**Hypercapnia and Acidosis in a Neonatal Thorascopic Tracheo-esophageal Fistula Repair using High Frequency Oscillatory Ventilation**

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**Objectives:**
At the end of this PBLD, the participant should be able to ...

1. Discuss the anesthetic implications for a patient with trachea-esophageal fistula (TEF)
2. Understand the differences in open vs. thorascopic TEF surgical approaches and their unique anesthetic implications
3. Obtain a basic understanding of high frequency oscillatory ventilation, appreciate the potential challenges in terms of oxygenation and ventilation when used for thorascopic surgical approaches and the management strategies employed to deal with hypercapnia and acidosis
4. Demonstrate the appropriate preoperative assessment, intraoperative management and post-operative care in a patient with TEF undergoing thorascopic repair using high frequency oscillatory ventilation

**Case Presentation:**
A 3-day-old, 3.5 kg otherwise healthy male with post-natal diagnosis of esophageal atresia (EA) with tracheo-esophageal fistula (TEF) is scheduled for rigid bronchoscopy and TEF repair. The patient was born full term via spontaneous vaginal delivery to a mother who had an uncomplicated pregnancy. Feeding and respiratory difficulties after birth prompted placement of a nasogastric tube which, after chest radiograph, revealed coiling in the upper thoracic region. Pediatric Surgery was consulted for possible EA with TEF. After confirmation of the diagnosis, Pediatric Surgery decided to proceed with rigid bronchoscopy and thorascopic TEF repair. After some consultation with other surgical colleagues and review of pertinent literature, the Pediatric Surgery team decided that the best surgical approach would include attempting high frequency oscillatory ventilation. You are consulted and need to prepare a safe and comprehensive anesthetic plan for this patient.

**What is TEF? What type is most common?**

**What are your concerns before proceeding with surgery? What imaging or lab evaluations would you like to see before proceeding?**

The infant had an ECHO and EKG. Both of which were normal. Genetic testing is pending. Basic chemistry and CBC are within normal limits. The patient had a PICC line placed in the NICU and is receiving D5 at an appropriate maintenance rate.

**Which syndromes are you most concerned about?**

VACTERL syndrome and Trisomy 18, 21 and 13q deletion are ruled out based on physical exam. The patient appears healthy and does not have any concerning evidence on physical exam. You decide to proceed to the OR tomorrow without further workup.
What are the implications of open vs. thorascopic TEF repairs? What are the implications of traditional one lung ventilation (OLV) vs. HFOV?

Thorascopic repair tends to be associated with shorter hospital stay and decreased hospital costs secondary to decreased post-op vent days, time to initial feeding, narcotic requirements, and ICU stay. From a surgical perspective, thorascopic repair has a lower incidence of long-term post-operative morbidity. This is because open procedures have been related to musculoskeletal deformities, thoracic scoliosis, and possibly chronic thoracotomy pain syndrome. Again, from a surgical perspective, there appears to be superior visualization of anatomy secondary to continuous lower pressure flows as opposed to larger pulse volumes.

OLV can produce a challenge for the anesthesiologist in a thorascopic procedure. It is usually achieved by either 1) advancing the ETT into the right mainstem, or 2) surgically packing the operative side which is difficult to do in a thorascopic procedure or 3) use of a bronchial blocker. Concerns usually relate to the surgical perspective where there can be sudden loss of the surgical field due to dislodgment. From an anesthetic perspective, controlling oxygenation and ventilation, barotrauma or pneumothorax, escalating ventilator pressures impacting cardiac output are all concerns. HFOV offers better surgical visualization to the surgeon and theoretically fewer issues with oxygenation and ventilation for the anesthesiologist.

What monitors would you like to use for this case? Is there anything aside from standard ASA monitors that you would like to use?

You decide to place an arterial line for blood pressure monitoring and ABG draws. You place near infrared spectroscopy (NIRS) on the forehead and the back near the kidney to assist in determining differences in regional oxygen delivery.

What is your anesthetic plan for the rigid bronchoscopy?

You decide to suction out the esophageal pouch prior to proceeding with a combined inhalational and intravenous induction using propofol, fentanyl and ketamine with sevoflurane to preserve spontaneous ventilation. The bronchoscopy is performed and the fistula is located. You then decide to proceed with intubation.

What, if any, concerns do you have regarding intubation? Where do you place the ETT in relation to the fistula and how do you assess? Do you plan to main stem prior to the repair?

You place the patient on the conventional anesthesia ventilator and position that patient in the left lateral decubitus position for thorascopic repair. You decide not to main stem intubate as the oscillatory ventilator allows for excellent surgical visualization. You place the ETT below the level of the fistula but above the carina and confirm placement by auscultation of breath sounds.

What is your anesthetic plan for the thorascopic repair? Will you need any additional monitors?

You decide to proceed with a total intravenous anesthetic consisting of propofol, remifentanil and ketamine, as the high oscillatory ventilator does not allow you to supply volatile gases. You also place a transcutaneous CO₂ (TcCO₂) monitor as this is there in no end-tidal CO₂ monitor
with HFOV. In addition, you add bispectral index (BIS) monitor to watch for trends in possible consciousness. Baseline NIRS (cerebral 90s, somatic 80s), TcCO₂ (45), ETCO₂ (40) and BIS (45) appear within normal limits. You send off a baseline ABG that is also within normal limits. The surgeon has prepped and draped the patient and is ready to begin. You need to switch the patient over to the HFOV.

What is HFOV? What are the settings to control? What variables control oxygenation and ventilation? What are the advantages and disadvantages?

High frequency oscillatory ventilation (HFOV) is a type of mechanical ventilation that uses a constant distending pressure with pressure variations oscillating around the MAP at very high rates (up to 900 cycles per minute). HFOV is essentially a vibrating CPAP machine. This creates very small tidal volumes at very high rates to supply oxygen. Frequency (Hz – cycles per second, 10 Hz = 10 cycles/sec = 600 cycles/min) is the ventilation rate. MAP is the mean airway pressure, which is the constant distending pressure and is measured in cmH₂O. Amplitude is the variation around MAP, as known as ∆P or power. Oxygenation is dependent on MAP and FiO₂. Ventilation, or CO₂ elimination, is dependent on ∆P and Hz. Advantages include maintaining constant lung recruitment, the ability to promote gas exchange using tidal volumes less than dead space minimizing barotrauma, and mobilization of secretions. In this case, the use of it provides better surgical visualization due to decreased lung movement in the field of surgical view. Disadvantages include higher risk of hemodynamic instability due to high MAP, the need for humidification, and hypercarbia via reduced ventilation.

What are your baseline settings?

You decide to set the MAP at 10 cmH₂O, frequency at 10 Hz, and ∆P at 20. FiO₂ is 30%. You make note of your baseline NIRS, TcCO₂, and BIS numbers; again, all within normal limits. The surgeon reports that he has good surgical visualization.

About 30 minutes into the case you notice that the TcCO₂ and ETCO₂ has been steadily increasing. You send off another ABG, which comes back with an acidosis with hypercarbia.

What changes do you make to your HFOV?

For poor oxygenation: increase either FiO₂ or MAP by 1-2 cmH₂O
For over oxygenation: decrease either FiO₂ or MAP by 1-2 cmH₂O
For poor ventilation: increase ∆P 2-5 first or decrease Hz by 1-2 if not responsive
For over ventilation: decrease ∆P 2-5 first or increase Hz by 1-2 if not responsive

You decide to increase the ∆P first by 5. TcCO₂ and ETCO₂ have not improved and in fact are worsening. You send off another ABG, which comes back with a base deficit of -8.

What is your next move?

You decrease the Hz by 2. The TcCO₂ and ETCO₂ have somewhat leveled off by are still high even taking some permissive hypercapnia into consideration. You feel that you have gotten behind in your ventilation and would like to proceed to a few recruitment breaths to assist in
your ventilation. You suggest this to the surgeon but he is obviously struggling with the repair and says that he is at a critical stage in the procedure.

What is your next move?

You increase ΔP by another 5. TcCO$_2$ and ETCO$_2$ have improved and a repeat ABG shows improvement in your acidosis and base deficit. You are willing to “live with” the permissive hypercapnia, as the surgeon now seems to be proceeding along. The surgeon reports that the “lungs are fluttering too much” which is now obstructing his view.

What do you say to him?

You explain to him that you have needed to make changes to the HFOV in order to improve the infant’s ventilation status and subsequent increasing acidosis. You ask if he can proceed under these conditions. You explain that if you revert back to your previous settings that you risk an increasing acidosis that will ultimately affect your hemodynamic status, which has been stable up to now. As he contemplates proceeding to an open thoracotomy, he is able to put in the finishing sutures. After checking for a leak with methylene blue, he is satisfied with the repair and says that you can convert to two-lung ventilation.

What is your plan for extubation and post-operative care?

TcCO$_2$ and ETCO$_2$ have now returned to baseline values. Final repeat ABG are also within normal limits. You decide to attempt extubation if all criteria are met and will send the infant to the NICU for close monitoring overnight.
Discussion

Types of TEF

<table>
<thead>
<tr>
<th>Organ System</th>
<th>Incidence (%)</th>
<th>Examples</th>
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<tbody>
<tr>
<td>Cardiac</td>
<td>29</td>
<td>VSD, PDA, Tetralogy of Fallot, ASD, right sided arch</td>
</tr>
<tr>
<td>Gastrointestinal</td>
<td>14</td>
<td>Duodenal atresia, imperforate anus, malrotation, pyloric stenosis, omphalocele</td>
</tr>
<tr>
<td>Genitourinary</td>
<td>14</td>
<td>Renal agenesis, hypospadias, horseshoe/polycystic kidney, ureteric/urethral abnormalities</td>
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<tr>
<td>Musculoskeletal</td>
<td>10</td>
<td>Radial limb abnormalities, polydactyly, lower limb defects, hemi-vertebra, rib defects, scoliosis</td>
</tr>
<tr>
<td>Respiratory</td>
<td>6</td>
<td>Tracheo-bronchomalacia, pulmonary hypoplasia, tracheal agenesis/stenosis, tracheal upper pouch</td>
</tr>
<tr>
<td>VATER/VACTERL Syndrome</td>
<td>10</td>
<td>Vertebral, anorectal, tracheoesophageal, renal or radial anomalies (expanded to include cardiac and limb defects)</td>
</tr>
<tr>
<td>Genetic</td>
<td>4</td>
<td>Trisomy, 21, Trisomy 18, 13q deletion</td>
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High Frequency Oscillatory Ventilation Definitions

- Frequency: high frequency ventilation rate in Hz (cycles/sec)
  - 10 Hz = 10 cycles/sec = 600 cycles/min
- MAP: mean airway pressure (cmH₂O)
  - Constant distending pressure
- Amplitude: variation around MAP (ΔP)
- Oxygenation: dependent on MAP and FiO₂
- Ventilation: CO₂ elimination; dependent on ΔP and Hz
Initial Management Strategies

- Choose your frequency (Hz)
  - Pre-term infant or < 2.5 kg = 15 Hz
  - Term infant = 10 Hz
  - 6-10 kg child = 8 Hz
  - > 10 kg child = 6 Hz
- Choose MAP (cmH₂O)
  - Neonates 2-4 cmH₂O above MAP on conventional mechanical ventilation (CMV)
    - MAP 8-10 cmH₂O
  - Infants/children 4-8 cmH₂O above MAP on CMV
    - MAP 15-18 cmH₂O
- Choose Amplitude (ΔP)
  - Pre-term 25 cmH₂O or greater
  - Term 16 cmH₂O or greater

HFOV Management Strategies

### Poor Oxygenation
- Increase FiO₂
- Increase MAP (1-2 cm H₂O increments)

### Under Ventilation
- Increase ΔP
  - 2-5 cmH₂O to achieve PaCO₂ change of 3-5 mmHg
  - > 5 cmH₂O to achieve PaCO₂ change of 5-10 mmHg
  - Decrease Hz (1-2) but only if PaCO₂ refractory to ΔP changes

### Over Oxygenation
- Decrease FiO₂
- Decrease MAP (1-2 cm H₂O increments)

### Over Ventilation
- Decrease ΔP
  - 2-5 cmH₂O to achieve PaCO₂ change of 3-5 mmHg
  - > 5 cmH₂O to achieve PaCO₂ change of 5-10 mmHg
  - Increase Hz (1-2) but only if PaCO₂ refractory to ΔP changes


