Oxygenation/Ventilation and Acid Base Homeostasis

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Disclosures

The following speaker of this CME activity has no relevant financial relationships with commercial interests to disclose:

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Objectives

- Define oxygenation, ventilation and other important terms
- Describe and explain blood gas interpretation
- Identify treatment modalities for neonates with respiratory distress
- Describe various types of mechanical ventilation
- List nursing interventions required to care for infants requiring assisted ventilation
- Describe common medications used during ventilation therapy

Oxygenation/Ventilation

Oxygenation- ability to get oxygen into body, across alveolar-capillary membrane, into circulating blood stream, and into the cell

Ventilation - ability to get carbon dioxide out of cell, into circulating blood stream, across the alveolar-capillary membrane, and out of body

Definitions

Hypoxemia -abnormal low amount of oxygen in ***blood***, major consequence of respiratory failure, lungs not able to perform chief function, gas exchange

Hypoxia - reduction of oxygen supply to ***tissues*** despite adequate perfusion of tissue by blood

Oxygen Saturation

Oxygen saturation- amount of oxygen bound to hemoglobin in blood, expressed as percentage of maximal binding capacity

A measure to determine the body's oxygenation status

Oxygen saturation monitoring - the *most common and widely used* method for assessing oxygenation status

Oxygen Saturation

Pulse oximetry

Relies on pulsatile arterial vascular bed between light source and photoreceptor

Difference in light absorption electronically processed - displayed as SpO_2

Normal oxygen saturations - vary based on gestational age and clinical condition

Goal <36 weeks gestation 88-95%

Goal >36 weeks gestation >91%

Why do we titrate supplemental oxygen?

*** Does not eliminate need for blood gas analysis, signs of ventilation & acid base balance must be evaluated*

What is FiO2?

FiO_2 - fraction of inspired oxygen in gas mixture, ranges 21% to 100%

FiO_2, set on oxygen blender, not always what patient's lungs receive, depends on device and flow rate

**Our goal when providing supplemental oxygen, regardless of device is to achieve NORMOXIA, not hyperoxia

Blood Gas Interpretation

Blood Gases - essential to properly diagnosis, manage, and determine outcome of ill neonate

Determine adequate ventilation and perfusion

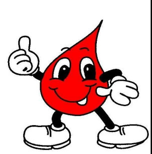
Used as indicator, in addition to clinical assessment

Assess when assisted ventilation initiated

Serum Lactate - indication of adequacy of oxygen delivery to tissues

Lactate accumulates in tissues, blood and CSF as a result of anaerobic metabolism

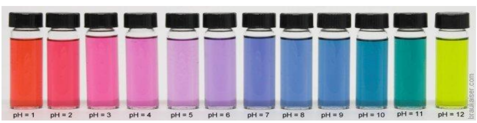
** Normal level healthy full-term infants - range 0.22-2.98 mmol/L



Acid/Base Homeostasis

First step determining acid-base homeostasis: **Measurement of pH**

Normal human pH - 7.35-7.45
Acidosis (or academia) - pH < 7.35
Alkalosis (alkalemia) - pH > 7.45



Carbon Dioxide

Carbon dioxide -produced by each living cell, as product of metabolism

CO_2 produced, dissolves in intracellular fluid, measured as partial pressure of dissolved gas (PCO_2)

Retention of carbon dioxide - will cause the pH to fall

Normal arterial partial pressure of **carbon dioxide: 35-45 mmHg (P_aCO_2)**

Partial Pressure of Oxygen (PaO2)

Oxygen, dissolved in the blood, described as partial pressure of oxygen (P_aO_2)

Measure of P_aO_2 is direct measure of oxygenation of blood, and, as a result, the tissue

Normal arterial partial pressure of **oxygen 60-80 mmHg (P_aO_2)**

Bicarbonate

Normal blood pH is maintained in body by kidneys - control of circulating **bicarbonate** (HCO_3^-)

Bicarbonate - acts as a base, or hydrogen ion acceptor, to lower blood pH

Normal arterial concentration **bicarbonate - 18-26 mEq/L (HCO_3^-)**

Base Excess/Deficit

Base excess and **base deficit** - amount base present in blood

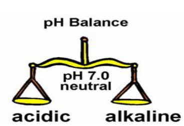
Reported as mEq/L

Positive numbers - excess of base

Negative numbers - deficit of base

Predominant base contributing to balance - bicarbonate

Normal arterial **base excess/deficit -5 to +5 mEq/L**



Blood Gas Interpretation

When ABGs are divided into major components (acid/base balance and oxygenation) - become much easier to understand

pH tells us - **acidotic** or **alkalotic ?**

P_aO_2 and O_2 saturation tell us about oxygenation

P_aCO_2 and HCO_3^- tell us where acid/base abnormality comes from & whether there is *compensation*

Acidosis	Respiratory	pH ↓	$PaCO_2$ ↑
Acidosis	Metabolic&	pH ↓	$PaCO_2$ ↓
Alkalosis	Respiratory	pH ↑	$PaCO_2$ ↓
Alkalosis	Metabolic	pH ↑	$PaCO_2$ ↑

Blood Gas Interpretation

6 Easy Steps ABG Analysis

- Is pH normal? (↓acidosis or ↑alkalosis)
- Is CO_2 normal? (↑respiratory or ↓metabolic)
- Is PaO_2 and SaO_2 normal?
- Compensation?
- Is HCO_3 normal? (↓metabolic acidosis or ↑alkalosis)
- Base excess or deficit?

Case Study 1

Baby A born at 31 weeks to G4 mother with previous stillbirths. Born by emergency C/S with BW 1.3Kg. Mom received one dose of BMTZ prior to delivery. Baby developed distress at birth with grunting, retractions, decreased aeration. Placed on CPAP 6cm, required FiO2 25% to keep saturations 88-94%.

ABG : 7.25/60/58/22/0

How would you interpret this ABG?
Compensated?
What are the risk factors?
What symptoms are common with this condition?

Case Study 2

Baby H born at 36 weeks to G2P1 mother with poor prenatal care. Polyhydramnios noted with fetal bilateral pleural effusions. Echo showed large heart. Baby delivered and required intubation for respiratory failure. Bilateral chest tubes placed for large pleural effusions with continuous drainage. Over the next days, baby treated with multiple doses of lasix for significant pulmonary edema.

ABG : 7.49/42/65/28/+4

How would you interpret this ABG?
Compensated?
What are the risk factors?

Case Study 3

Baby P born at 41 weeks to G1P0 mother who had placenta previa and bleeding. Delivered by urgent C/S for fetal distress. Apgars 1,1, 5, 7. Cord ph 7.0/-10. Depressed and apneic in delivery room requiring intubation and mechanical ventilation.

ABG: 7.2/40/62/16/-10

How would you interpret this ABG?
Compensated?
What are the risk factors?
What symptoms are common with this condition?

Respiratory Definitions

Peak Inspiratory Pressure (PIP)
- maximum pressure reached during inspiratory phase
- the pressure limit
- amount of pressure needed to distend alveoli

Functional Residual Capacity (FRC)
- volume of gas left in lung after normal expiration

Positive End Expiratory pressure (PEEP)
- amount of positive pressure maintained in airway at end of ventilatory cycle
- pressure maintains sufficient FRC at end of expiration
- prevent alveoli from collapsing

IMV (rate)
- preset rate of breaths/minute delivered by ventilator

Inspiratory Time
- amount of time the ventilator uses for inspiration

Respiratory Definitions

Tidal volume
- air inhaled and exhaled during normal quiet breathing

Pressure Support
- provides a preset pressure for spontaneous breaths allowing the patient to determine own tidal volume
- amount of pressure given set over the PEEP

Mean Airway Pressure (MAP)
- average pressure delivered to proximal airways from beginning of inspiration to beginning of next

Amplitude (Delta P)
- difference between PIP and PEEP

Frequency (Hertz)
- rate on HFOV, controls how rapid the internal piston moves
- effects ventilation

Non-Invasive Oxygen Delivery & Ventilation

- Blow-by Oxygen
- Simple Face Mask
- Oxyhood
- Nasal Cannula
- High Flow Nasal Cannula
- CPAP (Continuous Positive Airway Pressure)
- NIV-NAVA

Regular/High Flow Nasal Cannula

Regular nasal cannula (1LPM or less)
Humidified O2 delivered- set flow
Exact concentration of oxygen delivered - unable to measure

High flow nasal cannula
Uses higher flow rates to meet inspiratory flow demands & minute ventilation
Supplemental oxygen provided - actually what infant receives
Generates pressure upon lungs - variable & unmeasurable
High flow levels -range 0.5LPM increments
4-6LPM preterm, up to 8LPM term

Complications - FiO2 concentrations vary, unmeasurable pressure with HFNC, drying nasal mucosa

Continuous Positive Airway Pressure (CPAP)

Delivers pressure to lungs
Maintains functional residual capacity (FRC) - commonly reduced in RDS
Eases work of breathing - stenting airways open
Increases partial pressure of oxygen (PaO2)

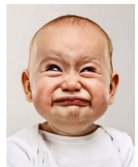
Indications for CPAP

Mild/Moderate respiratory distress syndrome
Primary or secondary apnea
Diffuse atelectasis - hypoventilation
Transitioning from mechanical ventilation
** Level of PEEP, usually 4-8 cm water pressure

Continuous Positive Airway Pressure (CPAP)

Complications

- Labor intensive - maintain consistent PEEP
  - Choose correct size of nasal prongs/mask
  - Proper positioning of apparatus - maintain bubbling
  - Always auscultate for adequate aeration
- Nasal obstruction - secretions
- Ineffective ventilation
- Pneumothorax – positive pressure
- Variable pressure delivery (open mouth)
- Gastric distention



NIV-NAVA

Non-Invasive Neurally Adjusted Ventilatory Assist

Non-invasive mode of ventilation - delivers assistance in synchrony with baby's own respiratory efforts

Uses **(Edi) catheter -** measures electrical activity of diaphragm, activity fed to ventilator, assist baby's breathing in synchrony with own effort

Benefits

Improves synchrony

Level of assistance determined by baby's own demand

Non-invasive - uses nasal prongs or mask

Mechanical Ventilation

Used to correct abnormalities:

- Poor oxygenation (low PaO2)
- Poor alveolar ventilation (increased PaCO2)
- Ineffective respiratory effort (apnea, ineffective respirations, and/or significant respiratory distress/failure)

Goal - Support respiratory status while minimizing barotrauma, volutrauma, & oxygen toxicity

Complications - Tube malposition, lung injury, pulmonary air leaks, infection, BPD, ROP

Conventional Ventilation

Set variables: **PIP, PEEP, rate, Inspiratory time, PS**

PIP, rate, PS - change $PaCO_2$'s (affect ventilation)
PEEP (Mean Airway Pressure) or inhaled FiO_2 - change PaO_2's (affect oxygenation)

- Pressure cycled (preset pressure) - PIP limit set, rate, PEEP, PS
- Volume cycled (common in NICU)

  PRVC (pressure regulated volume control)
  set Tv (4-6ml/kg), rate 20-60, PS 6-12, PEEP 4-8

Pressure support – supports breaths initiated by baby
delivers a preset volume with variable IT time

Ventilator Modes

Intermittent mandatory ventilation - breaths given set rate - regardless where patient in respiratory cycle, allows spontaneous breaths

Patient triggered ventilation - breaths delivered from patient's spontaneous effort, synchronized

SIMV Pressure Control + Pressure Support

Ventilator breaths synchronized with inspiratory effort

Set rate, spontaneous breaths exceed set rate are pressure supported (PS)

Pressures (PIP) set for both SIMV breaths and spontaneous breaths

SIMV Volume Control + Pressure Support

Ventilator breaths synchronized with inspiratory effort

Delivers volume set breaths (ml/kg) at set rate, all spontaneous breaths (above set rate) are pressure supported (goal tidal volume 4-8ml/kg)

Assist Control - synchronized breath given with each spontaneous breath at preset rate or set rate given if no spontaneous breathing

High Frequency Oscillating Ventilator

- Uses vibratory mechanics (piston) - deliver very fast, tiny respiratory rates (up to 900 cycles/min)
- Tidal volumes smaller
- Maintains constant lung volume - during each inspiratory cycle
- Most beneficial - diffuse homogeneous lung disease - RDS, Meconium Aspiration Syndrome and PPHN
- Uses active inspiration and expiration - push/pull mechanism- eliminating CO_2 & delivering O_2
- Oxygenation is separate from ventilation
- Gas exchange by diffusion
- Allows use of higher MAP with less barotrauma

High Frequency Oscillating Ventilator

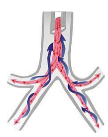
Set variables - MAP, Amplitude (Delta P), Inspiratory time, Frequency (Hertz)

Delta P and Frequency (Hz)- change PaCO2's (ventilation)

Mean Airway Pressure or inhaled FiO2 - change PaO2's (oxygenation)

High Frequency Jet Ventilator

- Uses mechanism - generates stream high frequency pulses - generates small tidal volumes for ventilation
- Inhalation active/Exhalation passive
  Convection carries gas deeply into lungs
  Once flow stops - diffusion completes gas exchange
- Range of PEEP - higher than conventional
  Uses small tidal volumes and MAP
- Used with conventional ventilator - to generate PEEP & sigh breaths



Indications for use

Pulmonary air leaks, excessive secretions (MAS, Pneumonia), hemodynamic compromise (CDH, Heart Failure), other forms of ventilation prove ineffective

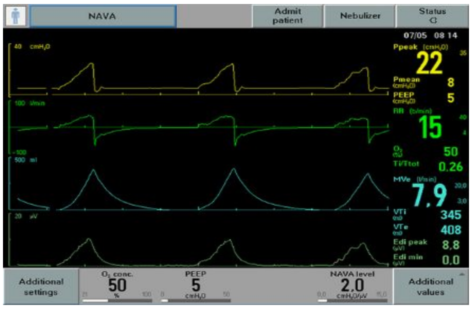
Neurally Adjusted Ventilatory Assist (NAVA)

- During normal breathing, brain's respiratory center sends signal to phrenic nerve = exciting the diaphragm
- Electrical activity of diaphragm (Edi)

Activity captured by catheter, fed to ventilator & used to assist patient's breathing in synchrony and proportion to patient's own efforts

- Conventional ventilator uses Edi signal to synchronize ventilation with patient's breathing effort
- Signal that excites the diaphragm is proportional to output of respiratory center in brain & controls depth & cycling of breath

NAVA



Extracorporeal Membrane Oxygenation (ECMO)

Pulmonary bypass circuit

Allowing gas exchange to occur outside lung -perfusion of blood through membrane oxygenator

Goal of therapy - "buy time" for severely injured lungs to heal, decreasing exposure to hyperoxia & barotrauma/volutrauma

Conditions treated: meconium aspiration syndrome, congenital diaphragmatic hernia, respiratory distress syndrome, sepsis/pneumonia, PPHN, air leak syndromes

Criteria to qualify for ECMO: gestational age, weight, no lethal congenital anomalies

Oxygenation Index - MAP x FiO2 (100%=1.0) x 100/PaO2

OI >40 for 4 hrs, FiO2 100%, PaO2 <40, severe PPHN, pressor resistance

Example: MAP 16, FiO2 100%, PaO2 40

Calculate OI?

ECMO

Common Medications used During Ventilation Therapy

Surfactant – phospholipid made by lungs - decreases surface tension

Bronchodilators – **albuterol** (beta 2 agonist) - dilates airways

Stimulants – **caffeine** - stimulates respirations in premature infants

Diuretics - **furosemide**, affects chloride transport-causing loss of Cl, Na, K, Ca resulting water loss

Spironolactone - inhibits aldosterone increases Na/water loss, sparing K

Hydrochlorothiazide/Spironolactone - **Aldactazide** - inhibit Na reabsorption and increased excretion of NaCl and water

Corticosteroids – **dexamethasone** - anti-inflammatory treat chronic lung disease & tracheal edema, systemic dose - increase risk of poor neurodevelopmental outcomes, high doses routine - not recommended

Paralytic agents – **vecuronium** - paralysis skeletal muscles, decrease resistance & improve oxygenation/ventilation

Pain Control/Sedation – **morphine, versed, fentanyl, precedex**

Inhaled nitric oxide – promote relaxation of pulmonary smooth muscle facilitating perfusion and gas exchange

References

Karlsen, Kristine. *The S.T.A.B.L.E Program: Pre-transport/Post Resuscitation Stabilization Care of Sick Infants.* American Academy of Pediatrics; 6th edition, 2012.

Rodriguez RJ, Martin RJ, and Fanaroff, AA. *Respiratory distress syndrome and its management.* Fanaroff and Martin (eds.) Neonatal-perinatal medicine: Diseases of the fetus and infant; 11th ed. (2019):1001-1011. St. Louis: Mosby.

Rogelet, Keri R., et al. *Neonatal Certification Review for the CCRN and RNC High-Risk Examination.* Sudbury, MA: Jones and Bartlett Publishers, 2nd edition, 2015.