# Concepts Of Neonatal ECMO

D Thakar, A Sinha, O Wenker

**Citation**

D Thakar, A Sinha, O Wenker. *Concepts Of Neonatal ECMO*. The Internet Journal of Pulmonary Medicine. 2001 Volume 2 Number 2.

**Abstract**

The principles of Extracorporal Membrane Oxygenation ECMO are discussed. The objectives are to summarize indications, contraindications, veno-venous and veno-arterial cannulation, main components of the ECMO circuitry, principles of oxygen content and delivery, complications, monitoring, management and statistics regarding ECMO in neonates.

## HISTORY

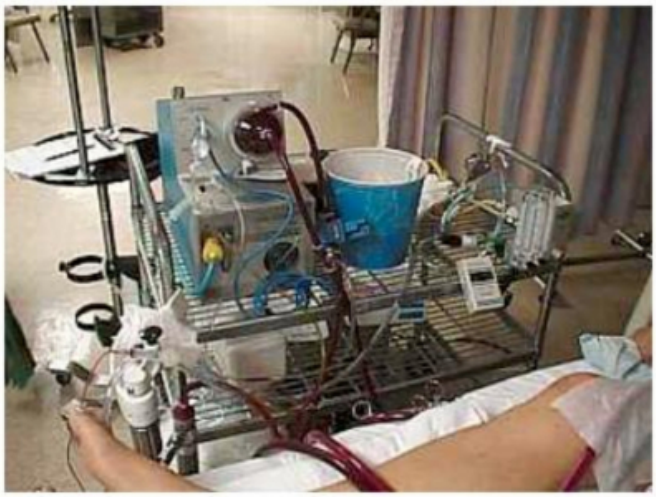
The concept of cardio pulmonary bypass was developed in the nineteen fifties. In 1972, the first case of ECMO was reported. The first successful survivor was not reported till 1975. Since then, about ten thousand newborn, a thousand pediatric and two hundred adult patients have been, with varying degrees of success supported with ECMO. In 1980, the large-scale clinical trial was abandoned because of irreversibility of pulmonary injury in 90% of patients and high mortality.

During the past few years, improvement in techniques and technology, along with changes in selection criteria, have all combined to improve the survival rate. The availability of high frequency jet ventilation (HFJV), high frequency oscillation ventilation (HFOV), the availability of nitric oxide and surfactant has also impacted the management and outcomes of these patients. The goal of ECMO is to provide temporary support to replace the function of the lung, heart or both to allow the patient's cardiopulmonary system to recover from an acute reversible insult or injury.

The survival rate for neonates is much higher than for either pediatric or adult patients. The improved neonatal survival rate is usually because of reversibility of the disease process and absence of chronic lung and heart disease.

**Figure 1**

Image 1: ECMO set-up with centrifugal pump



## PATIENT SELECTION AND ECMO CRITERIA

The use of ECMO is indicated when conventional management of cardiopulmonary disorders fails and the incipient predicted mortality is very high. The criterion for use of ECMO in the neonatal age group continues to evolve. In newborns with severe cardiopulmonary disease, it is the degree of ventilatory support required for maintaining adequate oxygenation, which determines the mortality risk. Since ECMO is an invasive procedure and involves significant risk, it is used only when absolutely necessary. Conversely, one should consider that delaying ECMO therapy might cause further deterioration of cardiopulmonary function.

The criterion for selection varies from institution to institution. Not every center is equipped for the use of HFJV, HFOV and nitric oxide. In addition, level of experience of

ECMO team varies from institution to institution. Most centers follow the criteria listed in Table I. The goal of these criteria is to assist the physician in making judgement for success or failure of medical therapy.

**Figure 2**

Table 1: Selection Criteria for ECMO

| | |
|---|---|
| Hypoxia | Greater than 4 hours<br>OI>40 [OI=(FiO2xMAP/PaO2)x100]<br>(A-a)Do2>400mmHg.<br>PaO2<50mmHg, while on ventilator, with PIP>35 or MAP>20 |
| Persistent acidosis | PH<7.20 in spite of alkalization therapy, hyperventilation, NaHCO3 infusion.<br>Rising lactic acid levels |
| Barotrauma | |
| Cardiac dysfunction | In the absence of major congenital heart disease |
| Weight >2Kg. | |
| No more then 7 days of assisted ventilation. | |
| Lung disease reversible in 10 to 14 days. | |
| Failure of maximal medical treatment. | |
| Absence of coagulopathy and major intracranial bleeding. | |
| Gestational age 35 to 40 weeks. | |

Most neonates who are candidates for ECMO have underlying persistent pulmonary hypertension, which results in right-to-left shunting through the foramen ovale and/or ductus arteriosus. Meconium aspiration syndrome, severe hyaline membrane disease, idiopathic persistent pulmonary hypertension, sepsis and congenital diaphragmatic hernia are some of the disease treated with ECMO.

## CONTRAINDICATIONS FOR NEONATAL ECMO

The goal is to use ECMO only in appropriate patients. In the past 25 years, ECMO has been used for treatment of cardiac and pulmonary failure. There may be incidents where despite specific contra indications the medical team elected to place a patient on ECMO. Ultimately, the physician who is in charge of the ECMO team should make the decision.

Patients weighing <2 Kg. have extremely small vessels for canullation, thus hindering adequate flow because of limitations from cannula size and subsequent higher resistance to blood flow. Infants of <34 weeks gestation are still premature and several physiologic systems are not well-developed, specially the cerebral vasculature and germinal matrix. These structures are highly sensitive to slight changes in pH, PaO2, and intracranial pressure. Due to the risk of IVH, it has become standard practice to ultrasound the brain prior to the institution of ECMO.

**Figure 3**

Table 2: Contraindications for Neonatal ECMO

| |
|---|
| Weight<2.0Kg |
| Gestation age <34 weeks |
| Intraventricular hemorrhage (IVH)>Grade 1 |
| Irreversible damage to brain, heart, liver, kidney |
| Lung disease not reversible in 10-14days |
| Mechanical ventilator for >7-10 days |
| Overwhelming sepsis |
| Severe coagulopathy |
| Parental refusal |

## OXYGEN TRANSFER AND DELIVERY

The amount of oxygen available to the body is determined by oxygen content and cardiac output.

Oxygen content is determined by three factors: hemoglobin saturation, number of hemoglobin molecules available to carry oxygen and partial pressure of the oxygen dissolved in the plasma. The dissolved oxygen plays a minor role in the amount of oxygen available in the blood.

$CaO2 = (Hb \times 1.34 \times SaO2) + (PO2 \times 0.003)$
Normal=18-22 volume percent.

DO2 = cardiac output X oxygen content Normal = 225-330mL O2/Kg/min

The majority (97%) of oxygen that is carried in the blood is bound to hemoglobin. It is therefore very important to maintain adequate hemoglobin levels. Table 3 shows relationship between hemoglobin, PaO2 and saturation.

**Figure 4**

Table 3: Hemoglobin, PaO2 and saturation

| Pao2 (TORR) | Hb | SaO2 | CaO2 | Status |
|---|---|---|---|---|
| 40 | 18.00 | 0.07 | 18.09 | Normal |
| 60 | 15.00 | 0.85 | 17.27 | Low (+)/(-) |
| 90 | 10.00 | 0.95 | 13.00 | Low |

The amount of hemoglobin available is the primary factor in determining the amount of oxygen the blood can carry. The delivery of oxygen to the tissues depends on cardiac output. When cardiac output diminishes, oxygen delivery is compromised. The lactic acid rises as a result of anaerobic metabolism. Serum lactic acid levels can be used to determine the need for ECMO

## COMPLICATIONS

There are three main categories of complications.

Due to heparinization, intracranial bleeding is the most common complication. Other sites of bleeding include, oozing from cannulation site, pericardial tamponade, postoperative intrathoracic bleeding, gastrointestinal bleeding and retroperitoneal hemorrhage. Management of bleeding is by maintaining ACT of approximately 200 seconds and platelet count above 100,000. If tolerated by the patient ECMO support may temporarily be discontinued with reinstitution of full ventilatory support. Oxygenator failure, failure of heat exchanger, pump failure and tube rupture are some of the other mechanical complications.

### Figure 5

Image 2: Bleeding from cannulation site in an adult patient

Right internal jugular vein and right common carotid artery access is routinely performed for veno-arterial ECMO. The common carotid artery is ligated during cannulation. Collateral flow is usually established after some time. No attempt is made to repair the artery. Some of these patients develop left side muscle tone abnormality. The symptoms of right hemispheric dysfunction are minimal. Some of the other less common complications are seizures, cardiac arrest, myocardial dysfunction, and renal failure

### Figure 6

Table 4: Complications of ECMO

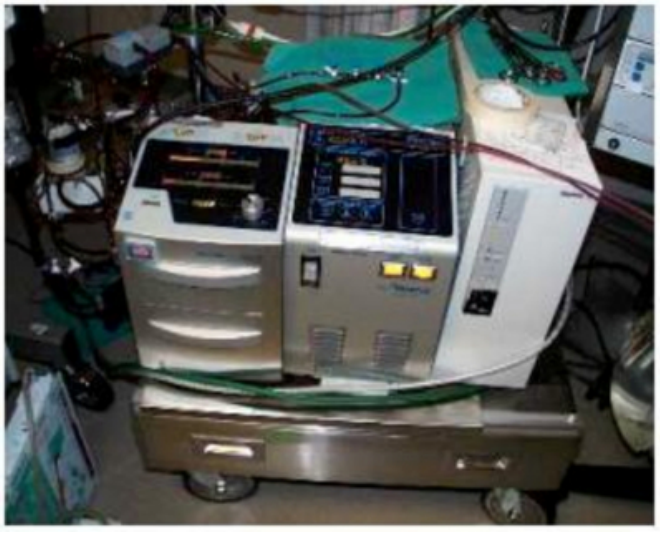
| Physiologic Complications | Mechanical Complications |
|---|---|
| Intracranial bleeding | Failure of Oxygenator |
| Bleeding from surgical site | Pump failure |
| Hemolysis | Tubing rupture |
| Seizures | Cannula problems |
| Neurologic complications | |
| Renal damage | |
| Arrhythmia | |
| Pneumothorax | |

## THE ECMO SYSTEM

The ECMO system provides temporary cardiac and pulmonary support. This is done by pumping blood through arterial and venous cannulation. The ECMO circuit is made up of PVC tubing. This circuit is attached to a venous cannula and arterial cannula. In (VA) ECMO the venous cannula is inserted into internal jugular vein and advanced through the superior vena cava up to the level of tricuspid valve. The arterial cannula is placed into the right common carotid artery with the tip of the cannula advanced up to the innominate artery.

### Figure 7

Image 3: The ECMO pump (roller pump)



Blood from the cannula drains passively into a small venous reservoir called the bladder. The ECMO pump draws blood from the bladder, which works like the right atrium. The function of this bladder is to prevent negative pressure from pulling the vessel wall into the cannula and reducing the risk of damage to the vena cava. The bladder is connected to a servo regulator mechanism, which reduces or stops pump flow in the event venous return decreases to unsafe levels.

The tubing from the bladder leads to ECMO pump, which is either a roller pump or a centrifugal pump. Usually a roller

pump is used in ECMO. The type of tubing used varies with the pump used. The roller pump requires special Tygon tubing that is resistant to creasing and erosion.

As the blood leaves the pump it enters the membrane oxygenator. The membrane is made up of thin silicon rubber sheath with a plastic screen spacer inside. The membrane is a very efficient gas exchanger. The size of the oxygenator ranges from o.4 to 4.5 meters squared. The size selected is based upon the patient size and total blood flow. The maximum blood flow through the oxygenator is equal to 1.5 times size of the oxygenator. The maximum sweep gas flow is limited to 3 times the size of the oxygenator.

**Figure 8**

Image 4: The oxygenator membrane

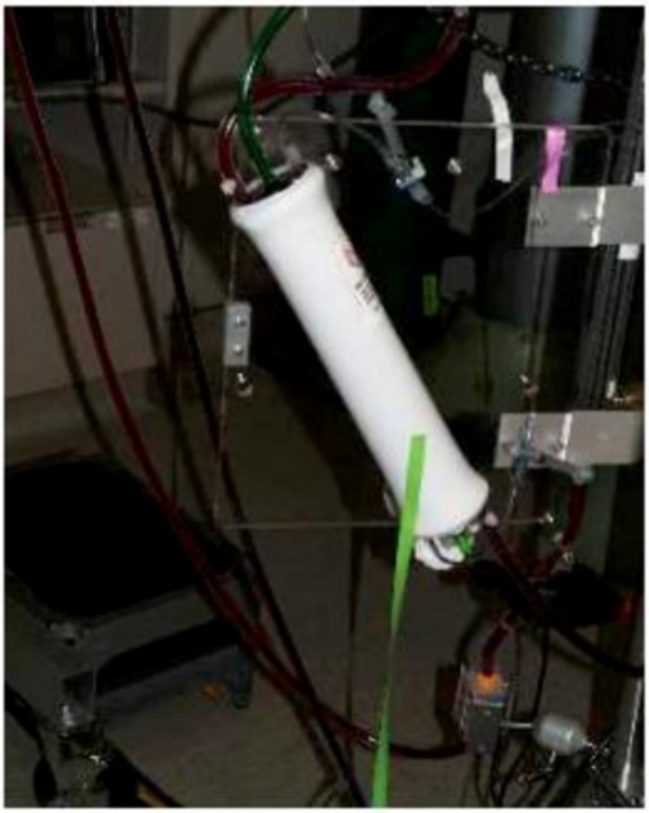


**Figure 9**

Image 5: Oxygenator and heat exchanger

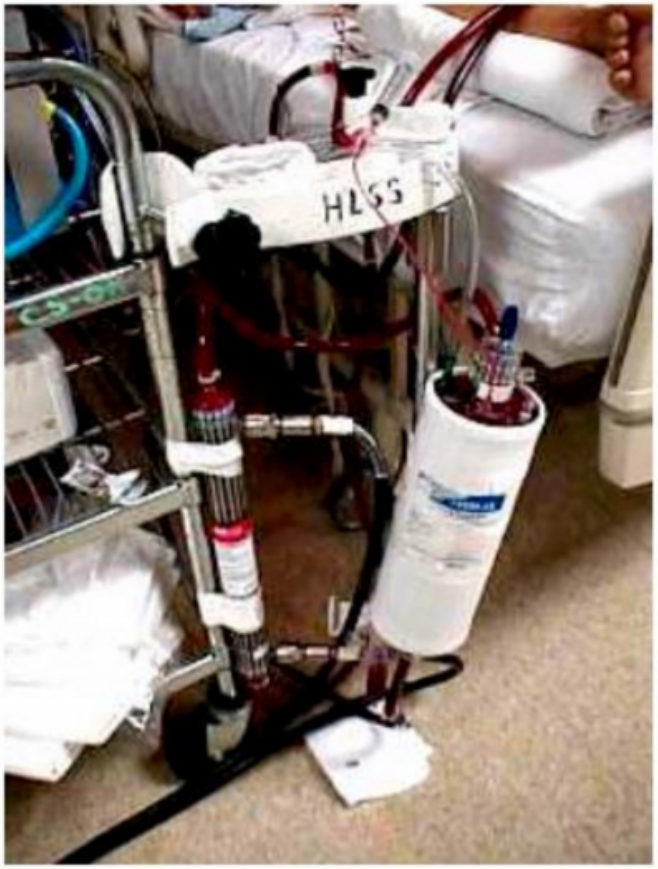


**Figure 10**

Images 6 and 7: Blenders to control oxygenation and airflow (FiO2 and sweep gas flow controls)

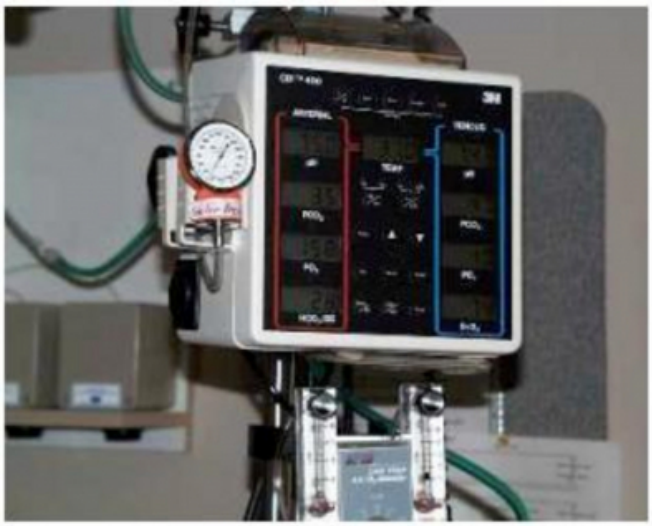


**Figure 11**


As the blood moves in the circuit, a great deal of heat is lost in extracorporal circulation. ECMO systems use a heat exchanger to maintain normothermia. The heat exchanger is located either post oxygenator or integrated into the oxygenator. The heat exchanger when placed after the oxygenator serves as a bubble trap as well.

The blood returns to the patient from the heat exchanger. In (VA) ECMO the arterial limb is attached to a cannula inserted into the right common carotid artery. The tip of the cannula is just proximal to the junction of the brachiocephalic artery and the aorta. With this type of cannulation ECMO becomes essentially a cardiopulmonary bypass system.

**Figure 12**

Image 8: Tubing in an adult patient

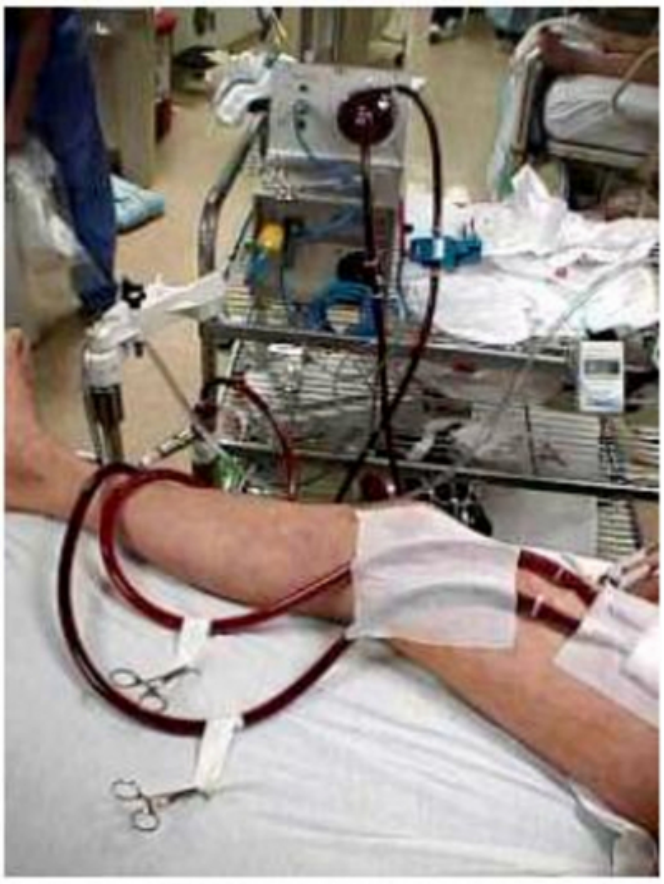


**Figure 13**

Image 9: Controls for pump flow (centrifugal pump) and ACT machine to check anticoagulation


In the veno-venous (VV) ECMO a double lumen cannula is often used so that only one vessel is cannulated. The bridge is the final component between arterial and venous limbs, so if for any reason

patient needs to be isolated from the main circuit, this bridge provides a by pass limb. This allows flow to continue through the circuit without the risk of clot formation in the circuit.

**Figure 14**

Table 5: Veno-venous and veno-arterial cannulation.

| | Veno-Venous | Veno-Arterial |
|---|---|---|
| Cannulation | one or two vein | Jugular vein and common carotid artery |
| Flow | 130ml/Kg/min | 100ml/Kg/min |
| Lung blood flow | Normal | Decreased |
| Systemic embolism | Unlikely | Possible |
| O2 Supply | Fair (PaO2 )40-80torr | Good (PaO2) 60-150torr |
| Cardiac effect | Negligible effect | Decreased preload, Increased after load |
| Pulmonary circulation | Unaffected | Moderate to markedly decreased |
| Left to Right shunt | No effect | Pulmonary Congestion, systemic Hypoperfusion |
| Right to Left shunt | Increased aortic saturation | Decreased aortic saturation |
| Oxygen delivery capacity | Moderate | High |
| Circulatory support | ? increase in cardiac output | Partial to complete |

Additional equipment consists of pressure monitor, bubble detector, and blood gas analyzer. The pressure monitor determines the pressure of blood returning to the bladder and serves as an indicator of volume status of the patient. Typically pressure monitor is placed before and after the oxygenator. Normally pressure drop across the oxygenator membrane is between 100 to 200mmHg. Any pressure drop above this value indicates that the blood flow through the oxygenator is meeting higher resistance. This higher resistance is typically because of clot formation in the oxygenator membrane.

One of the complications of ECMO is air embolism. This is especially critical with VA ECMO where air bubbles can directly enter the arterial blood and can cause systemic embolization. The bubble detector gives an early warning that air has entered in the circuit. The bridge allows bubbles to circulate down to the bladder where they can be easily aspirated.

The blood gas sensor analyses venous and arterial blood pH, PCO2, PO2, HCO3, BE and temperature. The venous blood returning from the patient is a good indicator of oxygen delivery and consumption. Post membrane blood gas is a good indicator of oxygen and CO2 delivery to the patient.

Heparin is given as an initial bolus (40-80 Unit/Kg) based on initial ACT desired, followed by 20-70 units/Kg/min. Heparin is given as a continuous infusion to maintain ACT between 180 to 220 seconds. Also 100 units of heparin are added to each adult unit of PRBC used for priming the circuit. Calcium is also added to reverse CPD-A anticoagulation effect. Remember that half-life of heparin in neonates on ECMO is about 45 to 70 minutes. Since heparin is excreted partially metabolized or intact in urine, variation in the rate of urine production will have a marked effect on the apparent heparin utilization rate. One must in fact be conscious of the occasionally decreased heparin utilization rate in oliguric patients. Heparin assay is performed every morning to check heparin levels.

## PRIMING THE ECMO CIRCUIT AND CANNULATION

Priming of the circuit may take approximately 15 to 60 min depending on the experience of the perfusionist and rest of the team members involved in taking care of the patient. Typically priming the neonatal ECMO circuit requires 2 units of PRBC, 1 unit of FFP, 25 to 50ml of 25% albumin, crystalloid, heparin, calcium gluconate and NaHCO3. The hematocrit of priming solution is maintained at 40% to 45%. CO2 is flushed through the circuit to replace all air.

Typically cannulation for neonatal ECMO has generally implied placement of cannulas in the right internal jugular vein and right common carotid artery. Occasionally some other alternative sites are used for cannulation. Conceptually cannulation of right internal jugular vein and right common carotid artery are not very complicated, but it requires technical skills and an experienced surgeon. It is very important to maintain the principal of sterilization, isolation and infection control, since this procedure is performed in the intensive care unit. During the procedure patient's vital signs are monitored very closely. As the patient is mechanically ventilated, most surgeons prefer to keep the patient relaxed and sedated. It is necessary to have available standard resuscitation medications, blood and FFP. It may occasionally be helpful to elevate the patient's body. This increases the height of the hydrostatic column, which draws blood from the right atrium by gravity into the venous reservoir. The sequence of cannulation of artery and vein varies from surgeon's preference. Generally 12Fr to 14Fr venous cannula is selected. The anticipated distance from mid right atrium to the proposed venotomy site is 6.5cm for typical neonate weighing 2 to 3Kg. The side holes at the distal end of the cannula are located within right atrium.

The procedure for inserting arterial cannula is a similar to the venous cannula. The size of the arterial cannula is 9.6 Fr to 10 Fr for neonates. Care must be taken not to advance cannula tip into the ascending aorta where the jet stream of the pump driven blood might be directed towards the aortic valve.

In (VV) ECMO blood drained from right atrium is oxygenated and returns again to the right atrium. There is

always some mixing of oxygenated and unoxygenated blood. Therefore there is some inherent inefficiency in the system. The portion of oxygenated to unoxygenated blood delivered to the membrane lung is known as recirculation fraction. Because of this intrinsic inefficiency, the total oxygen delivery available with VV bypass is often inadequate. In patients with severe hypoxia and poor ventricular function VV support may be inadequate and therefore these patients are candidates for (VA) ECMO.

## WEANING FROM ECMO

Weaning from ECMO is a gradual process, since initially almost 60 to 80 % of the cardiac output flows through the circuit in order to maintain a PaO2 in a range of 70 to 80 mmHg. As the lungs improve, PaO2 improves and the ECMO flow can be slowly decreased. Once the bypass flow reaches 10% of the cardiac output, the flow is continued for a further 8 to 12 hours to ensure that the patient is ready to come off the pump. During decanullation, the infant is kept sedated and paralyzed. The ventilator setting is changed at this time to inspired oxygen of 30 to 40%, respiratory rate of 40 to 50 bpm, and pressure limits of 15 to 20 cm H2O.The average time to extubation is 24 to 48 hr. Usually, supplemental oxygen is required for the first week.

**Figure 15**

Table 6: Survival Statistics by Diagnosis

| Neonatal | | Pediatric | |
|---|---|---|---|
| Meconium aspiration syndrome | 94% | Bacterial infections | 45% |
| Sepsis | 76% | Viral infections | 56% |
| Respiratory distress syndrome | 84% | Hematological disorders | 62% |
| Congenital heart disease | 58% | Atrial septal defect | 65% |
| Persistent fetal circulation | 83% | Pneumocystis carnii pneumonia | 38% |
| Air leak | 71% | Infant respiratory distress syndrome | 51% |
| Others | 74% | Others | 49% |

## CONCLUSION

The patients on ECMO are critically ill. Once the patient is placed on ECMO, the work of getting the patient off ECMO begins. Anticoagulation, prophylactic antibiotic, mild sedation with neuromuscular blocking agent, cardiopulmonary bypass and nutritional support is carefully monitored. Parents often need some emotional and psychological support. The number of ECMO cases continues to decline. This may be because of increased used of nitric oxide, HFOV, HFJV. It is interesting to note that survival on ECMO has also decreased. This may be due to delay in ECMO therapy because of pre ECMO trial of alternative treatment. The success of the therapy depends on prompt diagnosis and early initiation of treatment.

**References**

## Author Information

**Dilip R Thakar, MD**
Assistant Professor, Department of Anesthesiology, Anesthesiology and Critical Care, The University of Texas MD Anderson Cancer Center

**Ashish C Sinha, MD, PhD**
Assistant Professor, Department of Anesthesiology, Anesthesiology and Critical Care, The University of Texas MD Anderson Cancer Center

**Olivier C Wenker, MD, DEAA**
Associate Professor, Department of Anesthesiology, Anesthesiology and Critical Care, The University of Texas MD Anderson Cancer Center