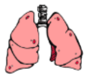

University Health Network

ABG Interpretation: A Respirologist's approach

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Outline

- A quick review of acid-base physiology
- The 8 steps to ABG interpretation
- Discuss the causes of hypoxemia and hypercapnea

What use is an ABG?

- Assess acid-base balance
- Assess adequacy of ventilation
- Assess oxygenation

Acid-Base Disturbances

- Acidosis = process that makes the blood acidic
- Alkalosis = process that makes the blood alkaline
  - This is a diagnosis
  - Mutliple disorders can exist simultaneously

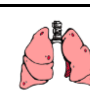
- Acidemia = blood pH below 7.35
- Alkalemia = blood pH above 7.45
  - This is a sign
  - Net result of all concurrent disorders

Two kinds of pH disorders
1. "Respiratory" = 1° abnormality in ventilation (CO2)
2. "Metabolic" = 1° abnormality in any other acid or base

Acid-Base Disturbances

- When acidosis or alkalosis occurs, the body tries to normalize pH by "compensating" using buffers
  - If the primary process is metabolic,
    - We use lungs to increase or decrease ventilation to alter p_aCO2
    - This "respiratory compensation" takes minutes
  - If the primary process is respiratory,
    - We use kidneys to excrete either acid (NH4) or base (NaHCO3)
    - This "metabolic compensation" takes hours or days
- Compensation is always in the same direction as the primary problem
  - If p_aCO2 rises, appropriate compensation increases HCO3-
  - If p_aCO2 falls, appropriate compensation decreases HCO3-
  - If HCO3- rises, appropriate compensation increases p_aCO2
  - If HCO3- falls, apppropriate compensation decreases p_aCO2

Alveolar Ventilation



- CO2 is normally tightly regulated
  - Small changes to CO2 alter ventilation
- Carotid body is essential to this regulation
  - This is a cluster of chemoerceptors in the carotid artery
  - Detects levels of [O2], [CO2] and [H+]
  - Sends signals to the brain
  - Alters ventilation in response to [CO2] and [H+]
- Carotid body response:
  - When patient has acidemia (low pH)
    - Carotid body makes you more sensitive to [CO2] = ↑ ventilation
  - When patient has alkalemia (high pH)
    - Carotid body makes you less sensitive to [CO2] = ↓ ventilation

Respiratory Acidosis

$$\uparrow CO_2 + H_20 \rightarrow \uparrow H^+ + \uparrow HCO_3^-$$

- Hypoventilation causes rise in p_aCO2, shifts equilibrium to the right.
  - Acutely (10:1)
    - For each 10 mm Hg rise in p_aCO2, HCO3 should increase by 1 mEq/L
    - This is due to equilibrium shift (buffering)
  - Chronically (10:3)
    - For each 10 mm Hg rise in p_aCO2, HCO3 should increase by 3 mEq/L
    - This is due to renal compensation (excretion of H+)
  - Common causes
    - Lung disease
    - Neuromuscular disease
    - Sedative drugs
    - Adaptation to extreme obesity and sleep apnea

$$[H+] = \frac{24 \times p_aCO2}{[HCO3]}$$

Respiratory Alkalosis

$$\downarrow CO_2 + H_20 \leftarrow \downarrow H^+ + \downarrow HCO_3^-$$

- Hyperventilation causes p_aCO2 to fall, shifts equilibrium to the left.
  - Acutely (10:2)
    - For each 10 mm Hg fall in p_aCO2, HCO3 should decrease by 2 mEq/L
    - This is due to equilibrium shift (buffering)
  - Chronically (10:4)
    - For each 10 mm Hg fall in p_aCO2, HCO3 should decrease by 4 mEq/L
    - This is due to renal compensation (excretion of HCO3-)
  - Common causes
    - Anxiety / panic (including panic attacks)
    - Pregnancy
    - Early sepsis
    - Drugs (one component of ASA toxicity)
    - Mechanical ventilation at excessive rate or volumes

$$[H+] = \frac{24 \times p_aCO2}{[HCO3]}$$

Metabolic Alkalosis

$$\uparrow CO_2 + H_20 \leftarrow H^+ + \uparrow HCO_3^-$$

- Increase in HCO3- shifts equilibrium to the left
  - p_aCO2 increases
  - Alkalemia makes the carotid body less sensitive to [CO2]
  - We "allow" the p_aCO2 to stay elevated (maximum ~ 50 mmHg)
- Compensation (1:0.7)
  - For every 1 mEq rise in HCO3-, p_aCO2 increases by 0.7 mmHg
- Causes
  - Volume depletion ("contraction alkalosis")
  - Nasogastric suction
  - Diuretics
  - Hyperaldosteronism

$$[H+] = \frac{24 \times p_aCO2}{[HCO3]}$$

Metabolic Acidosis

- Two possible mechanisms of onset
  - Loss of HCO3-
  - Gain of H+
- Mechanisms of compensation are a bit more complex

Metabolic Acidosis – Bicarb Loss

$$\downarrow CO_2 + H_20 \Leftrightarrow H^+ + \downarrow HCO_3^-$$

- Loss of bicarbinate (ie. diarrhea) creates an acidemia (a relative increase in [H+])
  - Acidemia makes the carotid body more sensitive to [CO2] leading to increased ventilation
- Compensation (1:1)
  - For every drop of 1 mEq of HCO3-, p_aCO2 falls by 1 mmHg

$$[H+] = \frac{24 \times p_aCO2}{[HCO3]}$$

Metabolic Acidosis – Acid Gain

$$\downarrow CO_2 + H_20 \leftarrow \uparrow H^+ + \downarrow HCO_3^-$$

- Some acid gets added to the body (ie. excercising muscle makes lactate), the equilibrium gets shifted to the left (which lowers HCO3- and H+)
  - This causes a transient rise in [CO2]
  - Excess CO2 is quickly exhaled
  - [CO2] falls even lower than baseline, because acidemia makes the carotid body more sensitive to [CO2] leading to increased ventilation
- Compensation
  - For every drop of 1 mEq of HCO3-, p_aCO2 falls by 1 mmHg
- Examples of metabolic acidosis
  - Diarrhea/GI losses (loss of HCO3)
  - lactic acidosis (lactic acid)
  - renal failure (metabolic acids and loss of HCO3)
  - diabetic ketoacidosis (acetic acid)
  - ASA (acetylsalicylic acid)

$$[H+] = \frac{24 \times p_aCO2}{[HCO3]}$$

ABG Interpretation

"ABG's in 8 steps"

A Case

- You get a call from a your clinical clerk…
  - "I need your input on Ms. K. She is a 65 year old woman who is here for a small bowel obstruction. Med consults is following her for long standing back pain and they are working her up for possible cancer."
- ABG (pH / PaCO2 / PaO2 / HCO3-)

7.30 / 80 / 45 / 38

Please interpret this ABG

3.6
140 | 3.9 /
100 | 35 \
85

Step 1

- **Step 1: Obtain ABG and electrolytes**
  - If you don't perform the test, you'll never know what is going on with the patient
  - An ABG and a lactate are the 2 best tests to help you get a sick patient to the ICU

•7.30 / 80 / 45 / 38

Step 2

- **Step 1: Obtain ABG and electrolytes**
  - If you don't perform the test, you'll never know what is going on with the patient
  - An ABG and a lactate are the 2 best tests to help you get a sick patient to the ICU
- **Step 2: Determine the primary process:**
  - Is it an acidosis or an alkalosis?
  - Is the primary problem respiratory or metabolic?

•7.30 / 80 / 45 / 38

Step 2: What is the primary process?

A. Look at the pH.
- Is it normal, acidemic or alkalemic?

B. Look at p_aCO2– is it "concordant" with pH change?
(i.e. CO2 is an acid… So, is ΔCO2 in the direction that would cause pH change?)

- If concordant, the primary problem is respiratory
  - Low pH and high p_aCO2 indicates respiratory acidosis
  - High pH and low p_aCO2 indicates respiratory alkalosis
- If not concordant, the primary problem is metabolic
  - Low pH and low p_aCO2 indicates metabolic acidosis
  - High pH and high p_aCO2 indicates metabolic alkalosis

Step 3: What is the compensation?

- Then look at HCO_3^-
  - Has it changed by the expected amount?
    - It doesn't have to be "perfect"
  - Change in $HCO3^-$ can tell you
    - if the disorder is acute or chronic
    - Whether multiple disorders are present

	Δ p_aCO2	Δ HCO3-
Acute Respiratory Acidosis	↑ 10	↑ 1
Acute Respiratory Alkalosis	↓ 10	↓ 2
Chronic Respiratory Acidosis	↑ 10	↑ 3
Chronic Respiratory Alkalosis	↓ 10	↓ 4
Metabolic Alkalosis	↑ 0.7	↑ 1
Metabolic Acidosis	↓ 1	↓ 1

•7.30 / 80 / 45 / 38

Step 3: What is the compensation?

- If compensation is “right”, there is one process
- If compensation doesn’t “fit”, there may be more than one process going on

	Δ p_aCO2	Δ HCO3-
Acute Respiratory Acidosis	↑ 10	↑ 1
Acute Respiratory Alkalosis	↓ 10	↓ 2
Chronic Respiratory Acidosis	↑ 10	↑ 3
Chronic Respiratory Alkalosis	↓ 10	↓ 4
Metabolic Alkalosis	↑ 0.7	↑ 1
Metabolic Acidosis	↓ 1	↓ 1

•7.30 / 80 / 45 / 38

Step 4: Determine the Anion Gap

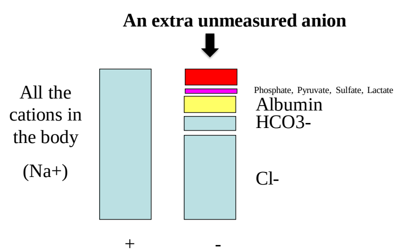
3.6
140 | ___/
100 | 35 \
85

Anion Gap = Na^+ - Cl^- - $HCO3^-$
= 140 – 100 – 35
= 5 (normal is < 12)

•7.30 / 80 / 45 / 38

Anion Gap

- What causes an increased anion gap?



Anion Gap – DDx

- Medical student answer
  - MUDPILES
- Real life answer…
  - Lactic acidosis
  - Ketosis (DKA, starvation, alcohol)
  - Renal failure
  - Poison (alcohols, ASA, cyanide)

Step 5: <u>If</u> an Anion Gap is present, is it the only process?

- Each molecule of unmeasured anion (ie. Lactate) donates a H+ which binds to HCO3-
- H^+ + $HCO3^-$ → H20 and CO2
- Therefore, if there is only one process,
  - Amount of added acid **=** the increase in H+ **=** the fall in HCO3-
  - The amount of added acid is measured using the anion gap
  - So, the **<u>change</u>** in Anion Gap should equal the **<u>change</u>** in HCO3-

Step 5: <u>If</u> an Anion Gap is present, is it the only process?

- Calculate ΔAG/ΔHCO3- ratio

ΔAG = measured AG – 12

Δ HCO3- = 24 – measured HCO3-

•7.30 / 80 / 45 / 38

Step 5: <u>If</u> an Anion Gap is present, is it the only process?

- Calculate ΔAG/ΔHCO3- ratio
- If ΔAG/ΔHCO3- ratio = 1 → no other process
  - Ratio > 1, HCO3 is too low → concomitant non-AG acidosis
  - Ratio < 1, HCO3 is too high → concomitant alkalosis

•7.30 / 80 / 45 / 38

Step 6: Determine the Osmolar (OSM) Gap

- OSM gap = measured OSM - calculated OSM
  - Measured OSM: given by the lab
  - Calculated OSM = (2 x Na^+) + BG + BUN
    - "Two salts and a sugar bun."
- Normal Osmolar gap < 10

Step 6: Determine the Osmolar (OSM) Gap

- DDx of a high osmolar gap
  - Methanol*
  - Ethylene glycol*
  - Ethanol
  - Mannitol
  - Acetone
  - Isopropyl alcohol
  - Others…

* Anion gap AND osmolar gap

Step 7: Calculate the A-a gradient

- A-a gradient = PAO2 – PaO2
- PAO2 = [(Pbar – PH20) x FiO2] – [PaCO2/RQ]
  = [(760 - 47) x FiO2] – [PaCO2/RQ]
  = [(713) x FiO2] – [PaCO2/RQ]
- PaO2 = measured with ABG

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Step 7: Calculate the A-a gradient

- PAO2 = [(Pbar – PH20) x FiO2] – [PaCO2/RQ]

- A-a = PAO2 – PaO2
- A-a = [(Pbar – PH20) x FiO2] – [PaCO2/RQ] – PaO2
- A-a = [(760 – 47) x 0.21] – [PaCO2 / 0.8] – PaO2
- A-a = [(760 – 47) x 0.21] – [1.25 x PaCO2] – PaO2
- A-a = [(713) x 0.21] – [1.25 x PaCO2] – PaO2
- **A-a = [150] – [1.25 x PaCO2] – PaO2 - Simplified version for pt on R/A**
- -
- -
- -
- -
- -

•7.30 / 80 / 45 / 38

Step 7: Calculate the A-a gradient

- Normal A-a gradient
  - A-a gradient < 10 is normal
  - A-a gradient is higher in elderly (up to 20)

Step 8: Causes of hypoxemia

- List the 5 major causes of hypoxemia
- Which have a normal A-a gradient?
- Which have a high A-a gradient?

Step 8: Causes of hypoxemia

1. Low inspired O2 content (low FiO2 or low PiO2)
2. Hypoventilation

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3. V/Q mismatch
   - Asthma, COPD, Alveolar filling (fluid, blood, pus), pHTN
4. Shunt
   - Physiologic shunt
   - Intra-cardiac (ASD, PFO or VSD)
   - Intra-pulmonary
     - With normal capillaries: atelectasis or consolidation
     - With abnormal capillaries: pAVM's or HPS
5. Diffusion abnormality
   - Severe ILD, severe COPD, etc…

Summarize this ABG

- Step 1: Get the ABG
- Step 2: Determine primary abnormality
- Step 3: What is the compensation
- Step 4: Assess the anion gap
- Step 5: Is the anion gap the only process
- Step 6: Calculate the osmolar gap
- Step 7: Calculate the A-a gradient
- Step 8: Cause of hypoxemia

7.30 / 80 / 45 / 38
140 | ___/ 3.6
100 | 35 \ 85

Summarize this ABG

- Step 1: done
- Step 2: chronic respiratory acidosis
- Step 3: compensated appropriately (10:3.5)
- Step 4: anion gap = 5 (normal)
- Step 5: no anion gap present
- Step 6: osmolar gap (can't do)
- Step 7: A-a gradient = 5 (normal)
- Step 8: hypoxemia due to hypoV

7.30 / 80 / 45 / 38
140 | ___/ 3.6
100 | 35 \ 85

Causes of Hypercapnia

- What are the determinants of PaCO2?
- PaCO2 = (VCO2) / RR (Vt-Vd) x K
  - CO2 production
  - Respiratory rate
  - Tidal volume
  - Dead space volume

Causes of Hypercapnia

PaCO2 = (VCO2) / RR (Vt-Vd) x K

- **High VCO2**
  - fever, sepsis, seizures
- **Low RR**
  - drugs, brainstem lesions, hypothyroid
- **Low Vt**
  - muscle weakness (rapid shallow breathing pattern), neuromuscular disease, low chest wall compliance
- **High Vd**
  - ARDS, PE, COPD

Back to the case

- You get a call from a your clinical clerk…
  - "I need your input on Ms. K. She is a 65 year old woman who is here for a small bowel obstruction. Med consults is following her for long standing back pain and they are working her up for possible cancer."
- ABG (pH/PaCO2/PaO2/HCO3-)

  7.30 / 80 / 45 / 38
- You diagnose a chronic respiratory acidosis with a normal A-a gradient due to hypoventilation
  - You remove the fentanyl patch from her arm
  - You transfer her to the ICU

Back to the case

- 15 minutes later
  - Patient arrives in ICU
  - RT feels patient is worse
- ABG: 7.30 / 80 / 30 / 38
  - What happened?

Baseline ABG:
7.30 / 80 / 45 / 38

Back to the case

- ABG: 7.30 / 80 / 30 / 38
  - Acid base status unchanged
  - PaO2 fell from 45 → 30
- A-a gradient has increased
  - A-a = PAO2 – PaO2
  - A-a = [150 – (1.25 x PaCO2)] – PaO2
  - A-a = [150 – (1.25 x 80)] – 30
  - A-a = [150 – 100] – 30
  - A-a = 20
- DDx?

Baseline ABG:
7.30 / 80 / 45 / 38

Back to the case: Causes of hypoxemia

1. Low inspired O2 content (low FiO2 or low PiO2)
2. Hypoventilation

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3. V/Q mismatch
- **Asthma, COPD, Alveolar filling (fluid, blood, pus), pHTN**

4. Shunt
- **Physiologic shunt**
- **Intra-cardiac (ASD, PFO or VSD)**
- **Intra-pulmonary**
  - **With normal capillaries: atelectasis or consolidation**
  - **With abnormal capillaries: pAVM's or HPS**

5. Diffusion abnormality
- **Severe ILD, severe COPD, etc…**

Back to the case: DDx of acute rise in A-a gradient

- V/Q mismatch
  - Aspiration pneumomitis
  - Flash pulmonary edema
  - Mucous plug
  - Pneumothorax
  - PE
  - (ARDS)

Review: ABG interpretation in 8 steps

- Step 1: Get the ABG
- Step 2: Determine primary abnormality
- Step 3: What is the compensation
- Step 4: Assess the anion gap
- Step 5: Is the anion gap the only process
- Step 6: Calculate the osmolar gap
- Step 7: Calculate the A-a gradient
- Step 8: Causes of hypoxemia