Baby’s Breath: Ventilation Strategies and Blood Gas Interpretation

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Session Summary

This presentation will provide a general overview of oxygen and ventilation strategies commonly used in neonatal care, as well as review of blood gas interpretation/manipulation to optimize the neonate’s status.

Session Objectives

Upon completion of this presentation, the participant will be able to:

- evaluate blood gas results;
- recognize the effects of common neonatal therapies for acid-base manipulation;
- describe the principles of ventilation.

Test Questions

1. Which of the following arterial blood gas results indicate metabolic acidosis?
   a. pH 7.24  PCO2 32  PaO2 65  HCO3 20
   b. pH 7.24  PCO2 49  PaO2 65  HCO3 26
   c. pH 7.47  PCO2 33  PaO2 65  HCO3 24

2. In which of the following situations would PSV alone be contraindicated?
   a. Term infant with pneumothorax weaning off mechanical ventilation
   b. Premature infant with apnea
   c. Term infant with TTNB

3. If a newborn infant has a PaO2 of 45 with a pH of 7.25, you would expect the PaO2 to ____________ as the pH corrects:
   a. Decrease
   b. Remain the same
   c. Increase
4. Compensation by the renal buffering system:
   a. Does not occur
   b. May take hours to days
   c. Occurs within minutes

5. The two blood gas values that one can directly affect are:
   a. PaO2 and PCO2
   b. HCO3 and PaO2
   c. pH and PCO2

6. When making ventilator changes to correct problems with oxygenation, the clinician can increase oxygenation by:
   a. Decreasing the PIP and PEEP
   b. Increasing the FiO2 and decreasing the PIP
   c. Increasing the FiO2 and PIP

References*


*Please review any references denoted on the slides.

Session Outline

See handout on the following pages.
Baby's Breath: Ventilation Strategies and Blood Gas Interpretation

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Objectives

- Upon completion of this presentation, the participants will be able to:
  - evaluate blood gas results
  - explore effects of common neonatal therapies for acid-base manipulation
  - review principles of ventilation

Blood Gas Components

- **pH** - numerical value based on hydrogen ions present (H+)/measure of the acid-base balance of the blood.
- **PaCO2** - the partial pressure of carbon dioxide found in arterial blood.
- **PaO2** - the partial pressure of oxygen found in arterial blood.
- **Bicarbonate** - the calculated value of the amount of bicarbonate in the blood (HCO3-).
- **Base excess (BE) / Base deficit (BD)** - another way of looking at the amount of bicarbonate in the blood. Normal value is -2 to +2 with 0 being ideal.

“Normal” Blood Gas Values

<table>
<thead>
<tr>
<th>Component</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>7.35 - 7.45</td>
</tr>
<tr>
<td>PaCO2</td>
<td>35 - 45</td>
</tr>
<tr>
<td>PaO2</td>
<td>80 - 100</td>
</tr>
<tr>
<td>HCO3</td>
<td>22 - 26</td>
</tr>
<tr>
<td>SaO2</td>
<td>88 - 100</td>
</tr>
</tbody>
</table>

Disclaimer

- Previous values are general ranges but are not a gold standard.
- pH varies with age. A pH of 7.30 is generally considered acceptable with 7.25 the lower limit with certain conditions.
- Higher PCO2 values are acceptable if pH remains normal.
- New evidence is evolving concerning what might be considered “normal” for a given situation and infant.

Guidelines for Interpretation

- Identify oxygenation status.
- Identify ventilation status.
- Identify Acidosis or Alkalosis
- Determine Respiratory or Metabolic etiology
- Check for Compensation
When evaluating blood gases, look at the components separately.

- Oxygenation is represented by the PaO2 and the O2 saturation of the blood.
- Acid-base balance is reflected by the pH, PaCO2, bicarbonate and base deficit.

Oxygenation

- Oxygenation refers to the supply of oxygen to the tissues.
- Affected by: Cardiac Output and Oxygen Content of the Blood

Oxygen Content

- Oxygen bonds to hemoglobin in the blood so the factors that determine this bond (saturation), as well as the hemoglobin content, directly affect the amount of oxygen available to the tissues.

Oxygen Content

- Blood carries the oxygen bound to hemoglobin as well as freely dissolved in the serum.
- Hemoglobin is almost fully saturated at PO2 of 80 to 100 mm Hg.

Oxygen Hemoglobin Dissociation Curve

Factors that affect shifts in curve

- The amount of oxygen attached to the hemoglobin or dissolved in the serum at a given PO2 is dependent upon the position of the dissociation curve (whether or not it is shifted). This has important clinical implications.
Factors that affect shifts in curve

- Decreased affinity may cause release of oxygen before it reaches the tissues.
- Increased affinity may prevent release of oxygen at the tissue level.

Position on Curve

- Position on the curve depends on the following factors:
  - Concentration of 2,3-DPG
  - Ratio of adult (HgA) to fetal (HgF) hemoglobin
  - Hydrogen ion concentration (pH)
  - PaCO2
  - Temperature

Right Shift

- With increasing age, concentration of DPG and ratio of HgA increase, shifting the curve to the right.
- As temperature, PCO2, or H+ concentration increase (e.g. pH decreases), the curve is shifted to the right.
- As the curve shifts to the right, hemoglobin releases oxygen more readily. This means you would have a higher PaO2 (as the blood gas measures the oxygen in the plasma).

Left Shift

- Newborns who have not received a PRBC transfusion have a higher ratio of HgF, therefore, have a Left shift.
- As temperature, PCO2, or H+ concentration decreases (e.g. pH increases), the curve is shifted to the left.
- As the curve shifts to the left, hemoglobin is less able to release oxygen to the tissues. Therefore, you would have a lower PaO2 (since the blood gas measures the oxygen in the plasma).

Important Clinical Implication

- The most important clinical implications for a left shift in the immediate newborn period are:
  - If the infant has a PaO2 of 45 with a pH of 7.23, you can expect the PaO2 to be much lower as the pH corrects.
  - Remember also that, in a left shift, the saturation will increase at a given PaO2 but the hemoglobin molecule will not be as likely to release it to the tissues, creating a condition of hypoxia.

Acid-Base Balance

- This is a measure of the acidity or alkalinity of the blood and is measured by pH.
- Considering a normal pH of 7.35 - 7.45, the body is well equipped to make certain changes in order to maintain this range by buffering systems.
Acid-Base Balance

- The body's buffering systems are:
  - The kidneys (renal excretion of excess hydrogen ions)
  - The lungs (pulmonary excretion of excess CO2).

You want to correct when possible by manipulating the system causing the problem.

Renal Buffering System

- excrete acid by acidifying urine and reclaiming all filtered bicarbonate
- excrete urinary ions (e.g. phosphate) which combine with H+ to form an acid that can be titrated
- produces ammonia (may bind H+ to form ammonium ions)
- This process may take from hours to days.

Pulmonary Buffering System

- quick response – minutes at times.
- increase in carbonic acid formed when there is excess CO2, stimulates the medulla, which drives respiration
- breathing faster increases minute ventilation to remove excess CO2
- respirations: either increases or decreases rate and depth of ventilation until an appropriate CO2 level is achieved

Basic Principles

<table>
<thead>
<tr>
<th>Increase in CO2</th>
<th>Decrease in CO2</th>
</tr>
</thead>
<tbody>
<tr>
<td>acidosis</td>
<td>alkalosis</td>
</tr>
<tr>
<td>Increase in HCO3</td>
<td>Decrease in HCO3</td>
</tr>
</tbody>
</table>

Interpreting Blood Gas Compensation

- Uncompensated: pH is abnormal and one of the acid-base components is abnormal and one normal
- Partial Compensation: 2 acid-base components are abnormal in opposite directions
- Compensated: pH reaches normal range

Compensation

- The body's attempts to manipulate the buffering systems is referred to as Compensation. If acidosis or alkalosis is present, a particular ABG may be Compensated, Uncompensated, or Partially Compensated.
Determining Acid-Base Balance

<table>
<thead>
<tr>
<th>Condition</th>
<th>Primary Disturbance</th>
<th>Compensation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metabolic Acidosis</td>
<td>Decreased HCO3</td>
<td>Decreased PaCO2</td>
</tr>
<tr>
<td>Metabolic Alkalosis</td>
<td>Increased HCO3</td>
<td>Increased PaCO2</td>
</tr>
<tr>
<td>Respiratory Acidosis</td>
<td>Increased PaCO2</td>
<td>Increased HCO3</td>
</tr>
<tr>
<td>Respiratory Alkalosis</td>
<td>Decreased PaCO2</td>
<td>Decreased HCO3</td>
</tr>
</tbody>
</table>

Differential Diagnosis for Metabolic Acidosis

- **Common causes:**
  - sepsis
  - NEC
  - hypothermia or cold stress
  - asphyxia

- **Less Common**
  - IVH
  - PDA
  - shock
  - iatrogenic
  - medications

DDx for Metabolic Acidosis

- **Less common causes:**
  - renal tubular acidosis
  - inborn Errors of Metabolism
  - maternal use of salicylates
  - maternal acidosis
  - primary renal failure
  - congenital lactic acidosis
  - GI losses

DDx for Metabolic Alkalosis

- **Common**
  - excess alkali administration
  - K depletion
  - Prolonged NG suction or vomiting
  - Diuretic therapy

- **Less Common**
  - Pyloric stenosis
  - Bartter’s syndrome
  - Primary hyperaldosteronism

DDx for Respiratory Acidosis

- **Less pH, high PCO2, normal bicarb**
- Usually caused by insufficient alveolar ventilation secondary to lung disease
- Disease states associated with hypoventilation:
  - asphyxia, apnea, upper airway obstruction, RDS, PIE, Pneumothorax, cardiac disease, VQ mismatch

DDx for Respiratory Alkalosis

- **High pH, low PCO2, normal bicarb**
- Caused by hyperventilation of the alveolus leading to deficiency of carbonic acid - usually iatrogenic
- Air bubble in syringe?
- Associated disease states: CNS, response to hypoxia, maternal heroine addiction
Mixed Metabolic/Respiratory Acidosis

- pH low, PCO2 high, HCO3 low
- Example: severe respiratory disease with hypercapnia leading to a respiratory acidosis along with hypoxia leading to lactic acid build-up and metabolic acidosis.

Understanding Ventilator Modes for Neonates

- There is no one way to ventilate all infants.
- Consider the underlying pathophysiology and the current condition of the infant.
- Institutional policies and practices vary and are based on what has proven successful for that particular population as well as current evidence.

Basic Ventilation Guidelines

- Gentle ventilation
  - Start with the least invasive respiratory support
  - Use the least amount of pressure and oxygen necessary
  - Use synchronization for babies who are breathing spontaneously
  - Try to reduce ventilator support as soon as possible

Permissive Hypercapnia

- A strategy used to avoid damage during ventilation.
- Allows the PCO2 to rise slowly so that the kidneys will have time to compensate.

Indications for Respiratory Support: NCPAP

- Recently delivered premature infant with minimal respiratory distress (to prevent atelectasis)
- Apnea of prematurity
- Clinically significant respiratory distress after recent extubation
- After intubation for surfactant administration and extubation (In and out surfing.)

HFNC

- The technical definition of HFNC is flow rates greater than 1 L/min.
- It provides humidified air flow and can be associated with a blender to provide varying amounts of supplemental oxygen.
- This method may (and probably does) provide positive end-expiratory pressure (PEEP), especially in premature infant.
- HFNC is an alternative form of respiratory support for preterm infant with apnea, RDS, or CLD.
**LFNC**

- Actually NC can be either HF or LF.
- LFNC, or simply NC, typically refers to the use of flow rates of ≤ 1 L/min. The gas is usually unblended, unheated and sometimes non-humidified. The usual indication is oxygen requirement for the convalescing preterm infant with CLD.

**Low Flow Oxygen Delivery**

\[
\text{FiO2 measured} = \text{oxygen flow (cc/min} \times 0.79) + (0.21 \times \text{VE})/\text{VE} \times 100
\]

\(\text{VE} = \text{minute ventilation in ml/min} \)

\(\text{(VE = VT x respiratory rate) assumed tide volume of 5.5 ml/Kg}\)

**Indications for Respiratory Support (Intubation)**

- Supplemental oxygen requirement > ? on CPAP; i.e. (PaO2 < 50 mm Hg with FiO2 > .60)
- Frequent apnea despite medications and CPAP
- Prolonged apnea event
- Deteriorating gas exchange
- Relieving “work of breathing” in infant with respiratory difficulty
- Administration of surfactant therapy
- General anesthesia

**Basic Ventilator Changes**

- There are only 2 blood gas values you can directly affect: PaCO2 and PaO2.
- Indirectly, the HCO3- level is affected only as a compensatory mechanism.

**Ventilator Strategies to Improve Ventilation**

- Increase the rate
- Increase the PIP or Tidal Volume
- Increase the PEEP for chronic; decrease the PEEP for acute
- Increase the Expiratory Time
- Increase the Flow

**Improving Ventilation: CO2 Elimination**

- Increase the rate
- Increase the PIP or Tidal Volume
- Increase the PEEP for chronic; decrease the PEEP for acute
- Increase the Expiratory Time
- Increase the Flow
**Ventilator Manipulations to Increase Oxygenation**

- Increase the FiO2
- Increase the MAP
- Increase PIP or Tidal Volume
- Increase the Inspiratory Time
- Increase the Flow

**Improving Oxygenation: Increase PaO2**

- Increase the FiO2
- Increase the MAP
  - Increase PIP or Tidal Volume
  - Increase the Inspiratory Time
  - Increase the Flow

**NCPAP**

- Nasal Continuous Positive Airway Pressure:
- Constant positive pressure intended to maintain end-expiratory pressure and prevent alveolar collapse. Continuous pressure is exerted on the airway during both the inspiratory and expiratory phase of respiration.

**NCPAP Technique**

- Supplemental oxygen may or may not be required.
- Initial settings of 3 - 5 cm H2O pressure are reasonable although many centers use higher values.
- Low PEEP is more likely to cause a pneumothorax than excessive PEEP. All of tidal volume goes to non-atelectatic areas.
- May use mask or nasal prongs for delivery. (CPAP may also be delivered via ETT.)

**Precautions / Limitations**

- Monitor cardiac output: Excessive pressure may lead to decrease in cardiac output and interferes with oxygen transport.
- Monitor integrity of nasal septum for signs of tissue damage or necrosis.
- May not be tolerated by the larger or older infant.
- Consider topical analgesia to nares to prevent pain.

**Exceeding the Optimal PEEP**

- Increasing the PEEP can be very beneficial up to a critical point where the alveolar capillaries are under such pressure that oxygen and carbon dioxide transfer cannot occur.
Conventional Mechanical Ventilation

There are two basic types of conventional ventilators used in the NICU.

- Pressure Modalities
  - TCPL (Time-cycled pressure limited)
  - Pressure Control
  - Pressure Support

Conventional Mechanical Ventilation

- Volume-limited
  - Volume Targeted (Limited)
  - Volume Guarantee
  - Pressure Regulated Volume Control (PRVC)

Pressure ventilators

- Constant-flow - constant flow of gas through the ETT
- Time-cycled - breaths are given at fixed intervals
- Pressure-limited - a preset peak inspiratory pressure is maintained through the duration of inspiration
- TCPL - Time-cycled, Pressure-limited Ventilation

Major Disadvantage of Pressure Ventilators

- Decrease in tidal volume if the compliance decreases
- Over-distention if compliance improves

Volume Ventilators

- Same tidal volume is delivered with each breath, regardless of the pressure needed to achieve the preset volume.
- Disadvantage is that a fixed volume will be delivered regardless of changes in compliance and may lead to the use of very high PIPs.

Pressure Support

- When used alone, is a form of ventilation that has no set rate and supports the infant’s own spontaneous effort.
- Similar to Pressure Control with the exception that the breath ends because of a decrease in flow (Flow cycling).
Operating Modes

- IMV - Intermittent Mandatory ventilation
- SIMV - Synchronous IMV
- A/C - Assist/control

IMV

- Constant flow of oxygen/air
- Infant can breath spontaneously.
- There is a preset Mandatory number of breaths per minute.
- *If the infant is breathing faster than the set rate, these breaths are not supported.
- Disadvantage - infants may exhale during the ventilator’s inspiratory cycle (fighting the ventilator).

Synchronized IMV

- Ventilator senses the infant’s spontaneous respirations and mechanically delivers the breaths to support the infant’s attempts.
- Infant can breath faster than the preset rate and those breaths are not supported.
- At low preset rates, the infant may exert considerable work of breathing and may fail at weaning.

A/C or Patient-triggered

- The infant’s spontaneous breath "triggers" a mechanical breath.
- Theoretical advantage in that all breaths will be assisted at preset parameters.
- Disadvantage is that very immature infants have weak respiratory efforts that may not trigger the machine.
- *Can have 'back-up' rate to reduce this disadvantage.

High Frequency Ventilation

- Capable of cycling > 150 bpm
- HFOV - High Frequency Oscillatory Ventilator
- HFJV - High Frequency Jet Ventilator
- HFFI - High Frequency Flow Interrupter

HFV

- Ventilatory techniques that utilize very high rates and small tidal volumes.
- Rationale: to reduce the risk of barotrauma, decrease the risk of air leak and chronic lung disease, and as rescue to facilitate resolution of existing air leaks.
HFOV

- Active inspiration and expiration
- Diaphragm or piston that oscillates a bias flow of gas to generate both positive and negative pressure.
- Adjustment parameters: MAP, Hz (frequency), and Amplitude. Inspiratory time is also set.
  - MAP – oxygenation
  - Amplitude - ventilation (chest wiggle)
  - Hz - rate of ventilation

- MAP - usually set one or two cm H2O higher than when on Conventional Mechanical Ventilation.
- Amp - may require 25 - 40 initially. Set to achieve adequate "chest wiggle" and adjust as necessary to achieve goal CO2.
- Hz - Usually 10 - 15 Hz for premature infants and 8 - 10 Hz for term infants.
  - One Hz is equal to one breath/second or 60 breaths/minute. So a Hz of 10 will deliver 600 breaths per minute.

HFJV

- Active inspiration with passive expiration
- High pressure gas source is connected to a small airway cannula with the use of a high-frequency flow interrupter valve which opens and closes rapidly, thus propelling the pressurized gas into the airway.
- Some use a background "sigh" breath which may decrease the risk for microatelectasis.

- requires intubation with triple-lumen endotracheal tube or the use of a special adaptor
- use is limited in infants < 900 gms due to outer diameter of ETT – unless adaptor used
- delay in response of up to 30 minutes

HFJV Parameters

- May adjust PIP and conventional ventilation as well as PEEP and frequency (60 - 600 bpm)
- Oxygenation - PEEP and FiO2
- Ventilation - dependent mostly on PIP to PEEP pressure difference.

HFFI

- have both conventional and high-frequency options
- high-pressure gas source is delivered into standard circuit
- flow is interrupted by a valve mechanism
- can adjust PIP, PEEP, and frequency
- Oxygenation - PEEP primarily
- Ventilation - difference between the PIP and PEEP
Additional Modalities

- Volume Guarantee - Drager Babylog
- Pressure Regulated Volume Control and Volume Support - Siemens 300
- Volume Assured Pressure Support - VIP Bird Gold

Volume Guarantee

- Deliver a pressure targeted breath at set inspiratory flow (fixed, not variable flow)
- Based on previous breath, pressure may increase or decrease to “guarantee” targeted volume

Pressure Regulated Volume Control

- Variable, decelerating flow pattern.
- Breaths are time-cycled, assist/control (wean in volume support).
- Establishes a “learning period” to determine patient’s compliance, which establishes regulation of pressure/volume.
- During learning period, 4 test breaths of increasing pressure are delivered.

Volume Assured Pressure Support (VAPS)

- Set pressure delivered.
- Breath continues to guarantee volume if targeted volume is not delivered at set pressure.
- PIP and Inspiratory time increase.
- Guarantees volume on current breath without averaging from previous breath.

NAVA

- NAVA, or Neurally Adjusted Ventilatory Assist, is a rather new mode of mechanical ventilation.
- The ventilator is triggered by the electrical activity of the infant’s diaphragm (Edi) and synchronizes the mechanical breath based on this input.
- The infant, therefore, determines the peak inspiratory pressure, respiratory rate, and inspiratory and expiratory times.

Adjunctive Therapies

- iNO
- ECMO
Inhaled Nitric Oxide

• The physiological rationale for the use of iNO therapy is based on its ability to achieve patent and sustained pulmonary vasodilation without decreasing systemic vascular tone. (Rapidly inactivated by hemoglobin in the pulmonary circulation.)
• Low dose iNO therapy can also improve oxygenation by redirecting blood from poorly aerated or diseased regions of the lung to better aerated air spaces.
• Approved for use in newborn infants > 34 weeks with hypoxic respiratory failure.
• Primarily used in the treatment of Persistent Pulmonary Hypertension of the Newborn (PPHN).
• Should not be used in infants suspected or proven to be dependent on right to left shunting of blood.

iNO

• iNO is the most commonly used and most specific agent for PPHN in the newborn. Has decreased the need for ECMO by > 35%. Leads to vasodilation by relaxation of vascular smooth muscle. Initiation of therapy frequently begins with 20 ppm with dosing adjustments as warranted. A common weaning protocol is to wean iNO if the infant can maintain PaO2 > 60 mm Hg in FiO2 < .60.
• Most clinically important side effect is the formation of methemoglobin when NO combines with hemoglobin. Rate of accumulation depends on dose and duration of treatment. NO also inhibits platelet adhesion to endothelium with potential complication of prolonged bleeding time.
• Use in center with ECMO available or insure ability to transport on iNO.

ECMO

• Each ECMO center will establish specific inclusion criteria.
• Generally accepted: ANY of the following AND underlying disease process which is likely to be reversible.
• Standard: OI > 40 on conventional ventilation or > 50 - 60 on HFOV. (0.5 - 6 hours)
• PaO2 < 40 mm Hg for >2 hours despite maximum ventilatory support.
• Acidosis and Shock (pH < 7.25 due to metabolic acidosis, lactate build-up, intractable hypotension)

Oi Calculation

• OI = FiO2 X MAP X 100 / PaO2 (mm Hg)
• Example: 1.0 X 18 X 100 / 40 = 45
• Oxygen Index calculators available online. One example:

Wrap-Up

• ABG Interpretation:
  – Know the clinical details of the patient.
  – Determine the acid base imbalance.
  – Determine the major primary process.
  – Take action to correct.
• Ventilation Strategies:
  Consider the underlying disease process.
  – Atelectasis
  – Pulmonary hypertension
  – Air leak
  – Air trapping
  – Circulatory failure.
  – Determine the appropriate strategy.

Thank You!