Perioperative Care of Patients on HFOV and ECMO in the NICU

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Objectives:
1. Describe the perioperative care of the neonate receiving High Frequency Oscillatory Ventilation (HFOV)
2. Describe the perioperative care of the neonate on extracorporeal membrane oxygenation (ECMO)
3. Identify the perioperative issues related to off-site anesthesia in the neonatal intensive care unit (NICU)

High frequency oscillatory ventilation (HFOV) is commonly applied to neonatal patients with respiratory failure to provide a lung protective strategy of ventilation. Extracorporeal life support (ECLS) is applied to neonatal patients with either cardiac and/or respiratory failure when less invasive therapies are failing, or are producing harm. Patients receiving HFOV or ECLS sometimes require surgery, most commonly at the bedside in the intensive care unit, and pediatric anesthesiologists need to be familiar with these forms of cardiac and respiratory support in order to optimize patient care.

HFOV

The lungs of a preterm infant are structurally immature, deficient in surfactant, and vulnerable to injury. Their rib cage provides minimal elastic recoil (support for the collapsing lung) and their conducting airways have walls that are more like gelatin than cartilage. The resulting respiratory system is poorly equipped for extra-uterine life. The current strategy of supporting immature lungs is to replace surfactant and use minimal positive pressure, such as nasal continuous positive airway pressure (CPAP). Many premature infants, even micropremies, survive with this approach and have improved survival along with a reduction in the incidence of chronic lung disease as compared to those treated with intubation and positive pressure ventilation. Over-inflation of the lung, or over-inflation of the ventilated portion of the lung, produces lung injury (volutrauma). In the preterm lung volutrauma can develop with a few excessively large inflations. Tidal recruitment–derecruitment injures the lung from excessive shearing forces produced in the terminal bronchiole and will occur whenever the lung is ventilated with insufficient positive end-expiratory pressure (PEEP) and alveolar units collapse at end-exhalation. Therefore, the open lung concept is that optimal (and least injurious) ventilation is produced when the lung is recruited with just enough pressure to produce a tidal volume of 3-5 ml/kg and with sufficient PEEP to maintain recruitment. Many clinicians and investigators feel that HFOV is the optimal method of achieving the open lung strategy; however, meta-analysis of multiple trials and multicenter randomized control trials of HFOV versus conventional ventilation have failed to show significant outcome benefits.
The HFOV uses a diaphragm (similar to a stereo speaker) to rapidly and actively drive gas during both inhalation and exhalation with extremely small tidal volumes. Rates can be set between 3.5 to 15 hertz (Hz), equal to 210 – 900 breaths per minute. The initial setting to consider is the mean airway pressure (PAW) which acts like PEEP in maintaining lung distension and is typically adjusted to optimize oxygenation. Lung distension and alveolar recruitment (reduction in atelectasis) is determined by chest radiography. The extremely small tidal volumes probably do not remove carbon dioxide (CO2) through the bulk movement of gas, and CO2 elimination is primarily through diffusion and the Pendelluft effect (movement of gas between alveolar units of different time constants). The small tidal volumes can be thought of as a vibrational wave, like on a stereo speaker. Greater pressure produces larger vibrations (tidal volumes) and slower frequency produces the greatest fluctuations in gas (the largest tidal volume). In order to improve minute ventilation the Δ P (the pressure delivered above and below the PAW is increased which effectively increases the tidal volume. Also, although somewhat counter-intuitive, the respiratory frequency can be decreased. This maneuver will more effectively deliver the pressure wave generated at the diaphragm.

Sensormedics is the only company that makes a true HFOV approved by the FDA. Other companies make flow interrupters that sometimes referred to as high frequency ventilation, yet this form of ventilation is altogether different. The sensormedics ventilator does not have a battery backup and therefore transporting a patient on HFOV requires conversion to conventional ventilation, or using a transport energy source. At Texas Children’s Hospital we have now installed external power sources on all HFOV for transport.

**Anesthetic Considerations**

- The initiation of HFOV is commonly associated with a reduction in blood pressure due to an increase in intrathoracic pressure. At initiation the care team should be prepared to treat this hypotension, initially by increasing the intravascular volume since increased intrathoracic pressure impairs ventricular filling, and with vasopressors as needed. The hemodynamic effect is quite variable, as is the improvement in oxygenation. Most commonly over time oxygenation will increase as alveolar units are recruited from the constant distending pressure.
- Once a patient is weaned from higher oxygen and pressures with HFOV, they are commonly converted to conventional ventilation. However, attempting to convert a patient on high levels of support can be associated with significant lung injury, or worsening gas exchange. If a patient is stabilized with HFOV, I recommend continuing with this form of ventilation, even when surgery is required.
- The oscillator must be “powered up” each time it is connected to the patient. Whenever there is disconnect in the circuit, intentional or unintentional, the ventilator powers down and after reconnecting the ventilator must again be “powered up”. If the anesthesiologist does not recognize this feature, they may assume that the ventilator has failed.
- Although there is limited experience from case reports and a small case series, it appears that most emergent surgical procedures can be performed while the patient is receiving HFOV.
- End-tidal CO2 is not useful
ECMO

The technology applied for extracorporeal life support continues to evolve and the indications continue to change. There are three major areas of support: respiratory support, cardiac support and extracorporeal cardiopulmonary resuscitation (ECPR).

History
Bartlett from the University of Michigan reported 45 neonatal ECMO cases with a survival rate of 50% in 1982, and his group published the first prospective randomized trial of ECMO for neonatal respiratory failure in 1985, with the second randomized trial published in 1989 from Boston. Both studies demonstrated high rates of survival (100% and 94%, respectively), and by 1986 eighteen centers had developed neonatal ECMO teams. In 1989 Extracorporeal Life Support Organization (ELSO) was founded and maintained a registry of extracorporeal life support (ECLS) cases. This group developed standard guidelines and practices, and published the textbook on ECLS known as the Red Book. As ECMO treatment evolved beyond cardiopulmonary support, the term ECLS has emerged to encompass all of the assistive therapies available, including cardiorespiratory support, renal support, and hepatic support.

Indications
ECLS is indicated for acute cardiopulmonary failure with high mortality/morbidity unresponsive to maximal medical treatment and with expected organ recovery. Patients can be supported with ECLS while native function improves from removing harmful supportive therapy (high ventilator pressures and high oxygen), the application of medical or surgical therapies, or organ transplantation.

Classic Contraindications
Technological advancements in ECLS are challenging these classic contraindications.
1. Estimated gestational age (EGA) less than 34 weeks because of the risk of intracranial bleeding. Nonthrombogenic coating of circuit components are under development and systemic heparinization may not be necessary with such circuits.
2. Grade III or greater intracranial hemorrhage (ICH). Systemic heparinization increases the risk of extension of the bleed in these patients.
3. Mechanical ventilation for longer than 7 to 10 days is associated with higher incidence of bronchopulmonary dysplasia and irreversible lung disease. However, data from the ELSO registry demonstrate survival of 50% to 60% among neonatal patients who received up to 14 days of mechanical ventilation prior to initiation of ECLS.
4. Cardiac arrest had been a contraindication but many centers report survival rates of up to 60% among patients who suffer cardiac arrest before or during cannulation.
5. Conditions incompatible with meaningful life after therapy such as profound neurologic impairment and congenital anomalies. This is a grey area with changing considerations.

Outcomes
ECMO is a part of routine management in the neonatal intensive care unit (NICU) in most tertiary care centers. The overall survival is 85%, and some diseases such as meconium aspiration have a 98% survival, while congenital diaphragmatic hernia has a 55% survival
rate. The overall survival after ECLS for neonatal respiratory failure has recently declined as have the number of cases. This is thought to be due to improvements in respiratory support from the use of inhaled nitric oxide, high-frequency oscillatory ventilation, and surfactant therapy. Neonatal patients who ultimately receive ECLS generally have more significant pulmonary disease than in the past.

**Modalities**

ECLS can support infants in respiratory failure with either a venovenous (VV) method of cannulation and flow or venoarterial (VA). Historically VA-ECLS has been used more than VV-ECLS in the support of neonates; however, the use of VV-ECLS is increasing. Newer cannulae have been developed for single site VV cannulation termed venovenous double-lumen (VVDL) cannulation in which a single cannula is placed in the right internal jugular (IJ) vein. Deoxygenated blood is drained from the distal port positioned in the inferior vena cava (IVC), pumped through the ECLS circuit where gas exchange occurs, and returned through a separate port on the same cannula into the right atrium. VA-ECLS provides complete cardiopulmonary support. Typically a cannula is placed in the right IJ to drain deoxygenated blood from the patient which is then pumped through the ECMO circuit and returned through a cannula in the right carotid artery. The first generation of ECMO devices used a silicon oxygenator membrane, rotational pump, and simple arterial and venous cannulae. Newer technology provides hollow-fiber oxygenators with a much lower resistance across the oxygenator membrane. Therefore centrifugal pumps consisting of a rotating impeller that spins on a small bearing or is magnetically suspended are now more commonly used. Finally, there has been significant research toward improving the biocompatibility of the circuit surface. The simplified modern ECMO circuit has a significantly smaller priming volume and can be managed by a trained ICU nurse or respiratory therapist.

**Anesthetic Considerations**

- A moderate degree of anticoagulation is routinely used, and coagulation abnormalities are common. Even though the activated clotting time (ACT) is the most common point of care testing (usually maintained at 180-220 sec), it is an unreliable test of coagulation. Many patients on ECLS will develop platelet dysfunction and a low grade consumptive coagulopathy. The anesthesiologist must have blood products prepared and available at bedside for transfusion. Consultation with the ECLS specialist or consultant hematologist about treatment of bleeding during surgery is useful.

- Adequate venous access for transfusion may be limited. Most ECMO circuits have ports added to them to administer medications and blood products. Remember, if platelets are transfused into the circuit, they should be administered after the oxygenator. If venous access is limited, medications can be delivered directly into the ECMO circuit.

- VV-ECLS relies on the patient’s cardiac output for circulation. Therefore surgery, and in particular thoracic surgery performed on patients reliant on VV-ECLS may impair cardiac output if the surgeon compresses the mediastinal contents, or impairs venous return from surgical manipulation. Close communication with the surgeon is key.

- Access to the patient is frequently compromised. In order to minimize priming volumes, short circuits are typically used in ECLS that requires the pump and perfusionist to be in close proximity to the patient. The surgeon and assistant obviously need to be close. Therefore access to the patient’s venous line for the
delivery of medications or blood, access to the arterial line and possibly the endotracheal tube should all be planned before draping the patient. Remember that arterial blood gas analysis can be obtained from the ECLS circuit.

- A perfusionist should be available, at the bedside, for surgical procedures. Even though modern pumps are frequently managed by a critical care nurse or respiratory therapist, the need for cannulae adjustment, acute manipulation of pump flow and trouble shooting flow reductions require the skills of a perfusionist.
- A reduction in pump flow or an interruption in pump flow will typically require an immediate increase in ventilation. The anesthesiologist should have a plan for this contingency.

**Surgery in the NICU**

Performing bedside surgery in the NICU requires significant planning, and most importantly effective communication. To every extent possible, the surgical care team should try to reproduce operating room settings in the remote location. The same standards for monitoring, of access to the patient, lighting, and sterility should be maintained. Bedside procedures are only performed when it is deemed safer for the patient to remain in the specialized environment of the NICU rather than be exposed to the hazards of transport. When NICU patients are transported to the operating room, there is transfer of care from the neonatologist to the anesthesiologist. However, when patients remain in the NICU, I believe that optimal management strategy is a shared responsibility model, rather than transfer of care. Anesthesiologists do not have similar experience and expertise in caring for patients on HFOV or ECMO, and typically are not familiar with methods of optimizing these forms of respiratory and cardiorespiratory support. Therefore, the neonatal specialist should remain at bedside and be available to the anesthesiologist and surgical team to assist with patient management. To make such a system work effectively, communication is paramount. Plans for care and decision making should be outlined with as much detail as possible before the start of a procedure. Checklists are great aids in assisting memory and developing a clear plan of action.

**References and Additional Resources**


Davis PG, Morley CJ, Owen LS. Non-invasive respiratory support of preterm neonates with respiratory distress: continuous positive airway pressure and nasal intermittent positive pressure ventilation.


