KEY POINTS:

- A:a gradient increases will occur in Shunt, VQ mismatch and diffusion impairment, but not low FiO2 or hypoventilation
- In chronic resp acidosis, oxygen becomes driver of respiration, so take care in correcting low PaO2 too drastically
- Compensation for resp acidosis occur distinct acute (RBC/hemoglobin mediated) and chronic mechanisms (increased NH3 synthesis)

Hypoxemia

- Five causes
    - Low FiO2 or PIO2 (partial pressure of inspired oxygen)
        - Decreased barometric pressure
        - Anesthesia problems
        - Results in hyperventilation to overcome hypoxemia
            - A:a gradient will be normal!!! (due to decrease in PIO2)
    - Hypoventilation
        - PAO2 and PaO2 will decrease as PACO2 and PaCO2 increase
            - No change in A-a gradient
        - Hyperventilation is very limited in its ability to increase PaO2 when PaO2 is already over 55-60 mmHg
        - Causes of hypoventilation
            - CNS disease
            - Respiratory depressants
            - Neuromuscular disease
            - Chest wall injury
            - Upper airway obstruction
            - Severe diffuse pulmonary disease
        - Diffusion impairment
            - Seldom the sole case of hypoxemia in veterinary medicine
            - Thickened basement membrane
            - Loss of alveolar or capillary surface area
                - Emphysema or vasculitis
            - High cardiac output decreases RBC pulmonary transit time
        - V-Q mismatch
            - One of the most common
            - Lungs are always operating at a VQ ratio of about 0.8 (ideal being 1.0)
                - However, this does not prevent normal oxygenation and ventilation
            - Low VQ units have
                - High PCO2
                - Low PaO2

        - Found in asthma, bronchitis, chronic obstructive pulmonary disease
    - High VQ (poorly perfused, adequately ventilated)
        - High PaO2 and low PaCO2
        - If VQ is >1, it DOES NOT improve oxygenation
        - Diseases such as emphysema (high compliance) or PTE (low output states)
    - VQ mismatch severity (in either direction) can be assessed with A-a gradient
        - Corrected by increasing FiO2
- Right to left Shunt
    - Other very common cause
    - Severe form of VQ mistmatch resulting in mixed venous blood bypassing ventilated pulmonary alveoli and reentering arterial circulation
    - Normal shunt fraction of 2-3% in mammals
    - Flow via atelectatic or consolidated lung (VQ = 0) is considered shunt
        - Pneumonia
        - Pulmonary edema
        - Atelectasis
    - Anatomic shunts
        - Right to left PDA, right to left VSD or ASD, Tetrology of Fallot
    - Even small shunts can be clinically relevant
        - Oxygenation is near 100% in normal lung, so is already at ceiling - thus other lung units cannot make up the difference, unlike with CO2
    - Increased A-a gradient
    - 100% oxygen may not return to normal

Resp Acidosis

- Increased PCO2 + HCO3- and decrease in pH
- Metabolic compensation
    - Acute respiratory acidosis
        - Bicarbonate ions are released from erythrocytes in exchange for chloride after hemoglobin buffers H+ from H2CO3
            - Decrease in plasma Cl- results in decreased strong ion difference
        - Intracellular buffers play 97% of the role in resp acidosis
            - Other 3% is plasma proteins
        - Each 1 mmHg rise in PCO2 results in increase of HCO3- by 0.15mEq/L
    - Chronic resp acidosis
        - WIthin 5 days, kidneys stabilize higher concentration of HCO3-
            - H+ is excreted in exchange for Na+

        - Excreted as NH4+Cl-
            - Cats may not be able to increase ammoniagenesis and may not be able to compensate for chronic resp acidosis
        - Bicarbonate is reabsorbed and exchanged for Cl-
            - Further increases strong ion difference
            - Chloruresis
            - Negative Cl- balance
            - Dogs will need chloride to correct this problem once resp acidosis is fixed
    - Each 1mmHg increase in PCO2 will increase HCO3- by 0.35mEq/L
- Longer term
    - >30 days, dogs may be able to bring pH back to normal range

Box 11-2 Predicted Metabolic Compensations in Respiratory Blood Gas Disorders

Acute Respiratory Acidosis
$[HCO_3^-]$ increases 0.15 mEq/L for every 1-mm Hg increase in P_{CO_2} in dogs
Same for cats

Chronic Respiratory Acidosis
$[HCO_3^-]$ increases 0.35 mEq/L for every 1-mm Hg increase in P_{CO_2} in dogs
Degree of compensation is not known for cats

Acute Respiratory Alkalosis
$[HCO_3^-]$ decreases 0.25 mEq/L for every 1-mm Hg decrease in P_{CO_2} in dogs
Same for cats

Chronic Respiratory Alkalosis
$[HCO_3^-]$ decreases 0.55 mEq/L for every 1-mm Hg decrease in P_{CO_2} in dogs
Degree of compensation is not known for cats, but pH is usually normal or slightly alkalemic

- Causes of resp acidosis
    - Acute resp acidosis usually results from
        - sudden and severe primary parenchymal disease

                - Fulminant pulmonary edema
            - Airway disease
            - Pleural space disease
            - Chest wall disease
            - Neurologic disease
            - Neuromuscular disease
            - Most of the time, hypoxemia is much bigger problem here

    - Chronic resp acidosis
        - Alveolar hypoventilation
        - Abnormal resp drive
        - Chest wall abnormalities
        - Resp muscle abnormalities
        - Increased dead space ventilation
    - Increased CO2 production by tissues rarely results in resp acidosis
        - Heat stroke and malignant hyperthermia may be exceptions
    - Central hypoventilation
        - CNS trauma, sedation, neoplasia, infection, general anesthesia, narcotics, cerebral edema
    - Regional hypoventilation
        - Needs to have other disease in the lung to prevent compensatory hyperventilation in other lung units
            - PTE
            - Emphysema
            - Fibrosis
- Results of hypercapnia
    - Acute hypercapnia results in cerebral vasodilation
        - Increased cerebral blood flow, but also increased ICP
            - Decreased CPP
        - CNS signs such as anxiety, restlessness, disorientation, somnolence, coma
    - Tachyarrhythmias
    - Electrolyte fluctuations
    - Hypoxemia
        - However, hypercapnia will result in shift of oxygen dissociation curve to the right, promoting oxygen unloading at tissues
    - Acidemia
    - Experimentally, dogs get increased cardiac output state
- Treatment of hypercapnia
    - Correct underlying disease process
    - Supplemental oxygen
        - Can decrease resp drive, so be careful

- Especially in chronic settings, as O2 becomes primary stimulus for ventilation
    - Aim for PaO2 60-65

Questions:

Explain the mechanism behind the increase in serum [HCO_3^-] in response to acute respiratory acidosis

Which cause of hypoxemia will be least responsive to oxygen supplementation

a. Diffusion impairment
b. VQ mismatch
c. Shunt
d. Low FiO_2

Explain why in the case of a anatomic shunt, a patient can still have a normal PCO_2, but cannot have a normal PaO_2.

Answers

Explain the mechanism behind the increase in serum [HCO3-] in response to acute respiratory acidosis

Increase in serum CO2 will diffuse into RBCs where CA will turn into HCO3- and H+. H+ will bind to hemoglobin and HCO3- will be exchanged for Cl-, increasing serum HCO3- by 0.15mEqL for each 1mmHg increase in PCO2

Which cause of hypoxemia will be least responsive to oxygen supplementation

a. Diffusion impairment
b. VQ mismatch
c. Shunt
d. Low FiO2

Explain why in the case of a anatomic shunt, a patient can still have a normal PCO2, but cannot have a normal PaO2.

Oxygen saturation of RBCs in near 100% in normal lung, so if blood bypasses lungs, it will mix with oxygenated blood and bring it down to below normal levels, while the increase in CO2 in the blood due to venous admixture will be able to be 'hyperventilated' in the functional lung units on the next pass to bring CO2 to normal