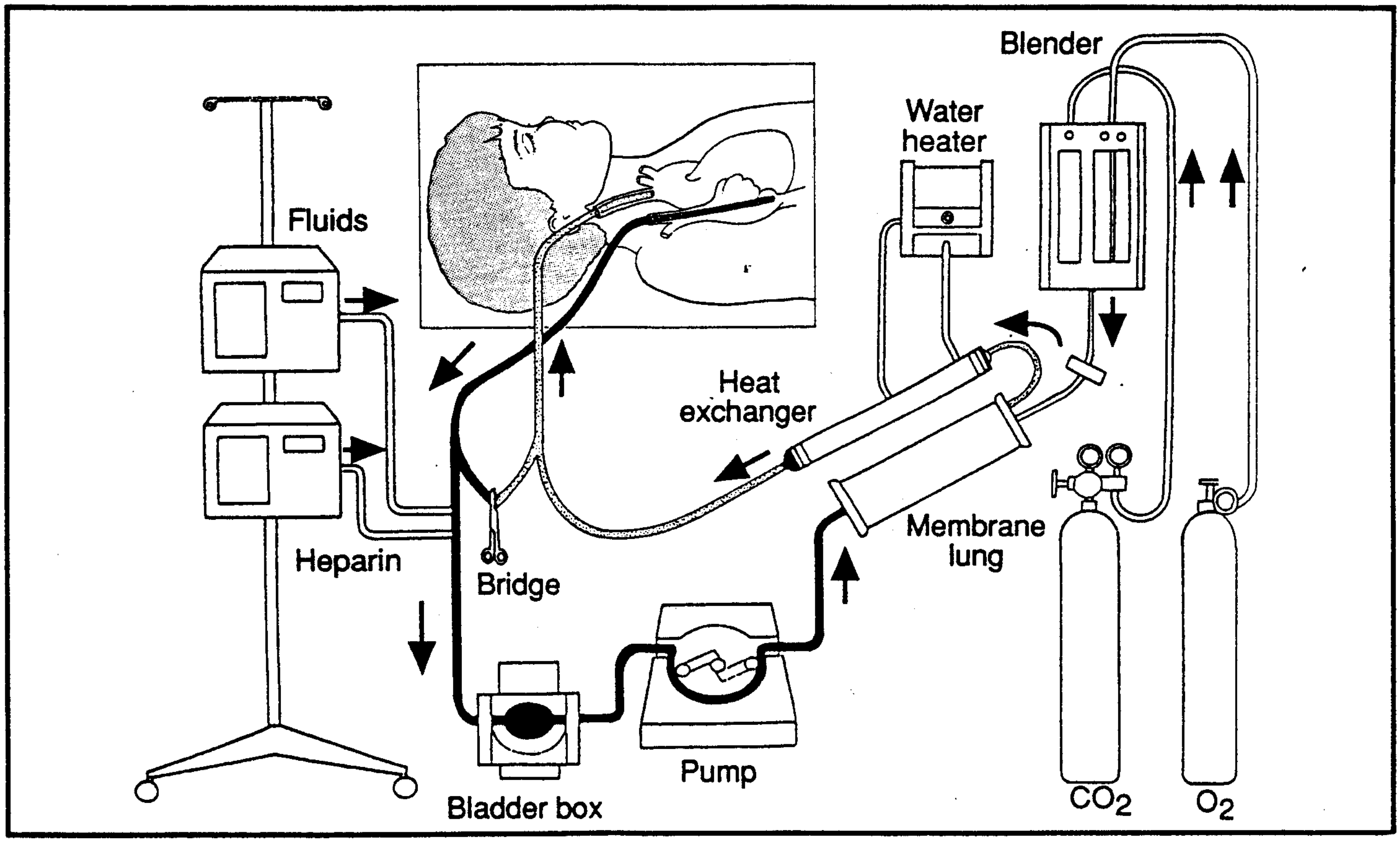

Figure 1. ECMO circuit.

Table 2. Sizes of Circuit Components for Venoarterial ECMO

Weight	Circuit	Raceway	Oxygenator	Cannulae
1.5-2.2 kg	1/4"	1/4"	0.4-m²	Ven. 10-14 Fr Art. 8-10 Fr
2.2-8.0 kg	1/4"	1/4"	0.8-m²	Ven. 10-16 Fr Art. 8-12 Fr
8.0-12.0 kg	1/4"	3/8"	1.5-m²	Ven. 16-21 Fr Art. 12-16 Fr
12.0-20.0 kg	3/8"	3/8"	2.5-m²	Ven. 20-24 Fr Art. 14-18 Fr
20.0-35.0 kg	3/8"	1/2"	3.5-m²	Ven. 22-26 Fr Art. 16-20 Fr
> 35.0 kg	3/8"	1/2"	4.5-m²	Ven. > 28 Fr Art. > 20 Fr

loid, then with colloid (usually albumin), and then finally with typed and crossed matched blood.

Cannulation

After the ECMO circuit has been assembled and primed, cannulation is done by a pediatric surgeon. This is performed in the intensive care unit, with the operating room team present, usually consisting of one scrub person and one circulator. Anesthesia is obtained locally with lidocaine after the patient is sedated and paralyzed. For venoarterial ECMO, the patient is cannulated in the femoral or internal jugular veins, with arterial access from the carotid, axillary, or femoral arteries. For venovenous ECMO, the femoral and/or internal jugular veins are cannulated. After exposure of the vessels, heparin 100 units/kg is administered via peripheral intravenous site. In choosing the size of the cannula, it is important to choose the largest caliber cannula that will fit in the vessel, particularly the venous cannula, so that the maximum amount of blood can be siphoned. In neonates, a 12 to 14 French venous cannula and an 8 to 10 French arterial cannula are placed in the internal jugular vein and the carotid artery, respectively. In older children and adults, larger caliber cannulae are placed, such as a 36 French venous cannula in the internal jugular vein, and a 22 to 24 French arterial cannula in the axillary or femoral artery.[2]

With the vessels successfully cannulated and the circuit primed, ECMO flow can be established. Flow is begun slowly and advanced over a period of 15 to 20 minutes to 100 cc/kg/min, which corresponds to approximately 85% to 90% of the patient's cardiac output. Flow is maintained at this level for 24 to 48 hours in order to provide maximal respiratory and hemodynamic support. During this time lung function usually improves as evidenced by the chest x-ray films, arterial blood gas analysis, and the ability to more easily ventilate the patient with hand bagging. As the patient's own pulmonary function improves, the ECMO support is weaned. If the arterial blood gases show good oxygenation and ventilation, the ECMO flow is weaned until the flow is less than 100 cc/min. Also during weaning, adequacy of oxygen delivery to the cells is assessed by following the mixed venous oxygen saturation (S_vO_2). This parameter should be kept above 65% for successful weaning.

Once the patient is maintained on minimal flows (50 to 100 cc/min), the patient is removed from ECMO by decannulating. The patient may have a trial off of ECMO before decannulation by clamping the circuit. If the patient tolerates a trial off, then decannulation may begin. The cannulae are removed under sterile conditions, just as the cannulation is performed, with the operating room team present in the intensive care unit. The vessels are ligated, and the wound is closed with a small drain in place. Occasionally the carotid artery can be reconstructed. This can be done when the ECMO course is short, and the artery appears to be in good condition at the time of decannulation. The technical feasibility of the repair is the major factor in determining if arterial reconstruction occurs.[6]

Complications During ECMO

The complications of pediatric ECMO are similar for neonatal ECMO; these are primarily bleeding or mechanical complications. The most commonly reported medical complications are surgical site bleeding (28.5%), need for hemodialysis or hemofiltration (24.5%), and the need for inotropes on ECMO (23.3%). The most commonly reported mechanical complications are oxygenator failure (17.4%) and cannula problems (15%). Overall mortality for pediatric ECMO patients due to the underlying disease and the complications is 45.5% as of July 1991.[5]

The experience of our team at Alton Ochsner Foundation Hospital and The University of Chicago Medical Center showed that hemorrhagic complications were the most serious, occurring in 39% of the pediatric patients. The most common sites for bleeding were the surgical site, gastrointestinal tract, lungs, and brain. These hemorrhagic problems can be reduced by maintaining the platelet count above 100,000 and the activiated clotting time between 170 to 180 sec for postoperative patients or between 200 to 220 sec for nonsurgical patients. Also fibrin glue may be used at the cannulation site to decrease bleeding; however, this is still being investigated and there is no consensus on the exact indications for use. The incidence of intracranial hemorrhage may be reduced by preventing sustained systolic hypertension. This can be accomplished with diuresis or with medications such as captopril and nitroglycerin.

The importance of mechanical complications was also noted in our experience. These occurred at a rate of 43% for pediatric patients. The most common site of a mechanical complication is the membrane oxygenator, particularly during prolonged ECMO runs. In addition, tubing rupture occurs with increasing frequency as the duration of an ECMO run increases. Usually both oxygenators and tubing can be replaced without compromise to the patient.[7]

Case Presentation

Of particular note in our series of ECMO patients are five children who had previously undergone liver transplantation. These children developed respiratory failure secondary to opportunistic infections. One of these children is presented as an illustration of how ECMO can be used in older children.

The patient is a 13-month-old female who received a living-related liver transplant at age 10 months for liver failure secondary to biliary atresia. She was discharged from the hospital on posttransplant day 13. Three months later, she contracted cytomegalovirus and pneumocystis pneumonia and pursued a rapidly deteriorating course despite aggressive ventilatory support. She was transferred to our ECMO center with five chest tubes placed for pneumothoraces, peak inspiratory pressures of 60 to 70 cm H_2O,

(continued on p 12)

THE DUES INCREASE: THINK POSITIVE

ARTICLE BY DEBORAH PEARSON, CST, AST PRESIDENT

During our 1992 conference in Washington, DC, the House of Delegates voted by a narrow margin to increase the national dues from $55 to $70. It was a tough decision by the membership, but we must be able to make tough, sound decisions for the betterment of our profession.

As consumers and persons who are concerned about issues such as the economy, health care, and job security, we must recognize that if we are to maintain and continue to upgrade our profession and member services, AST must be counted on the priority list of important needs, because without our organization our profession will not survive.

We have not had a dues increase in 9 years. The price of postage, paper, advertisements, printing, utilities, travel, etc, have continued to increase regardless of whether our salaries have. We have never been paid what we're worth, so we already know how to be innovative and creative. That's why it is so important over these next few years for us to think positive and work together as a team. Working as a team means: (1) coming together, (2) keeping together in order to progress, and (3) working together to show our success, because if we don't take care of each other no one else will. We have worked too hard and come too far to give up our momentum.

I challenge you to continue to be a part of the profession that we have fought so very hard for and will continue to do so. Here are some ideas to help you make dues a priority.

1. Save $1.38 a week (this ads up to $70.00 per year). Get a coffee can or cookie jar to save it in.
2. Give up at least a pack of cigarettes a week if you smoke.
3. Give up three cans of soda or juice a week, or a beer, or a mixed drink.
4. Lower your chapter dues or do away with them, and do fundraisers to help raise money for conference.
5. Offer to help a needy member maintain his or her dues if you or your chapter can afford it.
6. For parishioners who tithe, remember you must sow a seed for it to grow.
7. Work as hard to stay a part of the system as I've seen members work to beat the system.

We know these will take a great sacrifice on your part. In return, AST will use the most cost-effective means available to deliver quality member services.

This is our profession and organization. Those of you who participated in the member needs assessment survey expressed that you wanted to see increased journal publications, an expanded job placement program, more vendor ads, additional AST products, increased legislative awareness, an extensive public relations campaign, and stability of our cash reserve for regulatory issues that will affect our profession.

You must not make an irrational decision to pull out of your organization because of a dues increase. You must recognize that *Unity is the Key to Our Professional Growth,* and that every man owes a part of himself or herself to the growth of the profession of which he or she belongs. Think about it. ☐

ECMO — *continued*

positive and expiratory pressure of 15 cm H_2O, and an arterial oxygen tension of 49 mmHg on 100% FiO_2. The patient was placed on venoarterial ECMO with a flow averaging 110 cc/kg/min. Her pneumonia was successfully treated with gancyclovir and pentamidine. She was removed from ECMO after 406 hours. Eleven days later she was extubated and in another 12 days she was discharged. She required no oxygen at the time of discharge. Her hepatic transplant was functioning well on standard immunosuppression. After the ECMO run, cranial computed tomography, electroencephalogram, and brainstem auditory evoked potentials were normal.

This case is a good example of the application of ECMO in the pediatric population. It also illustrates a new setting for ECMO, that of the liver transplant patient with opportunistic infection. There have been four other post-liver transplant patients placed on ECMO in our series with a 60% survival. ☐

References

1. *Extracorporeal Support for Respiratory Insufficiency, A Collaborative Study.* Prepared in response to RFP-NHLI-73-20. Bethesda, MD, United States Department of Health, Public Health Service, National Institutes of Health, December 1979.
2. Hirschl RB, Bartlett, RH: Extracorporeal membrane oxygenation support in cardiorespiratory failure. *Adv Surg* 1987; 2:189-212.
3. Bartlett RH, Gazzaniga AB, Huxtable RF, et al: Extracorporeal circulation (ECMO) in neonatal respiratory failure. *J Thorac Cardiovasc Surg* 1977; 74:826-833.
4. Bartlett RH, Andrews AF, Toomasian JM, et al: Extracorporeal membrane oxygenation for newborn respiratory failure: Forty-five cases. *Surgery* 1982; 92(2): 425-435.
5. ECMO Registry, July 1991.
6. Adolph V, Bonis S, Falterman K, et al: Carotid artery repair after pediatric extracorporeal membrane oxygenation. *J Ped Surg* 1990; 25:867-870.
7. Klein MD, Arensman RM, Weber TR, et al: Pediatric ECMO. Directions for new development. *ASAIO Trans* 1988; 34:978-985.