Objectives

• List the five types of arterial blood sampling errors and describe the effect of the error on the results of blood-gas values.
• State how pulse oximetry may be helpful in distinguishing arterial from venous blood samples.
• State the effect of increased or decreased body temperature on blood gas results.
• Malley – Chapters 3 & 5

Topics to Be Covered – Module C

• Gas Laws.
• Air in the Blood Sample.
• Inadvertent venous sampling/venous admixture.
• Dilution due to anticoagulants.
• Effects of metabolism.
• Temperature effects.

Venous Blood Gas Values

• $P_{O_2}$ 35 - 45 mm Hg
• $P_{CO_2}$ 41 - 51 mm Hg
• pH 7.32 – 7.42
• $S_{O_2}$ 70 – 75%
• $C_{O_2}$ 12 - 15 vol%

Dalton’s Law

• John Dalton (1776-1844):
  “Total pressure of a mixture of gases is equal to the sum of the partial pressures of each constituent gas. (1802)
• If a gas comprises 25% of the total, it will exert 25% of the total pressure.
• $P_{BARO} = P_{N_2} + P_{O_2} + P_{CO_2} + \ldots$
• Effect of changes in barometric pressure.

More on Dalton

• If we know the fractional concentration, we can calculate the partial pressure.
• $F_{GAS} \times (P_{BARO} - P_{H_2O}) = P_{GAS}$ in blood
  - .21 \times (760-47) = 149.73 mmHg
• Water vapor pressure can be obtained for any temperature from tables (3-2 in Malley).
Gas Laws – Boyle’s Law

• Robert Boyle (1627–1691)
• Spring of Air
• Volume Inversely related to Pressure if Temperature is held constant.
• $P_1V_1 = P_2V_2$

Gas Laws – Charles’s Law

• Jacques Charles (1746–1823)
• Balloon and Benjamin Franklin
• Volume Directly related to Temperature if Pressure is held constant.
• $V_1/T_1 = V_2/T_2$

Gas Laws – Gay-Lussac’s

• Joseph Louis Gay-Lussac (1778–1850)
• Pressure Directly related to Temperature if volume is held constant
• $P_1/T_1 = P_2/T_2$
• [http://www.grc.nasa.gov/WWW/K-12/airplane/Animation/frglab2.html](http://www.grc.nasa.gov/WWW/K-12/airplane/Animation/frglab2.html)

Henry’s Law

• William Henry (1774–1836)
• Predicts how much gas will dissolve in a liquid.
• If the temperature of the liquid remains constant, the volume of a gas that dissolves in a liquid equals its solubility coefficient times its partial pressure (that is the gaseous partial pressure above the liquid).
• $V = \alpha \times P_{\text{gas}}$
• Solubility coefficient for oxygen is 0.023 ml/ml
• Solubility coefficient for carbon dioxide is 0.510 ml/ml
• [http://hyperphysics.phy-astr.gsu.edu/hbase/kinetic/henry.html](http://hyperphysics.phy-astr.gsu.edu/hbase/kinetic/henry.html)

Graham’s Law

• Thomas Graham (1805–1869)
• The rate of diffusion of a gas is inversely proportional to the square root of its gram molecular weight (GMW).
• $D_{\text{gas}} \propto \frac{1}{\sqrt{\text{GMW}}}$
• [http://www.chem.tamu.edu/class/majors/tutorialnote/files/graham.htm](http://www.chem.tamu.edu/class/majors/tutorialnote/files/graham.htm)

EXPRESSIONS

• BTPS – Body Temperature (37°C), Body Pressure (Ambient, i.e. Barometric), Saturated with water vapor (PH$_2$O = 47 mmHg)
  • FOUND IN THE BLOOD
• ATPS – Ambient Temperature (~22°C), Ambient Pressure (Barometric), Saturated with water vapor as determined by the Relative Humidity (PH$_2$O = 19.6 mmHg * RH)
• STPD - Standard Temperature (0°C), Ambient Pressure (Barometric), Dry Gas (0% Relative Humidity) - PH$_2$O = 0 mmHg
5 Common Errors

- Air in the Blood Sample.
- Venous sampling or admixture.
- Excessive or improper anticoagulant use.
- Rate of Metabolism.
- Temperature disparities between machine and patient.

Air in the Blood Sample

- Effect on $P_{aO_2}$
  - Primary parameter affected.
- Effect on $P_{aCO_2}$ (and pH)
- Relationship to time.
  - Within 2 minutes without mixing.
  - Very significant with the presence of frothy bubbles.
- Air contamination during measurement.

Venous Sampling or Admixture

- Most common in femoral punctures or hypotensive patients because of difficulty in assessment.
  - Flash
  - Pulsation
- Venous admixture – contamination of an arterial sample with venous blood.
  - Can be due to overshoot.
  - Femoral vein anomaly that is punctured.
  - 1/10th part leads to a 25% error.
  - 0.5 ml of venous blood with a $P_{O_2}$ of 31 mixed with 4.5 ml of arterial blood with a $P_{O_2}$ of 86, yields a mixed sample with a $P_{O_2}$ of 56.
  - Suspect whenever clinical status ≠ results.

Anticoagulant Effects

- Anticoagulants are necessary evil.
- Depends on type, concentration, & volume of anticoagulant.
- Lithium heparin is preferred anticoagulant.
  - Sodium heparin can increase Na$^+$.
  - Excess volume can lead to reduction in $P_{aCO_2}$ and other electrolytes (Ca$^{2+}$).
- Stronger concentrations than 1000 $\mu$g/ml can affect the pH.
- More prominent with samples from neonate.

Effect of Metabolism

- Metabolism continues after sampling.
  - Oxygen is consumed and Carbon Dioxide produced.
  - Depends on temperature of sample ($\downarrow$ temperature, $\downarrow$ metabolism)
  - pH: Decrease 0.05/hr
  - $P_{aCO_2}$: Increase 5 mmHg/hr
  - $P_{aO_2}$: Decrease by 20 mmHg/hr (150 mmHg/hr if initial $P_{aO_2}$ over 250 mmHg)
  - At room temperature (20-24 °C) 50% reduction
  - Icing sample to 4°C results in a 10% reduction
  - Solution is to analyze quickly!
  - "Leukocyte Larceny" – The rapid decrease in $P_{aO_2}$ that was observed in blood samples with high leukocyte counts (leukocytosis).
AARC CPG on ABG Sampling (ABS)

7.1.7 Specimens held at room temperature must be analyzed within 10-15 minutes of drawing; iced samples should be analyzed within 1 hour. The PaO2 of samples drawn from subjects with elevated white cell counts may decrease very rapidly. Immediate chilling is necessary. Some dual-purpose electrolyte/blood gas analyzers stipulate immediate analysis without chilling because of possible elevations in potassium from chilling, however, the accuracy of the blood gas results should not be affected by the chilling.

10.1.3 Container of ice and water (to immerse syringe barrel if specimen will not be analyzed within 15 min)

What isn’t stated for highlighted portion is that these samples should be collected in a glass syringe!

Effect of Temperature

Gay-Lussac’s law – Pressure and Temperature react directly with each other.
• Effect on PaO2.
• Effect on PaCO2.
• Effect on pH.
• Correction takes into account physical relationship between pressure & temperature.
• Does not take into account the change in metabolic activity at different temperature.
  • What is the "normal" PaO2 at 39°C?
  • Instrumentation temperature must be maintained at 37°C ± 0.1°C.

Assessment of Internal Consistency

• Does the pH correlate with the PaCO2 and HCO3-?
  • pH: 7.32  PaCO2: 23 mmHg  HCO3-: 31 mEq/L
• Does the degree of pH change match the PaCO2 or HCO3- change?
  • pH: 7.60  PaCO2: 30 mmHg  HCO3-: 23 mEq/L
• Use one of the following four methods to help assess internal consistency:
  • Indirect Metabolic Assessment
  • Rule of Eights
  • Modified Henderson Equation
  • Acid-Base Map

Metabolic Assessment

Premise: pH change is due to a respiratory (PaCO2) or metabolic (HCO3-) component.
• Acute decrease in PaCO2 by 10 mmHg yields a 0.10 increase in pH.
• Acute increase in PaCO2 by 10 mmHg yields a 0.06 decrease in pH.
• If the PaCO2 rises from a normal of 40 to 50 mmHg, the pH should fall by 0.06.
• The "expected pH" should then be compared with the "measured pH". If the variation is greater than 0.03 (error factor), a metabolic alteration is present.
• pH: 7.60  PaCO2: 30 mmHg  HCO3-: 23 mEq/L
• 30 mm Hg PaCO2 yields a pH of 7.50. Some additional metabolic alkalosis must be present. The HCO3- is actually 28.5 mEq/L.

Rule of Eights

• Used to predict plasma bicarbonate when the pH and PaCO2 are known.
• Factor x PaCO2 = Predicted Bicarbonate
• Compare actual with predicted (difference should be less than 4 mEq/L)
• pH: 7.60  PaCO2: 25
• Δ PaCO2 is 15 mmHg, therefore pH should be 7.55. It isn’t, so some loss of bicarbonate is present.
  • 25 / 6/8 = 18.75 mEq/L

Icing the Sample

• All samples should be analyzed immediately.
• If a delay of greater than 30 minutes is anticipated, a glass syringe should be used and the sample should be placed in an ice/Water slush solution capable of maintaining a temperature of 1-5 °C.
• Barrel should be immersed within slush solution.
• If sample is in a plastic syringe and can be analyzed within 10-15 minutes, icing the sample is not necessary.
• Plastic syringes have been shown to allow for an increase in PaCO2 if analysis is delayed more than 30 minutes.
• AARC CPG states that iced samples should be analyzed within 1 hour CPG), however it isn’t stated (but implied) that those samples are in a glass syringe.
Modified Henderson Equation

- \([H^+]\) in nanequivalents per liter to \(\text{PacO}_2\) & \([\text{HCO}_3^-]\)
  - \([H^+] = 24 \times \left(\frac{\text{PacO}_2}{[\text{HCO}_3^-]}\right)\)
  - Need to convert \(\text{pH}\) to \([H^+]\)
  - Linear between 7.20 & 7.50.
    - \(\Delta 0.01 \text{pH} = \Delta 1\ \text{nEq/L}\)
    - \(\text{pH} 7.40 = 40\ \text{nEq/L}\)

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External Congruity

- Ensure that all laboratory tests and observations are in harmony with blood gas results.
  - \([\text{HCO}_3^-]\) = Total CO\(_2\) from Electrolytes
    - Total CO\(_2\) = (\text{PacO}_2 \times 0.03) + \([\text{HCO}_3^-]\)
  - Patient-Laboratory Congruity
    - Appearance of patient & results
  - \(\text{FiO}_2\) - \(\text{PacO}_2\) Incongruity
    - Dalton's Law Estimate: \(\text{PacO}_2 < 130\ \text{mmHg}\) on RA
    - \(\text{FiO}_2 \times 5\) on higher \(\text{FiO}_2\)
  - \(\text{SaO}_2\) - \(\text{SpO}_2\) Incongruity
    - Compare invasive to non-invasive

Metabolic Acid-Base Indices

- Metabolic indices may lead to inaccurate conclusions in the presence of hypo- or hypercapnia.
  - EXAMPLE
    - \(\text{pH}\): 7.16
    - \(\text{PacO}_2\): 80 mmHg
    - \(\text{Pao}_2\): 80 mmHg
    - \([\text{HCO}_3^-]\): 28 mEq/L
    - \(\text{BE}\): -4 mEq/L
    - Std \([\text{HCO}_3^-]\): 20 mEq/L
    - \(\text{BE}_{\text{ext}}\): 0 mEq/L
    - \(T_{40}\) Std \([\text{HCO}_3^-]\): 24 mEq/L

Internal Congruity

- Indirect Metabolic Assessment
  - Predicts normal \(\text{HCO}_3^-\) of 24 mEq/L, not 28
- Rule of Eights
  - Predicts \(\text{HCO}_3^-\) of 22.5 mEq/L, not 28
- Modified Henderson Equation
  - Predicts \(\text{HCO}_3^-\) of 27.6 mEq/L, not 28
- SO WHO IS RIGHT?

Plasma Bicarbonate and Buffering for Respiratory Acidosis

- Hydrolysis Effect: Some rise in \(\text{HCO}_3^-\) will occur because of excess \(\text{PacO}_2\) in the system.
  - A 10 mmHg \(\uparrow\) in \(\text{PacO}_2\) will yield a 1 mEq/L \(\uparrow\) in plasma \([\text{HCO}_3^-]\) reading.
  - A 5 mmHg \(\downarrow\) in \(\text{PacO}_2\) will yield a 1 mEq/L \(\downarrow\) in plasma \([\text{HCO}_3^-]\).
- LOOK AT EXAMPLE
### Standard Bicarbonate

- The plasma bicarbonate concentration obtained from blood that has been equilibrated to a $PCO_2$ of 40 mmHg at 37°C and a $PO_2$ sufficient to yield full saturation.
- Some discrepancy exists because there is some exchange of bicarbonate between the plasma and the extracellular fluid space that cannot be approximated by simple tonometry of plasma.
- Look at Std $HCO_3^-$ in example.

### Base Excess of Extracellular Fluid

- Corrects for shifts of bases that occur *in vivo* that do cannot be replicated with nomograms & calculations.
- Also known as Standard Base Excess (SBE).
- The best way to determine the actual amount of buffer base in the body.
- Look at the example: $[BE]_{ecf}$ is normal.

### Case Study #1

- A 25-year-old female arrives in the ED in a coma. ABG results are: $pH$: 7.16, $P_{CO_2}$: 80 torr, $P_{O_2}$: 52 torr, $Sao_2$: 85%, $HCO_3^{-}$: 28 mEq/L, $BE$: -4 mEq/L.
- Interpret ABG.
- Are the results consistent?
- What other information is important?
- What additional information would you like to have?

### T40 Standard Bicarbonate

- An index that uses a nomogram to correct the standard bicarbonate for the discrepancy found.
- Probably the most accurate of the bicarbonate metabolic indices.
- Note the $T_{40}$ Standard Bicarbonate in the example; NORMAL (i.e. NO metabolic involvement).

### Buffer Base & Base Excess

- Bicarbonate Buffering is only one of the buffering systems present.
- The total amount of buffer base present is called the Whole Blood Buffer Base [BB].
- Affected by hemoglobin level.
- When we compare the normal BB to the observed BB we are calculating the Base Excess (BE).
- Derived in actual practice by the Siggard-Anderson nomogram.
- Same problem with ECF as seen in Std $HCO_3^-$.
- In the presence of hypercarbia, BE calculation may result in an false low value.

### pH: 7.16, $P_{CO_2}$: 80 torr, $P_{O_2}$: 52 torr, $Sao_2$: 85%, $HCO_3^{-}$: 28 mEq/L, $BE$: -4 mEq/L.

- Interpretation?
  - Classically, it is a partially compensated respiratory acidosis…but is it?
  - Cause of hypoxemia?
  - Where is there inconsistency?
  - High bicarbonate with low $BE$?