Arterial Blood Gases
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**PO$_2$**
**SO$_2$**
- measured
- calculated
- pulse oximetry

**PCO$_2$**
- ventilation

**pH**
**BE/BD**
**HCO$_3^-$**
- venous CO$_2$

**Acid-base**
**oxygenation**
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
  - FIO$_2$  PEEP  Lung function
  - Age  Ventilation  Altitude

\[
\text{PAO}_2 = \text{FIO}_2(\text{P}_B - \text{PH}_2\text{O}) - \text{PaCO}_2 \times 1.2
\]

\[
\text{PAO}_2 = \text{FIO}_2(700) - \text{PaCO}_2 \times 1.2
\]

Always interpret PaO$_2$ in relation to FIO$_2$. 
Oxyhemoglobin Dissociation Curve

Oxygen saturation (%) vs. PO₂ (mm Hg)

- Oxygen saturation increases as PO₂ increases.
- The curve shows the relationship between oxygen saturation and PO₂, with the maximum saturation occurring at a PO₂ of approximately 100 mm Hg.
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 $\times$ cardiac output

Oxygen content = PaO$_2$ (0.003) + Hgb(1.34)%sat

Once PaO$_2$ exceeds 70 mmHg further increases do not increase oxygen delivery
Arterial PCO₂ (PaCO₂)

- Normal: 35 to 45 mm Hg
- ↑PaCO₂ = hypoventilation
  - Respiratory center depression
  - Neuromuscular disease
  - Pulmonary disease
- ↓PaCO₂ = hyperventilation
  - Central
  - Pain
  - Anxiety
  - Iatrogenic
Acid-Base Balance

\[ \text{pH} \approx \frac{\text{HCO}_3^-}{\text{PCO}_2} \]

When \( \text{HCO}_3^- \) is 24 mmol/L and \( \text{PaCO}_2 \) 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: $\uparrow$ PaCO$_2$
    - Metabolic: $\downarrow$ HCO$_3^-$
    - BE: normal
  - **Alkalosis**: pH > 7.45
    - Respiratory: $\downarrow$ PaCO$_2$
    - Metabolic: $\uparrow$ HCO$_3^-$
    - BE: normal
Acid-Base Disorders

Rules

For a 0.08 change in pH – PaCO₂ 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 PaCO₂ to correct pH with metabolic acid-base imbalance
    - e.g., hyperventilation occurs with metabolic acidosis
  - Change in HCO₃⁻ to correct pH with respiratory acid-base imbalance
    - e.g., HCO₃⁻ increases with respiratory acidosis

\[
\leftrightarrow \text{pH} \approx \frac{\text{HCO}_3^-}{\text{PCO}_2} \downarrow \uparrow
\]
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: $\uparrow$ pH, $\downarrow$ PaCO$_2$, nl BE, HCO$_3^-$
- Compensated: nl pH, $\downarrow$ PaCO$_2$, $\downarrow$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$_4$Cl, 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

<table>
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<tr>
<th>Disorder</th>
<th>pH</th>
<th>PaCO\textsubscript{2}</th>
<th>HCO\textsubscript{3}\textsuperscript{-}</th>
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<td><strong>Respiratory acidosis</strong></td>
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<tr>
<td>Uncompensated</td>
<td>↓↓</td>
<td>↑↑</td>
<td>N</td>
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<tr>
<td>Partially compensated</td>
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<tr>
<td>Fully compensated</td>
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<td>↑↑</td>
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</table>
Test Your Skills

\[ \text{pH} = 7.25 \]
\[ \text{PaCO}_2 = 57 \]
\[ \text{HCO}_3^- = 24 \]

\[ \downarrow \text{pH} \approx \frac{\text{HCO}_3^-}{\text{PCO}_2} \]
Test Your Skills

pH = 7.25
PaCO₂ = 40
HCO₃⁻ = 17

\[
pH \approx \frac{\text{HCO}_3^-}{\text{PCO}_2}
\]
Test Your Skills

\[
\text{pH} = 7.38 \\
\text{PaCO}_2 = 60 \\
\text{HCO}_3^- = 34
\]

\[ \leftrightarrow \text{pH} \approx \frac{\text{HCO}_3^-}{\text{PCO}_2} \uparrow \uparrow \]
Test Your Skills

\[
pH = 7.28 \\
\text{PaCO}_2 = 28 \\
\text{HCO}_3^- = 13
\]

\[
pH \approx \frac{\text{HCO}_3^-}{\text{PCO}_2}
\]
Mechanical Ventilation

- Variables
- Mode
- FIO2 and PEEP
- Tidal Volume and frequency
- I:E ratio, inspiratory time
Mode

- **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 H2O
PEEP and FIO2

- Control oxygenation
- FIO₂ start at 100% and move down using SpO₂
- PEEP – 5 cm H₂O 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
- \( \text{PaO}_2/\text{FIO}_2 > 200 \)
- PEEP \( \leq 8 \text{ cm H}_2\text{O} \)
- \( f/V_T < 105 \) for one minute

Ely NEJM 1996;335:1864
Spontaneous Breathing Trials

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

Termination of the SBT

- 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