Acid-Base & CO_2 Balance

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This Presentation is Approved for
1 CRCE Credit Hour

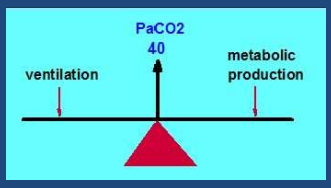
Learning Objectives

- Explain the physiology & pathophysiology of carbon dioxide exchange & acid-base balance
- Determine the ventilatory & acid-base status from blood-gas values

CO_2 Transportation & Regulation

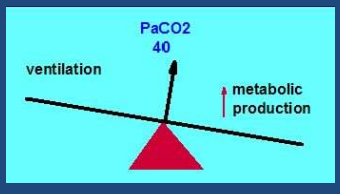
CO_2 Production & Excretion

- Produced with H_2O as part of glucose metabolism
- Excreted by ventilation



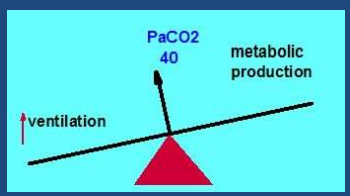
CO_2 Production & Excretion

- Increased metabolism



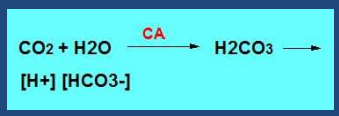
CO_2 Production & Excretion

- Increased ventilation



CO_2 Transport

- Mechanisms
  - Dissolved in plasma (PCO_2 x 0.03)
  - Converted to HCO_3-
    - Greatest amount of CO_2
    - Requires carbonic anhydrase (CA) as catalyst



CO_2 Transport

- Mechanisms
  - Combined with hemoglobin
    - Greatest amount of exchanged CO_2
    - CO_2-Hb dissociation increased by increased O_2- Haldane shift

CO_2 Transport

- Total CO_2 = HCO_3 + dissolved CO_2

Total CO_2 (mEq/L) = 24 + (0.03)(40) = 25.2 mEq/L

CO_2 Abnormalities

- Decreased: hyperventilation
  - Neurogenic hyperventilation
    - Increased intracranial pressure (ICP)
    - Anxiety
  - Hypoxemia
  - Compensation for metabolic acidemia

CO_2 Abnormalities

- Increased: hypoventilation
  - Depressed ventilation
    - Ventilatory fatigue
    - Depressant drugs, e.g. anesthetics
    - Neuromuscular dysfunction

CO_2 Abnormalities

- Increased: hypoventilation
  - Depressed ventilation
    - Ventilatory fatigue
    - Depressant drugs, e.g. anesthetics
    - Neuromuscular dysfunction
  - Increased dead space ventilation
    - Emphysema: loss of alveolar capillaries
    - Tachypnea: decreased tidal volume
    - Massive pulmonary embolism

CO_2 Abnormalities

- Increased CO_2 production
  - Increased metabolism
    - Fever
    - Shivering: recovery from hypothermia
    - Seizures: may also cause hypoventilation

CO_2 Abnormalities

- Increased CO_2
  - Excessive glucose intake, e.g. I.V. fluids
  - Compensation for metabolic alkalemia

Acid-Base Balance

Regulators of Acid-Base Balance

- Buffers
- Ventilation
- Renal function

Regulators of Acid-Base Balance

- Buffers
  - First to act
  - No pH change until they are depleted
  - HCO_3- is the most important one
  - Hemoglobin: second most important

Regulators of Acid-Base Balance

- Ventilation
  - Responds almost immediately to pH change
  - Excretes/retains CO_2 - volatile acid

Regulators of Acid-Base Balance

- Kidney
  - Requires time to respond
  - Excretes/retains HCO_3- or H^+ (fixed base, acid)

Acid-Base Balance

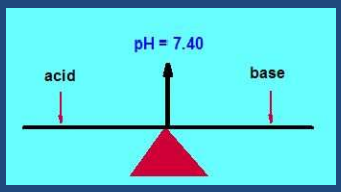
- Parameters used to interpret
  - pH - normal = 7.4
  - PCO_2 - normal = 40
  - HCO_3 - normal = 24

Acid-Base Balance

- Parameters used to interpret
  - Base change - also known as base excess
    - Defined: the quantity of base, in mEq/L, required to normalize the pH, with PCO_2 adjusted to 40
    - Normal value = 0 (zero)
    - Estimate by subtracting normal HCO_3 (24) from measured HCO_3
    - Used to calculate dosage of bicarbonate to treat acidemia

Acid-Base Balance

- Depends on maintaining 20:1 ratio of base:acid (Henderson-Hasselbalch equation)



Acid-Base Balance

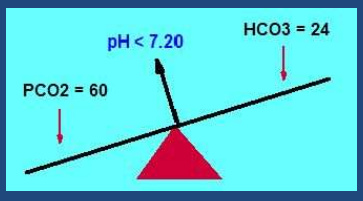
- Depends on maintaining 20:1 ratio of base:acid (Henderson-Hasselbalch equation)

pH = pKa + log (Base/Acid)

FYI see links below to view calculation of pH using the H-H equation

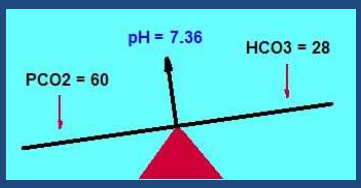
Respiratory Acidemia

- Hypoventilation - addition of volatile acid - CO_2
- Acute, uncompensated



Compensated Respiratory Acidemia

- Chronic hypoventilation
- Renal retention of HCO_3
- Occurs over hours-days
- Rarely fully compensated



Respiratory Acidemia

- Management
  - Increase alveolar ventilation - caution with chronic hypercapnia
    - Rapid reversal is hazardous - alkalemia
    - Complete reversal will delay ventilator weaning
  - If ventilation cannot be increased, e.g. permissive hypercapnia - Tromethamine (THAM™)

Metabolic Acidemia

- Fixed acid excess OR
- Base deficiency
- pH does not change until buffers are neutralized
- Ventilation compensates immediately, unless compromised or controlled
- Associated with hyperkalemia

Metabolic Acidemia

- Causes
  - Diabetes - ketones
  - Renal Failure
    - Non-production of HCO_3-
    - Failure to excrete acid ions
  - Hepatic failure: failure to catabolize lactic acid

Metabolic Acidemia

- Causes
  - Diarrhea - HCO_3- loss
  - Ingestion of acid
  - Congenital metabolic disease, e.g. maple syrup urine disease (MSUD)

FYI see links below for article on MSUD

Metabolic Acidemia

- Causes
  - Tissue hypoxia - lactic acidemia
    - Severe hypoxemia
    - Shock, e.g. septic shock
    - Nucleoside analogues (HIV meds)
    - Diagnosed with serum lactate measurement

FYI see links below for article on lactic acidemia & nucleoside analogues

Metabolic Acidemia

- Anion Gap = $[Na^+] - ([Cl^-] + [HCO_3^-])$
- Normal = [140 - (100 + 24)] = 16
- So what? If the source of acidemia is unclear, the anion gap can narrow the choices.

FYI see links below for more information on anion gap

Metabolic Acidemia

- Elevated anion gap acidemia causes
  - Methanol, metformin (diabetic agents)
  - Uremia
  - Diabetic ketoacidosis
  - Paraldehyde - rarely used
  - Iron, isoniazid, inhalants (abuse)
  - Lactic acid
  - Ethylene glycol, ethanol (alcoholic ketoacidosis)
  - Salicylates, solvents, starvation

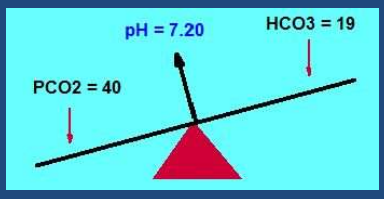
Metabolic Acidemia

- Non-anion gap acidemia sources
  - Gastrointestinal HCO_3^- loss - diarrhea
  - Renal failure - renal tubular acidosis
  - Hyperalimentation
  - Post-hypocapnea, e.g. normal postnatal maternal condition

FYI see links below for more information on renal acidosis

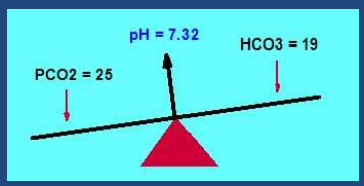
Uncompensated Metabolic Acidemia

- Negative base change - estimated = (19 - 24) = -5 mEq/L



Partly Compensated Metabolic Acidemia

- Full compensation is rare

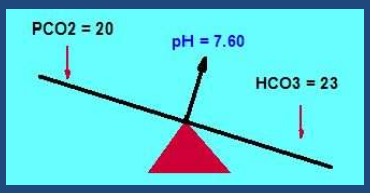


Metabolic Acidemia - Management

- Do not treat pH ≥ 7.20
- Treat underlying cause
  - Insulin - ketoacid
  - Restore oxygenation
  - Restore perfusion
  - Restore hemoglobin
  - Dialysis - renal failure
  - Withdraw any causitive agents
- Buffer therapy (later)

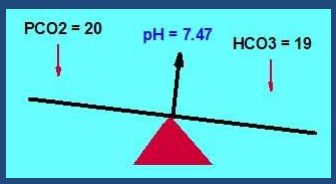
Respiratory Alkalemia

- Acute, uncompensated
- Hyperventilation



Respiratory Alkalemia

- Chronic hyperventilation: common in late pregnancy
- Renal compensation: excrete HCO_3-
- Management: treat underlying cause



Metabolic Alkalemia - Base Excess

- Causes
  - Administration of HCO_3
  - Vomiting, nasogastric suctioning
  - Diuretic therapy

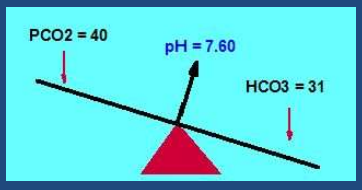
FYI see links below for article on metabolic alkalemia

Metabolic Alkalemia - Base Excess

- Causes
  - Administration of HCO_3
  - Vomiting, nasogastric suctioning
  - Diuretic therapy
- Consequences
  - Hypokalemia - tachydysrhythmias
  - Leftward shift in HbO_2 curve: aggravates hypoxia

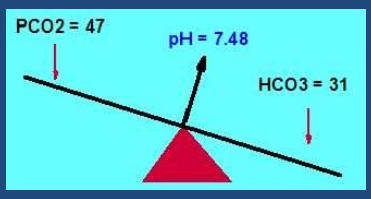
Metabolic Alkalemia

- Acute, uncompensated



Metabolic Alkalemia

- Partly compensated
- Hypoventilation to retain CO_2
- Results in base excess: estimated (31 - 24) = 7



Metabolic Alkalemia

- Management
  - Treat underlying cause
  - Acetazolamide (Diamox)
    - For pH = 7.48 & HCO_3 = 28 mmol/l
    - Single dose = 500 mg

FYI see links below for article on acetazolamide & alkalemia

Arterial vs. Venous Samples

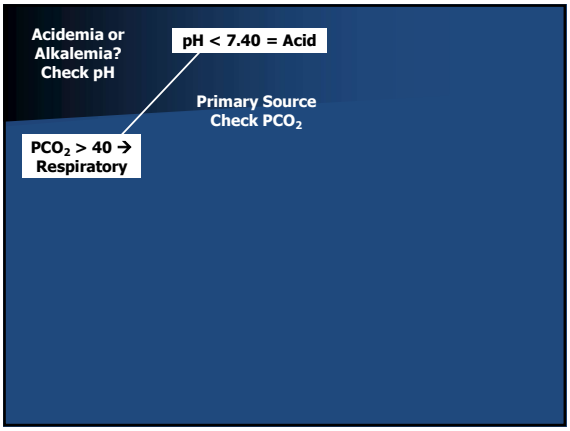
- Mixed venous samples
  - Superior to arterial samples in determining
    - Acid-base status, especially during resuscitation
    - Lactate levels
  - Sites
    - Pulmonary artery
    - Central veins
    - Peripheral vein - emergency

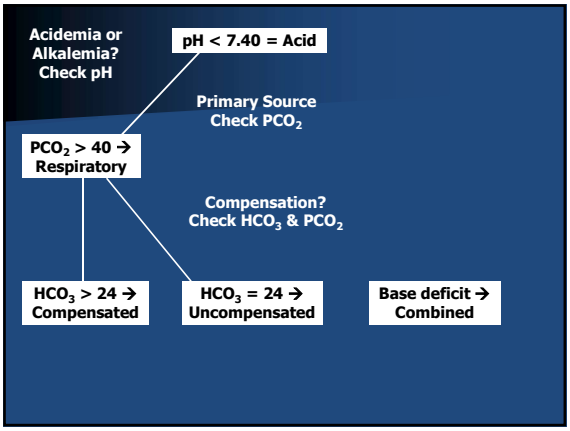
Arterial vs. Venous Samples

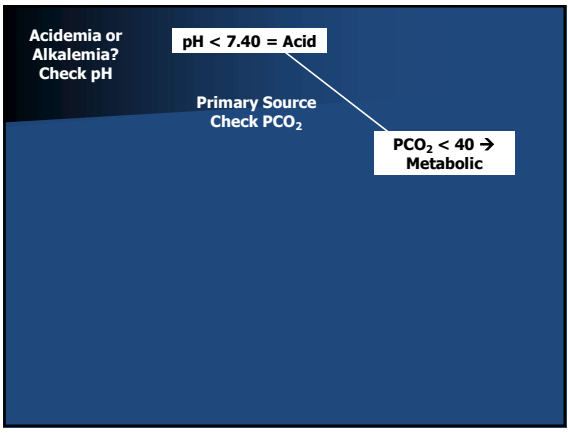
- Mixed venous normal values

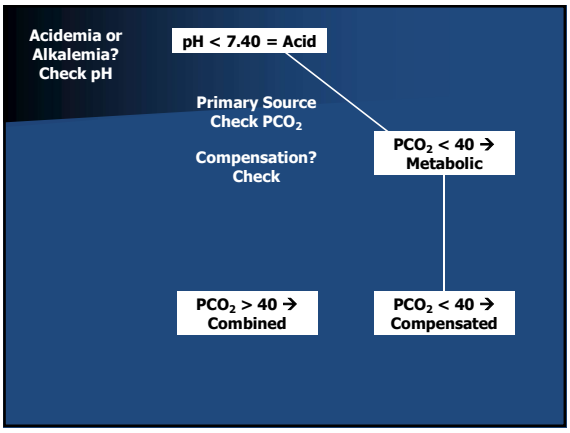
pH	7.36
PCO2	44
HCO3-	28
lactate	1mmol/L

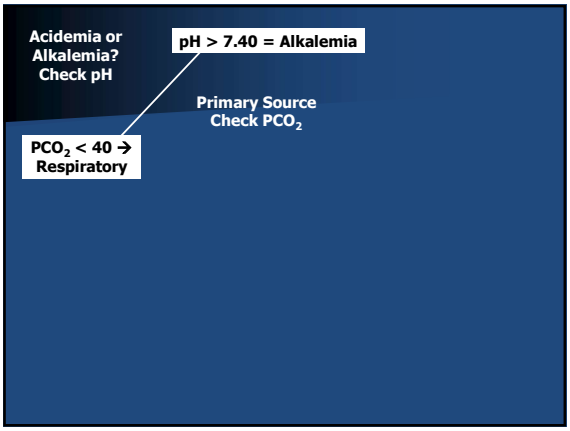
Acid-Base Balance Algorithm

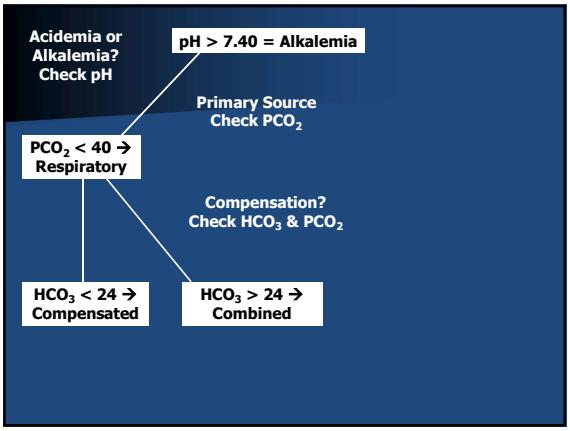


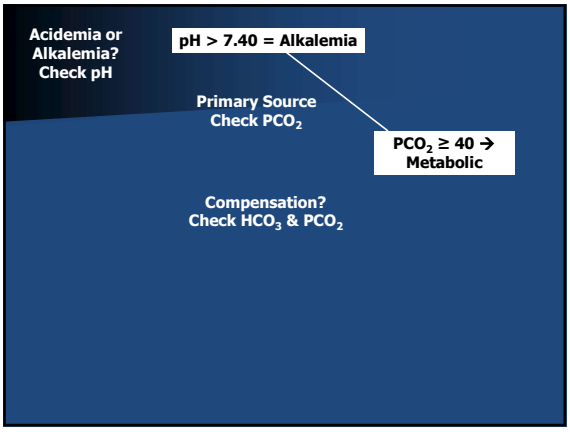



Acidemia or Alkalemia? Check pH
pH < 7.40 = Acid
Primary Source Check PCO_2
PCO_2 < 40 → Metabolic


Acidemia or Alkalemia? Check pH
pH < 7.40 = Acid
Primary Source Check PCO_2
Compensation? Check
PCO_2 < 40 → Metabolic
PCO_2 > 40 → Combined
PCO_2 < 40 → Compensated


Acidemia or Alkalemia? Check pH
pH > 7.40 = Alkalemia
Primary Source Check PCO_2
PCO_2 < 40 → Respiratory


Acidemia or Alkalemia? Check pH
pH > 7.40 = Alkalemia
Primary Source Check PCO_2
PCO_2 < 40 → Respiratory
Compensation? Check HCO_3 & PCO_2
HCO_3 < 24 → Compensated
HCO_3 > 24 → Combined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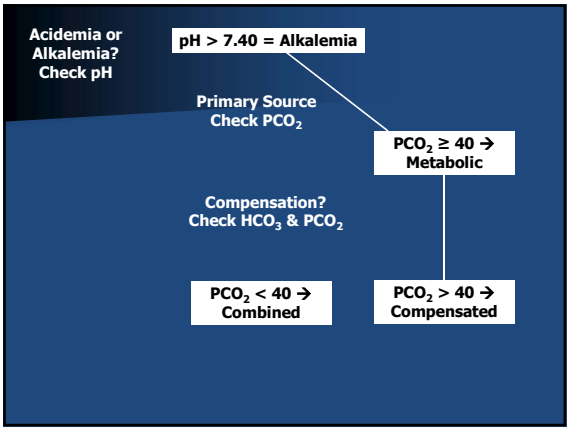
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pH > 7.40 = Alkalemia
Primary Source Check PCO_2
PCO_2 ≥ 40 → Metabolic
Compensation? Check HCO_3 & PCO_2
PCO_2 < 40 → Combined
PCO_2 > 40 → Compensated

Interpretation Practice

Interpret these values: pH = 7.48, PCO_2 = 32, HCO_3 = 24

Acidemia or Alkalemia? Check pH → pH > 7.40 = Alkalemia

PCO_2 < 40 → Respiratory

Primary Source Check PCO_2

HCO_3 = 24 → Uncompensated

Compensation? Check HCO_3 & PCO_2

Interpret these values: pH = 7.48, PCO_2 = 32, HCO_3 = 24

Acidemia or Alkalemia? Check pH → pH > 7.40 = Alkalemia

PCO_2 < 40 → Respiratory

Primary Source Check PCO_2

HCO_3 = 24 → Uncompensated

Compensation? Check HCO_3 & PCO_2

Acute (Uncompensated) Respiratory Alkalemia

Interpret these values: pH = 7.30, PCO_2 = 28, HCO_3 = 19

Acidemia or Alkalemia? Check pH → pH < 7.40 = Acid

Primary Source Check PCO_2

PCO_2 < 40 → Metabolic

Compensation? Check PCO_2

PCO_2 < 40 → Compensated

Interpret these values: pH = 7.30, PCO_2 = 28, HCO_3 = 19

Acidemia or Alkalemia? Check pH → pH < 7.40 = Acid

Primary Source Check PCO_2

PCO_2 < 40 → Metabolic

Compensation? Check PCO_2

PCO_2 < 40 → Compensated

Partly Compensated Metabolic Acidemia

Interpret these values: pH = 7.36, PCO_2 = 54, HCO_3 = 28

Acidemia or Alkalemia? Check pH → pH < 7.40 = acid

PCO_2 > 40 → Respiratory

Primary Source Check PCO_2

HCO_3 > 24 → Compensated

Compensation? Check HCO_3 & PCO_2

Interpret these values: pH = 7.36, PCO_2 = 54, HCO_3 = 28

Acidemia or Alkalemia? Check pH

pH < 7.40 = acid

PCO_2 > 40 → Respiratory

Primary Source Check PCO_2

Compensation? Check HCO_3 & PCO_2

HCO_3 > 24 → Compensated

Compensated Respiratory Acidemia

Buffer Therapy

Buffer Therapy

- Purpose: to reverse acid-base imbalance, usually acidemia
- $NaHCO_3$: action - provides HCO_3- → [H+] + [HCO_3-] → H_2O + CO_2 → depends on ventilation to excrete CO_2

$NaHCO_3$- Complications

- Respiratory acidemia if CO_2 not excreted
- Metabolic alkalemia (overdose)
- Hypernatremia
- Cerebral edema

$NaHCO_3$- Contraindications

- pH > 7.20
- Severe hypernatremia

$NaHCO_3$

- Administration titrated with blood pH
- Formula for dosage

HCO_3 (mEq) = kg x (15 - observed HCO_3-) x 0.5

Carbicarb

- Mixture of $NaHCO_3$ & $NaCO_3$
- Buffers without net generation of CO_2
- No human trials have been conducted

FYI see links below for article on lactic acidemia management (includes Carbicarb)

Buffer Therapy

- Tris-hydroxymethylaminomethane - Tromethamine (THAM™)
  - Reverses acidemia without excretion of CO_2
  - Action: organic proton acceptor (eats H+)

Buffer

- THAM™
  - Indications
    - Metabolic acidemia with hypernatremia
    - Acidemia in conjunction with limitations in ventilation-permissive hypercapnia

FYI see links below for article on THAM™ & permissive hypercapnia

Buffer

- THAM™
  - Complications
    - Apnea
    - Hypoglycemia
    - Hypokalemia
    - Alkalemia
    - Tissue necrosis from infiltration

Buffer

- THAM™
  - Dosage: ml's of THAM™ of 0.3 M solution = body weight in kg x base deficit in MEq/l

Buffer

- Trometamol (Tribonat™)
  - Currently used in Europe
  - Ingredients
    - $NaHCO_3$
    - THAM™
    - Acetate
    - PO_4

Buffer

- Trometamol (Tribonat™) advantages
  - Minimal effect on PCO_2
  - Minimal overcorrection risk
  - Less Na than $NaHCO_3$
  - No tissue irritability

O_2 Induced Hypercapnia

- COPD patients who are CO_2 retainers
- During exacerbations
- Underlying causes
  - VQ Mismatch: increased VDA
  - Haldane effect: increased release of CO_2 from Hb
- Maintain SPO_2 < 92%

See links below for abstract on O_2-induced hypercapnia

Summary & Review

- CO_2 transport & balance
  - Balance: production vs. excretion
  - Transport forms & mechanisms
  - Causes of abnormal PCO_2

Summary & Review

- Acid-base balance
  - Regulators
  - Parameters & normal values
  - Abnormalities
    - Values
    - Causes
    - Management
  - Acid-base algorithm

Summary & Review

- Buffer therapy
  - $NaHCO_3$ - Metabolic acidemia
  - Carbicarb
  - THAM™ - metabolic & respiratory acidemia
  - Trometamol (Tribonat™)
    - Best of both
    - Not available in USA

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