Approach to the Patient with Acid-Base Problems

**Maintenance of Normal pH**
- Normal pH = 7.40 → $[H^+] = 40$ neq / L
- $H_2O + CO_2 \leftrightarrow H_2CO_3 \leftrightarrow H^+ + HCO_3^-$

  dietary breakdown of protein
  (about 80 meq / d normally)

  13,000 to 20,000 mM CO2 produced per day

**Henderson - Hasselbach Equation**

- $H_2O + CO_2 \leftrightarrow H_2CO_3 \leftrightarrow H^+ + HCO_3^-$
  is equivalent to:

- $pH = 6.1 + \log \left( \frac{[HCO_3^-]}{[H_2CO_3]} \right)$
  is equivalent to:

- $pH = 6.1 + \log \left( \frac{[HCO_3^-]}{.03 \times pCO_2} \right)$

  which can be approximated by the formula

**$[H^+] = 24 \times pCO_2 / [HCO_3^-]$**

- Normally, $[H^+] = 40$ neq / L
- Normally, $pCO_2 = 40$ mm Hg
- Normally, $[HCO_3^-] = 24$ meq / L

  $\text{Remember this formula !!!!!}$

- This formula is easy to remember
- The constant is easy to remember (same as the usual [HCO3] level)
- And...most importantly →

**$[H^+] = 24 \times pCO_2 / [HCO_3^-]$**

This formula shows that it is the RATIO of CO2 and HCO3 which determines pH

$$\frac{pCO_2}{[HCO_3^-]}$$
[H\(^+\)] = \(24 \times pCO_2 / [HCO_3^-]\)

- Getting from [H\(^+\)] to pH (or back)
- Converting from [H\(^+\)] to pH can be easy if you are a savant, if you carry a calculator, or if you take advantage of the fact that, over the range of physiologic pH, the relationship between [H\(^+\)] and pH is almost linear

\[\begin{array}{|c|c|c|}
\hline
\text{pH} & \text{actual [H}^+\text{]} & \text{estimated [H}^+\text{]} \\
\hline
7.10 & 79 & 70 \\
7.20 & 63 & 60 \\
7.30 & 50 & 50 \\
7.50 & 32 & 30 \\
\hline
\end{array}\]

Regulation of pH – 3 mechanisms

- Buffering
- Respiratory regulation of pCO\(_2\)
- Renal regulation of [H\(^+\)] and [HCO\(_3^-\)]

Regulation of pH -- mechanisms

- **Buffering** -- OCCURS IMMEDIATELY
  - No semipermeable membranes to cross
  - No enzyme activation necessary
  - Everything needed is right at hand

- **Respiratory changes** OCCUR OVER HOURS
  - Brainstem response to pH
  - Delay in CSF pH changes
### Regulation of pH -- mechanisms

- **Buffering** -- OCCURS IMMEDIATELY
- **Respiratory changes** are INTERMEDIATE
- **Renal changes** OCCUR MORE SLOWLY
  - Physiologic changes in renal H+ excretion

### Buffering

- **Extracellular**
  - almost entirely through bicarbonate
  - it’s concentration is highest
  - small contribution from phosphate
- **Intracellular**
  - $\text{H}_2\text{O} + \text{CO}_2 \leftrightarrow \text{H}_2\text{CO}_3 \leftrightarrow \text{H}^+ + \text{HCO}_3^-$

### Respiratory regulation of pCO₂

- pCO₂ is inversely proportional to VENTILATION
- Ventilation increases in response to a drop in pH, and falls when pH rises
  - respiratory center in medulla
  - responds to pH “intermediate” between that of CSF and plasma
  - response is rapid (though not instantaneous)
  - response is more predictable for falls in pH than for increases

### Renal Regulation of [H⁺] and [HCO₃⁻]

TWO MAJOR FUNCTIONS OF THE KIDNEY (regarding acid-base reg.)

- Reclamation of filtered bicarbonate
- Excretion of Acid
### Renal Regulation of $[H^+]$ and $[HCO_3^-]$:

#### TWO MAJOR FUNCTIONS OF THE KIDNEY

- Reclamation of filtered bicarbonate
  - A normal occurrence
  - 4000 meq/day in normal persons
  - By far the greatest use of secreted acid
- Excretion of Acid

#### Factors which effect renal acid excretion

- Acidemia
- Hypercapnea
- Volume depletion (mediated by angiotensin II)
- Chloride depletion
- Hypokalemia
- Aldosterone

#### Acid Excretion is Stimulated by:
- Acidemia
- Hypercapnea
- Volume depletion (?mediated by angiotensin II)
- Chloride depletion
- Hypokalemia
- Aldosterone

#### Acid Excretion is Inhibited by:
- Alkalemia
- Elevated $[HCO_3^-]$
- Hypocapnea
- Hyperkalemia

### Definitions

- Acidemia = pH below the normal of ~ 7.40
- Alkalemia = pH above the normal of ~ 7.40

- Metabolic acidosis = loss of $[HCO_3^-]$ or addition of $[H^+]$
- Metabolic alkalosis = loss of $[H^+]$ or addition of $[HCO_3^-]$

- Respiratory acidosis = increase in $pCO_2$
- Respiratory alkalosis = decrease in $pCO_2$

### Remember:

Compared to buffering and respiratory adaptation, renal compensatory mechanisms take a bit longer.
The ANION GAP

- Na⁺ - Cl⁻ - HCO₃⁻ = 8-12 normally
  - mainly proteins, phosphates, and sulfates

- In any patient with an acid-base disturbance, and especially in those with a metabolic acidosis, you should calculate the Anion Gap

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<table>
<thead>
<tr>
<th>High Anion Gap Metabolic Acidosis</th>
</tr>
</thead>
<tbody>
<tr>
<td>USUALLY FROM ADDITION OF ACID</td>
</tr>
<tr>
<td>• Ketoacidosis</td>
</tr>
<tr>
<td>- DKA, Alcoholic KA, Starvation</td>
</tr>
<tr>
<td>• Lactic acidosis</td>
</tr>
<tr>
<td>- hypoperfusion; other causes</td>
</tr>
<tr>
<td>• Ingestions</td>
</tr>
<tr>
<td>- ASA, Ethylene glycol, methanol</td>
</tr>
<tr>
<td>• Renal insufficiency</td>
</tr>
<tr>
<td>- inability to excrete acid</td>
</tr>
</tbody>
</table>

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<table>
<thead>
<tr>
<th>Normal Anion Gap Metabolic Acidosis</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Rise in Chloride matches the decrease in HCO₃⁻</td>
</tr>
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</table>

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<table>
<thead>
<tr>
<th>Normal Anion Gap Metabolic Acidosis</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Renal Disease</td>
</tr>
<tr>
<td>- proximal or distal RTA</td>
</tr>
<tr>
<td>- renal insufficiency (HCO₃⁻ loss)</td>
</tr>
<tr>
<td>- hypoaldosteronism / K⁺ sparing diuretics</td>
</tr>
<tr>
<td>• Loss of alkalai</td>
</tr>
<tr>
<td>- diarrhea</td>
</tr>
<tr>
<td>- ureterosigmoidostomy</td>
</tr>
<tr>
<td>• Ingestions</td>
</tr>
<tr>
<td>- carbonic anhydrase inhibitors</td>
</tr>
</tbody>
</table>
A “simple” acid-base disturbance is one with a primary problem (respiratory or metabolic, acidosis or alkalosis) leading to a compensation in the other arm.

THREE THINGS TO REMEMBER

1) Compensation is not immediate
2) Compensation is not complete
3) The pCO2 and HCO3 move in the same direction

These formulas are EMPIRICALLY DERIVED from observation and measurement.

Respiratory Compensation for Metabolic Changes

- Metabolic acidosis
  - pCO2 decreases by 1.2 x the drop in [HCO3-]
- Metabolic alkalosis
  - pCO2 increases by .7 x the rise in [HCO3-]
  - less predictable than the comp. for acidosis

COMPENSATION IS USUALLY NOT COMPLETE

Metabolic Compensation for Respiratory Changes

- Respiratory Acidosis
  - ACUTE: [HCO3-] increases by .1 x the rise in pCO2
  - CHRONIC: [HCO3-] increases by .35 x the rise in pCO2
- Respiratory Alkalosis
  - ACUTE: [HCO3-] decreases by .2 x the fall in pCO2
  - CHRONIC: [HCO3-] decreases by .5 x the fall in pCO2

COMPENSATION IS USUALLY NOT COMPLETE
Approach to the Patient

- History and Physical Examination
  - In the majority of cases you should be able to predict, qualitatively, the type of disturbance

- Examples:
  - a patient with septic shock (hypoperfusion)
  - a patient with severe COPD
  - a patient with one day of worsening asthma

Approach to the Patient

- Is the patient ACIDEMIC or ALKALEMIC?
- What is the \([\text{HCO}_3^-]\) ?
  - elevated ---- metabolic alkalosis
  - decreased -- metabolic acidosis

- What is the Anion Gap
- What is the pCO$_2$ ?
  - elevated --- respiratory acidosis
  - decreased -- respiratory alkalosis

- Is the degree of compensation what you expect?

Notation for Laboratory Values

<table>
<thead>
<tr>
<th>Na$^+$</th>
<th>Cl$^-$</th>
<th>BUN</th>
<th>Glu</th>
</tr>
</thead>
<tbody>
<tr>
<td>K$^+$</td>
<td>HCO$_3^-$</td>
<td>Cr.</td>
<td></td>
</tr>
</tbody>
</table>

pH / pCO$_2$ / pO$_2$ / base excess ON FIO2