Arterial Blood Gases

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PO_2
SO_2
- measured
- calculated
- pulse oximetry

→ oxygenation

PCO_2 → ventilation

pH
BE/BD
HCO_3^-
- venous CO_2

→ Acid-base

Arterial PO_2 (PaO_2)

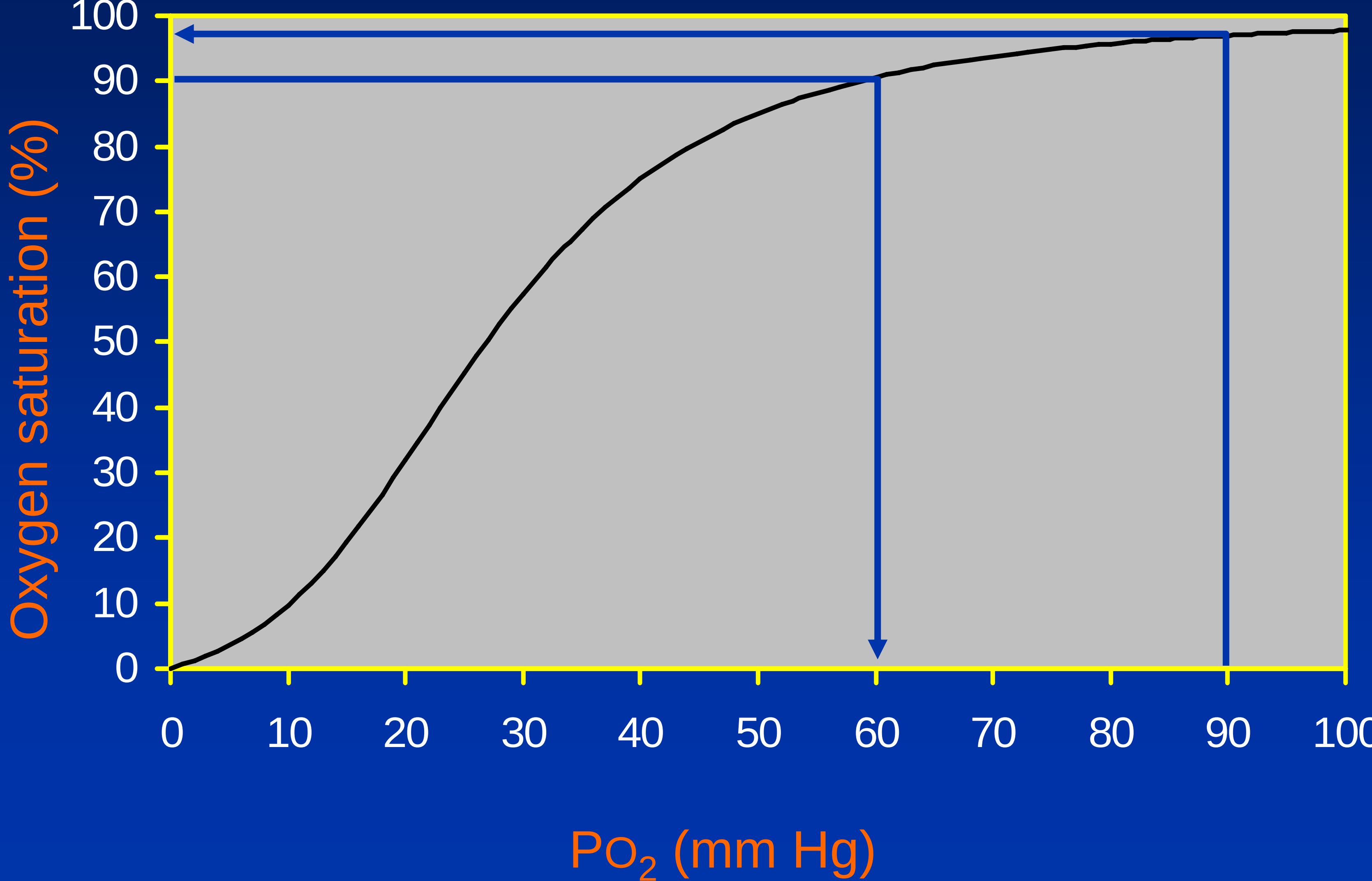
- Normal: 80 – 100 mm Hg breathing room air at sea level in healthy young adults (103- 0.5 x age)
- PaO_2 affected by
  - F_IO_2 PEEP Lung function
  - Age Ventilation Altitude

$$PAO_2 = FIO_2(P_B - PH_2O) – PaCO_2 \times 1.2$$

$$PAO_2 = FIO_2(700) - PaCO_2 \times 1.2$$

Always interpret PaO_2 in relation to F_IO_2

Oxyhemoglobin Dissociation Curve



PaO_2/SaO_2

Shifting of the Oxyhemoglobin Dissociation curve
-Temperature
-pH
-2,3, DPG (stored blood loses 2,3, DPG)
-Dyshemoglobins (carboxy, fetal, methhgb)

Shift to left facilitates Oxygen loading
Shift to right facilitates Oxygen unloading

PaO_2/SaO_2

30 mm Hg = 60% saturation
60 mm Hg = 90% saturation
40 mmHg = 75% saturation

Oxygen delivery = Oxygen content x cardiac output

Oxygen content = PaO2 (0.003) + Hgb(1.34)%sat

Once PaO2 exceeds 70 mmHg further increases do not increase oxygen delivery

Arterial PCO_2 ($PaCO_2$)

- Normal: 35 to 45 mm Hg
- ↑ $PaCO_2$ = hypoventilation
  - Respiratory center depression
  - Neuromuscular disease
  - Pulmonary disease
- ↓ $PaCO_2$ = hyperventilation
  - Central
  - Pain
  - Anxiety
  - Iatrogenic

Acid-Base Balance

$$pH \approx \frac{HCO_3^-}{PCO_2}$$

metabolic component (HCO_3^-)

respiratory component (PCO_2)

When HCO_3^- is 24 mmol/L and $PaCO_2$ is 40 mm Hg, the pH is 7.40

Normal Values

- pH 7.35 – 7.45
- PaCO2 35-45 mmHg
- HCO3- 22-26 meq/L
- BE/BD –2 to +2
- Base Excess or Base Deficit reflects the non-respiratory portion of acid-base balance
- Includes RBC buffering

Acid-Base Disorders

- Primary disturbance
  - Acidosis: pH < 7.35
    - Respiratory: ↑ $PaCO_2$
    - Metabolic: ↓ HCO_3^-
    - BE: normal
  - Alkalosis: pH > 7.45
    - Respiratory: ↓ $PaCO_2$
    - Metabolic: ↑ HCO_3^-
    - BE: normal

Acid-Base Disorders

Rules

For a 0.08 change in pH – $PaCO_2$ changes 10 mmHg

7.40 → 40 7.32 → 50 7.48 → 30

Respiratory compensation is rapid

Metabolic compensation is slow

Acid-Base Disorders

- Compensation
  - Change in $PaCO_2$ to correct pH with metabolic acid-base imbalance
    - e.g., hyperventilation occurs with metabolic acidosis
  - Change in HCO_3^- to correct pH with respiratory acid-base imbalance
    - e.g., HCO_3^- increases with respiratory acidosis

$$\leftrightarrow\downarrow pH \approx \frac{HCO_3^- \;\downarrow\uparrow}{PCO_2 \;\downarrow\uparrow}$$

Respiratory Acidosis

- Uncompensated: ↓ pH, ↑ $PaCO_2$, nl BE, HCO_3^-
- Compensated: nl pH, ↑ $PaCO_2$, ↑ BE, HCO_3^-
- Causes: respiratory center depression, neuromuscular disease, lung disease
- Treatment: treat cause, mechanical ventilation, buffers

Respiratory Alkalosis

- Uncompensated: ↑ pH, ↓ $PaCO_2$, nl BE, HCO_3^-
- Compensated: nl pH, ↓ $PaCO_2$, ↓BE, HCO_3^-
- Causes: respiratory center stimulation, iatrogenic
- Treatment: treat cause

Metabolic Alkalosis

- Uncompensated: ↑ pH, ↑ HCO_3^-, nl $PaCO_2$
- Compensated: nl pH, ↑ HCO_3^-, ↑ $PaCO_2$
- Causes: hypokalemia, nasogastric suctioning or vomiting, contraction alkalosis, bicarbonate administration, steroid therapy
- Treatment: treat cause, KCl, volume, diamox, NH_4Cl, arginine monohydrochloride, HCl

Metabolic Acidosis

- Uncompensated: ↓ pH, ↓ HCO_3^-, nl $PaCO_2$
- Compensated: nl pH, ↓ HCO_3^-, ↓ $PaCO_2$
- Causes: hypoxia (lactic acidosis), diabetes (ketoacidosis), renal failure (uremic acidosis), GI loss of HCO_3^- (diarrhea), renal loss of HCO_3^- (renal tubular acidosis, diamox), poisons (aspirin, methanol, ethylene glycol)
- Treatment: treat cause, buffer

Acid-Base Interpretation

- Classify the disturbance: acidosis, alkalosis, metabolic, respiratory
- Determine the degree of compensation: uncompensated, partially compensated, fully compensated
- Identify the cause of the disturbance
- Develop a treatment plan

Acid-Base Interpretation

Disorder	pH	$PaCO_2$	HCO_3^-
Respiratory acidosis			
Uncompensated	↓↓	↑↑	N
Partially compensated	↓	↑↑	↑
Fully compensated	N	↑↑	↑↑
Respiratory alkalosis			
Uncompensated	↑↑	↓↓	N
Partially compensated	↑	↓↓	↓
Fully compensated	N	↓↓	↓↓
Metabolic acidosis			
Uncompensated	↓↓	N	↓↓
Partially compensated	↓	↓	↓↓
Fully compensated	N	↓↓	↓↓
Metabolic alkalosis			
Uncompensated	↑↑	N	↑↑
Partially compensated	↑	↑	↑↑
Fully compensated	N	↑↑	↑↑

Test Your Skills

pH = 7.25

PaCO2 = 57

$HCO_3^- = 24$

$$\downarrow pH \approx \frac{HCO_3^- \leftrightarrow}{PCO_2 \uparrow}$$

Test Your Skills

pH = 7.25

$PaCO_2$ = 40

HCO_3^- = 17

$$\downarrow pH \approx \frac{HCO_3^- \downarrow}{PCO_2 \leftrightarrow}$$

Test Your Skills

pH = 7.38

$PaCO_2$ = 60

HCO_3^- = 34

$$\leftrightarrow pH \approx \frac{HCO_3^- \uparrow}{PCO_2 \uparrow}$$

Test Your Skills

pH = 7.28

$PaCO_2$ = 28

HCO_3^- = 13

$$\downarrow pH \approx \frac{HCO_3^- \downarrow}{PCO_2 \downarrow}$$

Mechanical Ventilation

- Variables
- Mode
- FIO_2 and PEEP
- Tidal Volume and frequency
- I:E ratio, inspiratory time

Modes

- CMV or assist control – every breath is the same volume or pressure, time
- IMV – spontaneous breaths are allowed between mandatory breaths
- Pressure support – a set pressure is delivered with each breath the patient takes (a boost)
- CPAP/PEEP – elevated end expiratory pressure

Tidal Volume & Frequency

- Control minute ventilation & $PaCO_2$
- $V_E = f \times V_T$
- $PaCO_2 = VCO_2/V_A$
- $V_A = V_T – Vds$
- Postop – 8-12 mL/kg
- Restrictive – 4-8 mL/kg
- Obstructive – 8-10 mL/kg

Tidal Volume – Weight & Height

The major determinant of lung volume is height not weight

Women – 45.5 + 2.3 (Ht in inches -60)

Men - 50 + 2.3 (Ht in inches – 60)

Modify tidal volume to maintain airway plateau pressure < 30 cm H_2O

PEEP and FIO2

- Control oxygenation
- FIO_2 start at 100% and move down using SpO_2
- PEEP – 5 cm H_20 minimum
- ARDS – 10 – 20 cm H2O
- COPD – 5-10 cm H2O
- PEEP is titrated to oxygenation, lung mechanics, oxygen delivery or other clinician determined endpoints

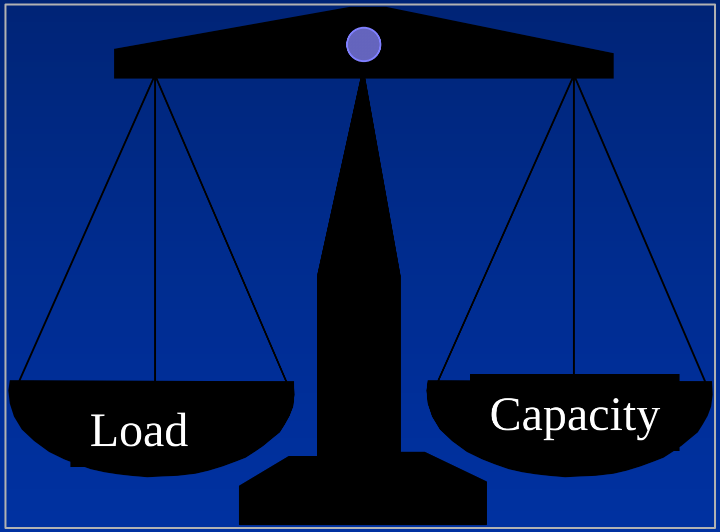
Writing Ventilator Orders

- Mode (A/C, IMV, PSV)
- Pressure or tidal volume
- Frequency
- FIO2
- PEEP
- Goals of support
- Better to write adjust FIO2 to maintain SpO2 > 92% then to write six orders to reduce FIO2

Terminology

- Weaning implies the gradual withdrawal of support
- Liberation from mechanical ventilation is more appropriate
- Liberation may not require weaning
- Extubation is removal of the ET tube
- Decannulation is removal of the tracheostomy tube

Weaning Failure



Minute Volume

pain, anxiety
sepsis, DS, VCO2

Resistive

Airway, secretions
bronchospasm

Elastic

Lung compliance
chest wall compliance
PEEPi

Ventilatory Drive

sedation, brain injury

Neuromuscular

Spinal injury,
polyneuropathy
Hyperinflation
malnutrition
electrolytes

Chest Wall

flail chest, pain

WHEANS NOT

- Wheezes
- Heart disease
- Electrolytes
- Anxiety, airway problems, alkalosis
- Neuromuscular disease
- Sepsis, sedation
- Nutrition (over and underfeeding)
- Opiates, obesity
- Thyroid disease

Ely EW, RCCNA 2000;6:303

Weaning Readiness

Daily Screen – 5 Criteria

- Patient coughs when suctioned
- No continuous vasopressor or sedative infusions
- $PaO_2//FIO_2 > 200$
- PEEP $\leq$ 8 cm H_2O
- $f/V_T < 105$ for one minute

Ely NEJM 1996;335:1864

Spontaneous Breathing Trials

- All pts who pass the daily screen – SBT 30 mins

<u>Termination of the SBT</u>

- Resp rate > 35 for > 5 mins
- SpO2 < 90% for > 30 secs
- 20% increase or decrease in heart rate for > 5 mins
- SBP > 180 or < 90 for 60 secs consecutively
- Agitation, anxiety, diaphoresis > baseline for > 5 minutes

Ely NEJM 1996;335:1864