Chapter 8: Laboratory Analysis and Diagnostic Studies

Lecture

I. Introduction

Time: 5 Minutes
Slides: 1–3
Lecture/Discussion

A. Laboratory tests
   1. May include laboratory examinations of the patient's blood, urine, cerebrospinal fluid (CSF), or other body fluid.
      a. Called "labs."
   2. Serve many purposes in critical care transport environment, requiring CCTP to:
      a. Feel comfortable with normal ranges for each lab value and associated physiologic meaning of test
      b. Understand the purpose of performing tests
         i. Should be ordered with thoughtful, evidence-based approach
         ii. Not meant to satisfy curiosity, "complete the picture" for particular test panel, or reassure concerned family or staff

II. Principles of Analysis

Time: 8 Minutes
Slides: 4–8
Lecture/Discussion

A. CCTP should always keep certain principles that guide the analysis of all laboratory values in mind.
   1. Appreciation of lab test's precision and accuracy essential to its proper use
      a. High precision:
         i. Value will be the same each time
         ii. Measure of tolerance or variation within multiple measurements
         iii. Does not reflect how well measurements compare with true value
      b. Accuracy: Value (or average value) conforms to standard or true value.
      c. Scientists strive for tests that are precise and accurate.
   2. Awareness that laboratory tests have differing levels of sensitivity and specificity
      a. Sensitivity: Ability of test to indicate whether person does or does not have a certain condition
         i. Highly sensitive test: Most people with the condition would have a positive result.
         ii. Low sensitivity: Many people with the condition would have a negative result.

            iii. Considered the proportion of people with target disorder who have positive test result
        b. Specificity: Proportion of people without target disorder who have negative test result
        c. D-dimer test of hypercoagulability to test for DVT example of sensitivity and specificity
            i. Sensitivity calculated by dividing number of patients with positive test result by actual number of patients with disorder (93%)
            ii. Specificity calculated by dividing number of patients with negative test result by actual number of patients without disorder (79%)
    3. Awareness that certain tests lend themselves to certain levels of analysis
        a. Qualitative assessment: Result does not identify specific level
            i. Example: Serologic blood test examining for presence or absence of hepatitis B virus
        b. Quantitative test: Indicates exact amount
        c. Semiquantitative assessment
    4. Refraining from becoming overly concerned about notion of normal versus abnormal lab values
        a. Remember, a normal range, empirically derived, represents values that 95% of healthy people would have for a particular test.
            i. Critically ill people do not fit this profile
            ii. 5% of healthy people have results outside of "healthy" range
        b. Normal range for particular lab test subjective in ED or intensive care unit context
        c. Abnormal result may be desired effect of particular treatment
        d. Do not ignore abnormal lab values, but put into context of patient's entire clinical picture
            i. Confirm abnormal findings
            ii. Check validity of test by other tests or assessment methods
            iii. Re-examine validity if other tests do not support abnormal results
            iv. Consider technical errors as a factor
    5. Understand that different laboratories have different normal ranges for the same tests.
        a. Example: Three different sets of normal ranges for each test they perform
        b. Pay careful attention to normal values (indicated on report forms) when reviewing lab reports.

III. Specimen Cultures

Time: 2 Minutes

Slide: 9

Lecture/Discussion

A. Blood, urine, sputum, and other body fluid cultures provide information that is used to identify microorganisms and treat specific infections.
    1. Culture tests
        a. Example: Sputum culture for suspected respiratory infection
    2. Sensitivity test
        a. Example: To determine appropriate antibiotic for bacterial infection
    3. C and S: Culture and sensitivity

a. Usually takes 3 days for culture and sensitivity report
    i. Initial report within 24 hours
    ii. Complete, final report in 72 hours

IV. Chemistry Review

Time: 6 Minutes
Slides: 10–13
Lecture/Discussion

A. Physiology is built on the basics of chemistry and cellular biology.
  1. CCTPs should have knowledge of principles
    a. Necessary for insightful test interpretation
B. Ions
  1. Atoms that have gained or lost electrons
    a. Each electron has single, negative charge
    b. Loss of electron makes atom more positive, or with a "less negative" charge
    c. Gain of electron makes atom more negative, or with a "less positive" charge
  2. Cation: Positively charged ion
  3. Anion: Negatively charged ion
  4. Adding or deleting electrons
    a. If one electron is deleted, charge is +1; if two electrons are deleted, its charge is +2.
    b. If one electron is added, charge is –1; if two electrons are added, its charge is –2.
  5. Ionic bond: When ions of opposite charge join together
    a. Example: Sodium chloride (NaCl—table salt)
  6. Amounts expressed in moles or equivalents
    a. Mole: Unit representing 6.02×10^{23} atoms
    b. Equivalents (Eq): Measure amounts of charged particles
      i. 1 Eq equal to 1 mole of ionic charges
      ii. Example: 1 Na^{+} atom has 1 charge; 1 mole of Na^{+} atoms has 1 mole of charges (1 Eq)
      iii. Example: 1 mole of Ca^{++} has 2 moles of charges (2 Eq)
    c. Concept applies only to charged particles
      i. Uncharged molecules (proteins) electrically neutral overall
C. Osmolarity
  1. Osmotic pressure created by blood, CSF, or urine sample of interest to CCTPs
    a. Created in space divided by semipermeable membrane
      i. Based on differences in concentrations of solutes found in solutions on either side of membrane
    b. Osmolarity
      i. How osmotic pressure is measured in humans
      ii. Measures amount of dissolved substance in 1 kg of water
      iii. Often mislabeled as osmolality
      iv. Osmole (Osm): Unit of measurement; pressure created by 1 mole of particles in solution
    c. Osmolality
      i. Measures amount of dissolved substance in 1 L of water
  2. Osmotic pressure depends only on number of particles in fluid, not size of the particles

        a. Example: Single protein or sugar molecule induces same osmotic pressure as single ion of sodium (Na^+)
    3. Concentration
        a. Amount of substance present in given volume of fluid
        b. Most concentrations incredibly small:
            i. Units of 1/1,000 (milli-) include: millimoles (mmol), milliequivalents (mEq), milliosmoles (mOsm)
    4. Reporting laboratory values
        a. Conventional units
            i. Example: Milliequivalents per liter
        b. Système International d'Unités (SI units)
            i. Example: Millimoles per liter
        c. Many laboratories use both
        d. Make sure reported units of measure are same as units of measure given in normal range
    5. Variations in normal ranges exist
        a. Among laboratories
        b. From one instrument manufacturer to another
        c. CCTP should know normal ranges for tests used in critical care

V. Biochemistry Review

Time: 2 Minutes
Slide: 14
Lecture/Discussion

A. Examining proteins and enzymes in serum samples is also critical to determining condition of patient
    1. The human body contains thousands of different kinds of proteins.
    2. Enzymes are proteins that act as catalysts for biochemical reactions.
        a. Formation of one biologic substance from another may proceed slowly when just two substances are present.
            i. Adding appropriate enzyme may cause the reaction rate to increase many times.
            ii. Methods of measuring enzyme levels rely on this basic catalytic principle.
        b. Calculating amount of enzyme present involves:
            i. Knowing beginning amount of substrate
            ii. Knowing amount of product produced
            iii. Assuming normal enzyme function
        c. Function measured in units per liter (U/L)
            i. Equals the amount of enzyme that catalyzes 1 micromole (μmol) of substrate per minute

VI. Lab Profiles

Time: 39 Minutes
Slides: 15–40

Lecture/Discussion

A. Groups of related tests can be performed as a single unit, called a panel (or profile).
    1. Single unit comprising related tests often named for tests' common link
        a. Example: Liver panel consists of a set of tests that examine liver function
        b. Written as matrix in patient's hospital chart
B. Lab values in blood samples
    1. One of the most basic, fundamental assessments done in ED or intensive care unit.
        a. Basic metabolic panel (or Chem-7)
    2. Sodium (Na^+)
        a. Major extracellular ion
            i. Serum concentration in healthy person: 136 to 142 mEq/L (mmol/L)
            ii. Intracellular concentrations: 3 to 20 mEq/L
        b. Serum sodium level may change dramatically.
            i. Primarily due to changes in extracellular water concentrations
            ii. Convenient marker for patient's fluid status
            iii. One of key components of serum osmolality calculation
            iv. Abnormal level will not manifest with ECG changes, but revolve around neurologic sequelae owing to changes in osmolality
            v. Elevated levels not uncommon in patients undergoing critical care transport
        c. Low levels (hyponatremia)
            i. Abnormally low level of sodium in blood
            ii. Often results from excess of free water or excessive sodium depletion
            iii. Congestive heart failure, renal failure, liver disease, diuretic therapy
            iv. To correct, slower is better: 0.5 mEq/L per hour
        d. Elevated levels
            i. Found in patients with traumatic brain injuries; may often exceed 170 mEq/L
        e. Patient care for high or low levels:
            i. Monitor intake and output, including oral and IV input
            ii. Level of less than 125 mEq/L can result in behavioral changes, confusion, delirium, increased respiratory rate, muscle twitching, increased intracranial pressure, and cardiac abnormalities
            iii. Increased sodium levels can cause fluid retention and cardiac abnormalities
    3. Potassium (K^+)
        a. Major intracellular cation
            i. Extracellular concentration normally 3.5 to 5.0 mEq/L
        b. Hyperkalemia (abnormally high K^+ level)
            i. Abnormally high level
            ii. Can cause cardiac arrhythmias
            iii. Level of 5.5 to 6.5 mEq/L can result in classic peaked T waves, with flattened P waves occurring when the potassium level exceeds 7.0 mEq/L
            iv. Exacerbated by derangements in other electrolytes
            v. May be caused by: excessive potassium supplementation, intracellular to extracellular fluid shifts with cellular lysis, drug administration, metabolic acidosis, decreased excretion (acute renal failure)
            vi. Be aware that many abnormally high potassium levels are actually reported in error

vii. May cause: cardiac abnormalities (atrioventricular and intraventricular blocks), atrial arrest if level reaches 9 mEq/L

c. Hypokalemia (abnormally low K^+ level)
   i. Causes: cellular shifts, increased potassium excretion
   ii. May lead to arrhythmias and ECG changes in older patients
   iii. May also cause muscle pain, hyporeflexia, nausea, vomiting, orthostatic hypotension

4. Chloride (Cl^-)
   a. Major extracellular anion
      i. Single electrical charge offsets positive charge of Na^+ and K^+
      ii. Maintains electrical neutrality within body
   b. Healthy range: 96 to 106 mEq/L
   c. Hypochloremia (abnormally low level)
      i. May cause impending renal dysfunction
      ii. Patients receiving diuretic therapy
   d. Hyperchloremia (abnormally high level)
      i. May be exhibited by patients with excess diuresis
      ii. May cause: circumoral numbness and tingling, muscle hypertonicity, decreased respiratory rate and depth, possible complaints of nervousness, signs of central nervous system stimulation
   e. Mimic sodium levels
5. Carbon dioxide (CO_2)
   a. Venous bicarbonate level is most basic indication of acid-base status
      i. Indicates the amount of bicarbonate (HCO_3) in venous sample
   b. Carbon dioxide and bicarbonate are equilibrium
      i. CO_2 is a gas; express value as partial pressure
      ii. HCO_3 is an ion; express as a concentration
   c. Low levels may indicate
      i. Metabolic acidosis
      ii. Respiratory alkalosis
   d. Elevated levels could indicate
      i. Metabolic alkalosis
      ii. Respiratory acidosis
   e. Normal HCO_3 value: 21 to 28 mEq/L
   f. Normal CO_2 value: 22 to 28 mEq/L
6. Blood urea nitrogen (BUN)
   a. Product of protein catabolism
      i. Related to the amount of protein intake, protein metabolism, and rate of excretion
   b. Useful marker for adequate kidney function
   c. Normal range: 8 to 23 mg/dL
   d. Levels may increase with age: 28 to 35 mg/dL
   e. Monitor values over 40 mg/dL
   f. Elevated levels may occur with:
      i. Decreased renal function
      ii. High-protein diet
      iii. Presence of a high-protein catabolism state (burns and crush injuries)
7. Creatinine
   a. Major storehouse of intramuscular high-energy phosphate
   b. Degraded to creatinine (Cr) at relatively steady rate by muscles
      i. Rate varies by only 10% per person

  c. Used to assess kidney function
    i. Filtered by kidneys; excreted in urine
    ii. Urine function decrease causes levels to rise
    iii. Normal: 0.6 to 1.2 mg/dL
  d. An abnormal serum level does not indicate disease or its cause, but does indicate some level of decreased renal function
  e. Care must be taken when a geriatric patient has a Cr level slightly higher than the upper normal value
    i. Near 1.5 mg/dL
  f. May cause permanent damage to kidneys
    i. Lifetime dialysis
    ii. Kidney transplantation
  g. Creatinine clearance is the most accurate measure of glomerular filtration rate.
8. Glucose
  a. Most important carbohydrate in body
  b. Assessed in the field with point-of-care testing device
    i. May be performed on unconscious or semiconscious patients
  c. Normal: 70 to 110 mg/dL
  d. CCTP work to maintain normal level
    i. Hypovolemic shock
  e. High levels can lead to:
    i. Coma
    ii. Death
  f. Low levels
    i. Easier to detect (dizziness, nausea)
    ii. Can lead to unconsciousness
9. Total calcium
  a. Essential electrolytes
    i. Range of functions: Muscle contraction to intracellular signal transduction
  b. Three states:
    i. Free (47%)
    ii. Chelated
    iii. Bound to proteins (43%)
  c. Sum of all calcium in the body is expressed as the total calcium level (Ca^{++}_{TOT})
    i. Normal range: 8.2 to 10.2 mg/dL
  d. High levels:
    i. Hyperparathyroidism
    ii. Parathyroidsecreting tumors
  e. Low levels:
    i. Renal insufficiency
    ii. Hypomagnesemia
    iii. Hyperphosphatemia
    iv. Massive blood transfusion
    v. Decreased parathyroid hormone states
10. Ionized calcium
  a. Only calcium that is not bound or chelated is physiologically active
  b. Assess free calcium in states where there are altered fractions of bound or chelated calcium
    i. Renal failure or nephrotic syndrome (hypoalbuminemia)
    ii. Acid-base derangements (acidosis)

            iii. Decreases or elevations in chelating compounds (citrate, bicarbonate, lactate, phosphate, sulfate)
        c. Normal range: 4.60 to 5.08 mg/dL
        d. Low levels:
            i. Serious arrhythmias, especially in prolonged cardiac arrest
        e. Calcium administration may be warranted for:
            i. Hyperkalemia
            ii. Hypocalcemia
            iii. Toxic levels of calcium-channel blockers
    11. Magnesium (Mg)
        a. Affected by many body systems
            i. GI and endocrine systems
        b. Normal: 1.3 to 2.1 mEq/L
        c. High levels unusual, caused by:
            i. Renal defects
            ii. Severe dehydration
            iii. Overadministration of Mg
            iv. Untreated diabetic coma
            v. Aspiration of sea water
        d. Low levels (more common)
            i. GI distress
            ii. Vomiting and diarrhea
            iii. Hepatic cirrhosis
            iv. Pancreatitis
C. Blood components
    1. Complete blood count (CBC) test
    2. Hematocrit (Hct)
        a. High sensitivity, low specificity
        b. Percentage of formed elements (cells) in venous blood sample
            i. Example: Hct value of 45% indicates sample consists of 45% cells or cellular debris, and 55% plasma
        c. Normal range: 41% to 50%
    3. Hemoglobin (Hg or Hb)
        a. Protein that carries oxygen to cells and carbon dioxide back to lungs
        b. Levels vary by gender
            i. Males: 135 to 175 g/L (14.0 to 17.5 g/dL)
            ii. Females: 120 to 160 g/L (12.0 to 16.0 g/dL)
        c. Elevated levels
            i. People with hemoconcentration caused by dehydration, burns, or excessive vomiting
        d. Low levels
            i. Of more concern
            ii. Most types of anemia (microcytic, normocytic, and macrocytic)
    4. Carboxyhemoglobin (COHb)
        a. Normal levels: Not to exceed 0.02 (2%) based on amount of total hemoglobin
        b. Assessment used to:
            i. Confirming carbon monoxide poisoning
            ii. Guide therapy
        c. Use caution when assessing in smokers
            i. Have higher baseline
    5. Red blood cell (RBC) count

  a. Number of erythrocytes per microliter (µL) of blood
  b. Normal range: 3.9 to 5.5 × 106/µL
    i. Abnormal number does not always indicate disease
  c. High levels
    i. Patients with elevated white blood cell counts may have erroneously high RBC level
  d. Low levels
    i. All types of anemia

6. White blood cell (WBC) count
  a. Measures total number of leukocytes in blood
  b. Normal range: Between 4,500/µL and 11,000/µL
  c. Low levels
    i. Anemias (aplastic anemia)
    ii. Vitamin deficiencies
    iii. Sepsis
  d. High levels (leukocytosis)
    i. Inflammation or infection
    ii. Malignancies (leukemia, lymphoma)
    iii. Vascular conditions (pulmonary embolism, AMI, DVT
    iv. Steroid administration
    v. Stress from trauma
7. Platelet count (Plt)
  a. Assesses patient's coagulation status
  b. Normal range for whole blood sample: 150 to 350 × 103/µL
  c. Elevated levels
    i. Myeloproliferative disorders (polycythemia, chronic myelogenous leukemia)
  d. Low levels
    i. Thrombocytopenia caused by splenomegaly, disseminated intravascular coagulation, high circulating levels of platelet antibodies
8. Proteins
  a. Total protein
    i. Examines total quantity of protein in blood sample
    ii. Normal range: 6.0 to 8.0 g/dL
    iii. Fluctuations in serum albumin levels cause variations
  b. Albumin
    i. Acts as transport protein for free fatty acids, bilirubin, hormones, drugs
    ii. Acts as free radical scavenger
    iii. Serves as main source (70%) of protein-generated oncotic pressure
    iv. Normal range: 3.5 to 5.0 g/dL
    v. Low levels: increased catabolism of protein, decreased production, edema, liver disease or damage, hypoalbuminemia can lead to acute respiratory distress syndrome
    vi. High levels: dehydration, not pathologic
  c. C-reactive protein (CRP)
    i. Indicator of inflammation (rises 4 to 6 hours after injury)
    ii. Normal range: 0.08 to 3.1 mg/L
    iii. Level above 10 mg/L indicates significant inflammatory disease
  d. Myoglobin
    i. Oxygen-carrying heme protein present in high concentrations in cytoplasm of cardiac and skeletal muscles

   ii. Levels may increase in cardiac patients
   iii. Negative myoglobin result used to rule out myocardial infarction
   iv. Normal range: 19 to 92 µg/L

e. Lactate dehydrogenase (LDH)
   i. Not sensitive or specific for any disease
   ii. Normal range of LDH: 100 to 200 U/L
   iii. Analysis of isoenzyme forms (LD1 to LD5) useful in clinical setting; aid in diagnosis of cellular damage
   iv. Calculate the LDH1/LDH2 ratio
   v. The normal range for LD1 is 17% to 27%; for LD2, 27% to 37%
   vi. Ratio over 85% indicates possible AMI
   vii. Also be helpful in assisting with the diagnosis of *Pneumocystis carinii* pneumonia and determining severity of pancreatitis

f. Creatine kinase (CK)
   i. Found in muscle, liver, lung, GI, brain, kidney, spleen tissues
   ii. Released into vascular space if any of these tissues damaged
   iii. Elevated levels: Muscle damage, which may or may not be specific to AMI
   iv. Normal range for total CK level: 40 to 150 U/L
   v. MB fraction of CK (CK-MB) refers primarily to CK in heart muscle
   vi. The normal range for CK-MB level: 0 to 7 ng/mL

g. Troponin I
   i. Key protein involved in muscle contraction
   ii. Has three subunits: T, C, I, each with three separate isoforms
   iii. One isoform found only in cardiac muscle
   iv. Normal range for cardiac troponin I (cTnI): 0 to 0.04 ng/mL, but elevations following myocardial injury detectable in serum sample after 4 hours; 6 hours following AMI; levels still detectable 5 to 7 days later
   v. Also useful to detect severe unstable angina
   vi. Normal values for various troponins depend on test method, but general normal range: 0 to 0.4 ng/mL for troponin I; 0 to 0.1 ng/mL for troponin T

h. B-type natriuretic peptide (BNP)
   i. Indicative of abnormal ventricular function, congestive heart failure if outside of normal range
   ii. Normal range: less than 167 pg/mL

i. Aspartate aminotransferase (AST)
   i. An elevated liver function test (LFT) that measures enzymes normally appearing in liver cells
   ii. Previously called SGOT
   iii. Found in liver, skeletal muscle, brain, RBCs, and heart
   iv. Normal range: 10 to 30 U/L
   v. Elevated levels seen in liver damage, especially acute hepatitis or biliary tract obstruction, alcoholic cirrhosis, hepatitis, cancer
   vi. Low levels of no consequence

j. Alanine aminotransferase (ALT)
   i. Previously called SGPT
   ii. Enzyme found in liver, kidney, skeletal muscle, heart
   iii. Normal range: 10 to 40 U/L
   iv. High levels found in same conditions as with AST
   v. Low levels of no consequence

k. Total bilirubin
    i. By-product of RBCs metabolization
    ii. Indirect bilirubin: Not water soluble
    iii. Direct bilirubin: Conjugated in liver, excreted in bile
    iv. Normal range: 0.3 to 1.2 mg/dL
    v. Elevated levels may indicate liver disease, biliary tract obstruction, RBC hemolysis
l. Direct bilirubin
    i. Normal values for direct and indirect bilirubin: 0.1 to 0.3 mg/dL and 0.2 to 0.9 mg/dL, respectively
    ii. Bilirubin may be fractionated to indicate respective levels of unconjugated (indirect) and conjugated (direct) bilirubin
m. Alkaline phosphatase
    i. Found in almost all body tissues
    ii. Manufactured by bone, liver, intestine, placenta
    iii. Essential for proper digestion and absorption through mucous membrane of GI tract
    iv. Clinically useful for testing liver function and diagnosing common bile duct obstruction
    v. Normal range: 30 to 120 U/L
n. Amylase
    i. Produced by the salivary glands and the pancreas, and in smaller amounts by ovaries, small and large bowels, and skeletal muscle
    ii. Normal range: 27 to 131 U/L
    iii. Test to detect: pancreatic insufficiency or damage, (pancreatitis, pancreatic cancer, diabetic ketoacidosis), bile duct obstructions, head trauma
    iv. Low amylase levels seen in people with cystic fibrosis
o. Lipase
    i. Normal range: 31 to 186 U/L
    ii. Test of lipase levels have poor sensitivity in terms of identifying chronic pancreatitis and pancreatic cancer, elevated levels are often seen with both diseases
    iii. Levels prone to elevation in bile duct obstruction or biliary disease

D. Coagulation
1. Assessment of the coagulation system involves looking at the intrinsic and extrinsic pathways of the coagulation cascade.
    a. Begins with activation of factor XII, then factors XI and IX, ultimately resulting in activation of factor X and initiating the common pathway of coagulation
    b. Extrinsic pathway following tissue injury begins with tissue factor and factor VII, and leads to activation of factor X, initiating common pathway of coagulation
    c. Fibrin eventually produced, resulting in a clot
    d. Enzymes involved in coagulation are synthesized in the liver
        i. Some clinicians consider these enzymes to be the true “liver function tests”
2. Prothrombin time (PT)
    a. Rate of conversion of prothrombin to thrombin in blood sample
    b. Represents function of extrinsic pathway
    c. Normal range: 10 to 13 seconds
    d. Increased in liver disease or warfarin therapy
    e. Decreased with low levels of vitamin K, in DIC, and after massive transfusions

3. Activated partial thromboplastin time (aPTT)
    a. Indicates health of the intrinsic and common pathways of coagulation system
    b. Elevated levels: hemophilia A, hemophilia B, von Willebrand disease
    c. Used to assess for DIC (grossly elevated from normal range)
    d. Used to assess for the correct therapeutic effect of heparin
    e. Normal range: 25 to 40 seconds
4. International normalized ratio (INR)
    a. Normalizing index that uses international sensitivity index
    b. Normal range: 0.9 to 1.3
    c. Increased ratios seen in same diseases in which PT is increased and in persons receiving anticoagulants
    d. Often used to target anticoagulant therapy
        i. Typical anticoagulation target for INR often ranges from 2.0 to 3.0

E. Lactate
1. Venous lactate level is a popular indicator of patient's tissue and end-organ perfusion and oxygenation.
    a. Perfusion and oxygenation of cells, tissues, end organs considered inadequate if serum lactate level is more than normal (normal range, 5.0 to 15 mg/dL).
        i. Nonspecific
        ii. Lactate level slow to respond to adequate resuscitation with fluid, oxygen

F. Osmolality
1. Normal range: 275 to 295 mOsm/kg
    a. Patient with low level of free water (dry); osmolality high because there will be more particulate matter for a given volume of serum
    b. Patient with high level of water ("wet"); low osmolality

G. Ethanol (EtOH)
1. Not normal physiologic product in body, result of alcohol consumption
    a. Legal intoxication in most states: More than 80 mg/dL
2. Refer to their protocols and guidelines before drawing sample

H. Calculated values
1. AST:ALT
    a. Determines cause of liver dysfunction
2. BUN:Creatinine
    a. Determines cause of increased levels of two metabolites that indicate renal pathology: BUN and Cr
3. Anion gap (AG)
    a. Normal range: 8 to 16 mEq/L
    b. Increase indicates that unmeasured anions (such as in lactic acid) are present

VII. Blood Gases

Time: 12 Minutes
Slides: 41–48
Lecture/Discussion

A. Typical arterial blood gas (ABG) panel
1. Assesses patient's acid-base status (pH) based on CO_2 tension ($PaCO_2$), bicarbonate level, and base excess (BE)

2. Measures patient's oxygen status, oxygen tension (PaO_2), and oxygen saturation (SaO_2)

B. Acid-base status
   1. Hydrogen ion concentration (PH)
      a. Quantifies the amount of unbuffered H^+ present
      b. Related to the amount of CO_2 and the amount of HCO
      c. Increase in PCO_2 results in smaller fraction component, causing lower pH (acidic)
      d. Increase in the HCO_3^- will cause a larger fraction and result in pH increase (alkaline)
      e. Decreased PCO_2 will increase pH; decreased HCO_3^- will decrease pH
      f. Normal range for arterial pH: 7.35 to 7.45
      g. Normal range for venous pH: 7.31 to 7.41
      h. Normal physiologic reactions may be drastically affected with extreme variations
   2. Partial pressure of carbon dioxide
      a. Considered the "respiratory" component of blood gas analysis
      b. Respiratory derangement present either above or below the normal range of 35 to 45 mm Hg
         i. Primary: Respiratory acidosis or alkalosis
         ii. Secondary: Compensated metabolic acidosis or alkalosis
      c. Elevations above sea level increase respiratory rate as result of lower partial pressure of oxygen
         i. Lower-than-normal $PaCO_2$ in blood
   3. Bicarbonate
      a. Represents the metabolic component
      b. If there is a metabolic aspect to an acidosis- or alkalosis-related condition, a corresponding derangement will be seen
      c. Normal range: 21 to 28 mEq/L
      d. Administration of intravenous bicarbonate to treat metabolic acidosis controversial
         i. Not generally indicated unless underlying cause of acidosis cannot be corrected or the pH is less than 7.20
   4. Base excess (BE)
      a. Measurement of metabolic derangement that is included as part of the ABG panel
      b. Also known as base deficit (BD) because value can be either positive number (excess) or negative value (deficit)
         i. Healthy people do not have appreciable BE
      c. Measured in units of mEq/L
         i. Normal range of $^{-}2$ to $^{+}3$
         ii. Negative: excess amount of acid or lack of base
         iii. Positive: deficient amount of acid or an excess amount of base
      d. Some clinicians use base excess to assess for proper fluid resuscitation

C. Oxygenation status
   1. Partial pressure of oxygen
      a. Measures amount of oxygen dissolved in blood
      b. Normal range: 80 to 100 mm Hg
      c. Most important is for to remain within normal range
      d. Hypoxia: Falls below 80 mm Hg
      e. Lower levels in the blood at elevations above sea level
   2. Oxygen saturation
      a. Measures percentage of potential oxygen-binding sites on hemoglobin occupied by oxygen molecules

b. Oxygen saturation measured transcutaneously using saturation monitor and probe differs from oxygen saturation calculated from arterial or venous blood sample reported on blood gas report
c. Normal value for measured SaO_2: greater than 93%
d. Calculated saturation from blood gas values can give falsely elevated saturation when abnormal hemoglobin variants, such as carboxyhemoglobin and methemoglobin, are present in sample

D. Obtaining an arterial blood sample
1. Review Skill Drill 8-1: Obtaining an Arterial Blood Sample

VIII. Blood Group Testing

Time: 3 Minutes
Slides: 49–50
Lecture/Discussion

A. Blood typing is done to determine the blood group according to the ABO system and other classification systems.
1. ABO system based on antigen groups that cause largest humoral response
   a. Four result from two primary antigens, A and B:
      i. A, B, AB, O
   b. Type A carries A antigen
   c. Type B carries B antigen
   d. Type AB carries both antigens
      i. Universal recipients
   e. Type O carries neither antigen
      i. Universal donors
   f. People with any blood type can develop an immune response if they receive large amounts of unmatched blood
2. Rh antigens found in all blood types
   a. Rh antigen D (Rh factor) important in immune responses
      i. Rh positive means person has this antigen
      ii. Rh negative means person does not have the antigen
   b. Majority of population is Rh positive
   c. Rh-negative patient who receives Rh positive blood transfusion may have immune response reaction (anaphylaxis, anaphylactic shock)
      i. Rh-negative woman receiving Rh-positive blood will develop antigens that can harm future pregnancies
   d. Most patients needing blood products are given type O–negative blood until typing and crossmatching are done.

IX. Obtaining a Venous Blood Sample

Time: 5 Minutes
Slides: 51–53
Lecture/Discussion

A. Ideally complete during baseline evaluation of patient, before administering any IV fluids or medications
    1. Some antibiotics require peak and trough be monitored at certain times.
        a. Samples for serial levels of CK-MB and troponins
        b. PT and aPTT testing
    2. Use another extremity if patient has IV line and receiving fluids, medications
        a. If lines in both, use one without the medications
        b. Stop flow of fluid or medication immediately prior to obtaining blood sample to avoid contamination with infusate
B. Blood tube usage
    1. Selected primarily for preservatives or lack of preservatives they contain
        a. Most laboratories have specific requests they will communicate to CCTP

X. Urine Lab Values

Time: 6 Minutes
Slides: 54–57
Lecture/Discussion

A. Urinalysis (UA) involves performing various laboratory tests (some of the same performed on blood samples) on a patient's urine.
    1. Range from simple (color) to complex (specific gravity)
    2. Detect drugs for hours, days, or weeks after use of drug
        a. Toxic levels of selected substances
B. Color
    1. Simple test that notes urine's color:
        a. Yellow, pale, clear, and so on
    2. Function of concentration
        a. More concentrated urine darker yellow
    3. Particulates can also affect
        a. Blood or damaged glomeruli or renal tubular: reddish
        b. Protein: brown or tea-colored
            i. Hallmark sign of rhabdomyolysis
C. Appearance
    1. Categorized as clear or turbid
        a. Turbidity can be indicative of bladder infection
D. Specific gravity
    1. Chemical property of a fluid that relates its density to density of water.
        a. Distilled water: Specific gravity of 1
        b. Fluid denser than water: Specific gravity greater than 1
    2. Urine
        a. More concentrated urine samples are denser with higher specific gravity
        b. Diluted urine samples have low specific gravity
    3. Numerous factors can affect the kidney's ability to concentrate the urine, including:
        a. Low levels of antidiuretic hormone secreted from pituitary gland causing diabetes insipidus
        b. Glomerulonephritis
        c. Pyelonephritis
    4. Normal range: 1.003 to 1.035

a. In a setting of impaired ability to concentrate urine, specific gravity may approach 1.001

E. pH
  1. Useful marker for metabolic acidosis.
  2. Urine pH has relatively wide normal range: 4.5 to 8.0
     a. Patients with acidic urine often have large amounts of unbuffered acid
     b. Salt wasting may also occur as body excretes positive ions to counteract negatively charged acid salt of lactate or keto acetate
  3. Four types of renal tubule acidosis (RTA) may induce inability to excrete
     a. CCTPs should be able to identify presence of RTA:
        i. Arterial pH of less than 7.35
        ii. Urine pH of greater than 6.0
     b. Causes wasting of potassium and magnesium

F. Glucose
  1. Presence of glucose (glycosuria) is almost always indicative of elevated serum glucose levels.
     a. Value is 0 in healthy people
     b. Amount graded on scale of mild to severe: $^{+}1$, $^{+}2$, $^{+}3$, $^{+}4$
  2. May signal:
     a. Ineffective insulin production or use (diabetes mellitus)
     b. Result from administration of a carbohydrate-containing IV fluid
     c. Context of patient will dictate when value outside normal range is pathologic

G. Ketone bodies
  1. Describes a number (typically three) of organic products:
     a. Acetoacidic acid
     b. Acetone
     c. Beta-betahydroxybutyric acid
  2. Acetoacidic acid and beta-hydroxybutyric acid are keto acids that result from poorly controlled diabetes mellitus
     a. Presence of in urine can help identify
  3. Other causes of ketonuria include:
     a. Alcoholic ketoacidosis
     b. Starvation ketosis
  4. Grading level scale of mild to severe: $^{+}1$, $^{+}2$, $^{+}3$, $^{+}4$

H. Protein
  1. Normal reference value in qualitative test would be negative (or not detectable)
  2. Presence of may indicate kidney diseases
     a. Renal causes:
        i. Glomerulonephritis
        ii. Polycystic kidneys
        iii. Diabetic nephropathy
        iv. Toxic nephropathy
        v. Nephrosclerosis
        vi. Nephritic syndrome
     b. Extrarenal causes:
        i. Preeclampsia
        ii. Multiple myeloma
        iii. Urinary tract disease
        iv. Amyloid disease
        v. Systemic lupus erythematosus
        vi. Congestive heart failure

vii. Constrictive pericarditis

I. Blood and hemoglobin
1. Presence of blood (hemoglobinuria) highly suggestive of kidney or urinary tract damage
    a. Often indicates traumatic passage of RBCs through collecting ducts, urinary bladder, or urinary tract
    b. Filtering of serum hemoglobin during hemolytic transfusion reactions or certain blood disorders
        i. Hemolytic anemia
2. Presence of RBCs (hematuria) may indicate presence of glomerular membrane or urinary tract disease caused by:
    a. Infectious processes (commonly from urinary tract infections)
    b. Neoplasms
    c. Ureterolithiasis
    d. Trauma
3. Presence of hemoglobin without presence of RBCs can indicate rhabdomyolysis
4. Quantitative analysis of urine performed

XI. Cerebrospinal Fluid

Time: 3 Minutes
Slides: 58–59
Lecture/Discussion

A. Obtained by lumbar puncture
1. Used to detect:
    a. Increased intracranial pressure
    b. Diabetic coma
    c. Diabetes
    d. Multiple sclerosis
    e. Guillain-Barré syndrome
    f. Bacterial meningitis
    g. Fungal meningitis
2. Normal results:
    a. Pressure: 50 to 180 mm H2O
    b. Appearance: clear, colorless
    c. Total protein: 10 to 45 mg/100 mL
    d. Glucose: 50 to 80/100 mL
    e. Cell count: 0 to 5 WBCs, no RBCs
    f. Chloride: 110 to 125 mEq/L

XII. Common Errors in Specimen Collection

Time: 2 Minutes
Slide: 60
Lecture/Discussion

A. Incorrect patient identification and the mislabeling of samples are the most common specimen collection errors.
B. Two of the most common problems associated with any specimen collection in the field are improper technique or handling and improper labeling.
   1. Resolve improper labeling by placing minimal required information on label for sample, including:
      a. Patient's name and date of birth
      b. Date and time specimen was collected
      c. CCTP's name or initials
      d. Patient identification number or last four digits of patient's Social Security number
   2. Improper technique or handling can be difficult to address, especially in the field setting, because:
      a. Extreme temperatures can affect optimal processing and results
      b. Trauma to blood specimens may create hemolyzed sample
      c. Fluids or medication patient receiving may interfere with obtaining "clean" sample
      d. Particular laboratories may require samples to be supplied in specific tubes or containers

XIII. Diagnostic Imaging

Time: 6 Minutes
Slides: 61–63
Lecture/Discussion

A. CCTP should be familiar with these studies and be able to perform basic interpretation for obvious abnormalities, such as long-bone fractures, masses, and catheter placements.
   1. Have a system and use it every time to prevent overlooking findings
   2. Extensive interpretation beyond scope of book
B. Standard radiographs
   1. Rapidly obtained and used for quick diagnostics in patient care
   2. Typically obtained in a lateral or anteroposterior (AP) view
   3. Can provide confirmation of:
      a. Endotracheal tube placement
      b. Cervical fractures
      c. Chest interpretations
      d. Most major bone fractures
C. Computed tomography (CT) or cat scanning
   1. Provides cross-sectional images of body structures in the body plane
   2. Commonly used when necessary to evaluate different characteristics of tissues, bones, organs
      a. Views or "slices" can pick up abnormalities not seen with traditional plain radiography
   3. Can reveal conditions such as:
      a. Aortic dissection
      b. Lung injuries
      c. Abdominal organ injuries

        d. Fractures
        e. Pulmonary emboli
        f. Pleural effusions
        g. Acute respiratory distress syndrome
    4. When transporting a critically ill patient who has had a recent CT scan, CCTP should attempt to obtain a printed or electronic copy to expedite care on arrival at receiving center.
D. Magnetic resonance imaging (MRI)
    1. Diagnostic imaging technique most commonly used to visualize internal structure and function of body
        a. Provides greater contrast of different soft tissues than CT scan
        b. Patient not exposed to radiation
    2. Useful when performed:
        a. On brain
        b. On spinal cord
        c. In musculoskeletal, cardiovascular, oncologic imaging
    3. May be limited by:
        a. Patient's size
        b. Patient's ability to tolerate enclosed, "tunnel" environment
    4. Safety precautions required
        a. Keep equipment and other metals away from control area
E. Ultrasonography
    1. Advantages:
        a. Does not expose patient to radiation
        b. Portable
    2. Typically used for:
        a. Obstetrics and gynecology
        b. Abdominal diagnostics
        c. Blood-flow studies and cardiac diagnostics

