Anatomy and Physiology Learning Outcomes

Revised Fall 2019

HAPS Anatomy & Physiology Learning Outcomes
MODULE A: Body Plan & Organization

Topic from HAPS Guidelines (in bold font)
Learning Outcomes (indented, regular font)[1]

1. Anatomical position
1. Describe the human body in anatomical position.
2. Describe how to use the terms right and left in anatomical reference.

2. Body planes and sections
1. Identify and define the anatomic planes in which a body might be viewed.

3. Body cavities and regions
1. Identify and describe the location of the body cavities and the major organs found in each cavity.
2. List and describe the location of the major anatomical regions of the body.
3. Identify and describe the location of the four abdominopelvic quadrants and the nine abdominopelvic regions, and the major structures found in each.

4. Directional terms
1. List and define the major directional terms used in anatomy.
2. Describe the location of body structures, using appropriate directional terminology.

5. Basic terminology
1. Define the terms anatomy and physiology.
2. Give specific examples to show the interrelationship between anatomy and physiology.
3. Describe the location of structures of the body, using basic regional and systemic terminology.

6. Levels of organization
1. Describe, in order from simplest to most complex, the major levels of organization in the human organism.
2. Give an example of each level of organization.

7. Survey of body systems
1. List the organ systems of the human body and their major components.
2. Describe the major functions of each organ system.

[1] An asterisk (*) preceding a learning outcome designates it as an optional, advanced learning outcome. The HAPS A&P Comprehensive Exam does not address these optional learning outcomes.

HAPS Anatomy & Physiology Learning Outcomes
MODULE B: Homeostasis

Topic from HAPS Guidelines (in bold font)
Learning Outcomes (indented, regular font)[2]

1. Definition

1. Define homeostasis.
2. Define the following terms as they relate to homeostasis: setpoint, variable, receptor (sensor), effector (target), and control (integrating) center.
3. List the main physiological variables for which the body attempts to maintain homeostasis.
4. *Explain the difference between a regulated variable and a controlled variable.
5. Define the law of mass balance and relate it to body homeostasis.
6. Compare and contrast equilibrium and steady-state.

2. General types of homeostatic mechanisms

1. List the steps in a response pathway, starting with the stimulus and ending with the response.
2. List the steps in a feedback mechanism (loop) and explain the function of each step.
3. Compare and contrast positive and negative feedback in terms of the relationship between stimulus and response, and describe examples of each.
4. Explain why negative feedback is the most common mechanism used to maintain homeostasis.
5. Describe a feedforward (anticipatory) response, how it helps maintain homeostasis, and an example of a feedforward response.

[2] An asterisk (*) preceding a learning outcome designates it as an optional, advanced learning outcome. The HAPS A&P Comprehensive Exam does not address these optional learning outcomes.

HAPS Anatomy & Physiology Learning Outcomes
MODULE C: Chemistry & Cell Biology

Topic from HAPS Guidelines (in bold font)
Learning Outcomes (indented, regular font)[3]

Note: This module is provided for A&P courses that do not have a prerequisite class which includes chemistry and cell biology. Content covered by required prerequisite courses does not need to be repeated in Anatomy & Physiology.

1. Atoms and molecules

1. Compare and contrast the terms atoms, elements, molecules, and compounds.
2. Describe the charge, mass, and relative location of electrons, protons, and neutrons in an atom.
3. Relate the number of electrons in an electron shell to the atom's chemical stability and its ability to form chemical bonds.
4. Compare and contrast the terms ion, electrolyte, free radical, isotope, and radioisotope.
5. Explain how ions and isotopes are produced by changing the relative number of specific subatomic particles, using one element as an example.
6. Distinguish among the terms atomic number, mass number, and atomic weight.

2. Chemical bonding

1. Explain the mechanism of each type of chemical bond and provide biologically significant examples of each: covalent, ionic, and hydrogen bonds.
2. Compare and contrast nonpolar covalent and polar covalent bonds.
3. List the following types of bonds in order by relative strength: nonpolar covalent, polar covalent, ionic, and hydrogen bonds.

3. Inorganic compounds and solutions

1. Describe the physiologically important properties of water.
2. Compare and contrast the terms solution, solute, solvent, colloid suspension, and emulsion.
3. Define the terms salt, pH, acid, base, and buffer.
4. State the pH values for acidic, neutral, and alkaline (basic) solutions.

4. Organic compounds

1. Define the term organic molecule.
2. Explain the relationship between monomers and polymers.
3. Define and provide examples of dehydration synthesis and hydrolysis reactions.
4. Compare and contrast the general molecular structure of carbohydrates, proteins, lipids, and nucleic acids using chemical formulas.

[3] An asterisk (*) preceding a learning outcome designates it as an optional, advanced learning outcome. The HAPS A&P Comprehensive Exam does not address these optional learning outcomes.

5. Describe the building blocks of carbohydrates, proteins, lipids, and nucleic acids, and explain how these building blocks combine with themselves or other molecules to create complex molecules in each class, providing specific examples.
6. Describe the four levels of protein structure and the importance of protein shape for function.
7. Define enzyme and describe factors that affect enzyme activity.

5. Energy transfer using ATP

1. Explain the role of ATP in the cell.
2. Describe the generalized reversible reaction for ATP synthesis and the release of energy from ATP.

6. General organization of a cell

1. Describe the three main parts of a cell (plasma [cell] membrane, cytoplasm, and nucleus), and explain the general functions of each part.
2. Compare and contrast cytoplasm and cytosol.
3. Describe the structure and roles of the cytoskeleton.

7. Cellular membrane structure and function

1. Describe the chemical composition, general structure (i.e., fluid mosaic model), and properties of all cellular membranes.
2. Describe the structure of the plasma (cell) membrane, including its composition and arrangement of lipids, proteins, and carbohydrates.
3. Describe the functions of different plasma membrane proteins (e.g., structural proteins, receptor proteins, channels).

8. Mechanisms for movement of materials across plasma (cell) membranes

1. Compare and contrast intracellular fluid and extracellular fluid with respect to chemical composition and location.
2. Compare and contrast simple diffusion across membranes and facilitated diffusion in respect to their mechanisms, the type of material being moved, and the energy source for the movement.
3. Compare and contrast facilitated diffusion, primary active transport, and secondary active transport in respect to their mechanisms, the type of material being moved, and the energy source for the movement.
4. Define osmosis and explain how it differs from simple diffusion across membranes.
5. Compare and contrast osmolarity and tonicity of solutions.
6. Describe the effects of hypertonic, isotonic, and hypotonic solutions on cells.
7. Compare and contrast exocytosis, endocytosis, phagocytosis, and pinocytosis in respect to their mechanisms, the direction of movement, the type of material being moved, and the energy source for the movement.

9. Membrane potential

1. Define resting membrane potential (RMP).
2. Explain the role of ion concentration gradients and membrane permeability to ions in establishing a membrane potential.
3. Explain how sodium-potassium ATPase pumps help maintain the resting membrane potential.

10. Organelles

1. Define the term organelle.
2. Describe the structure and function of the various cellular organelles.

11. Protein synthesis

1. Define the terms genetic code, transcription, and translation.
2. Explain the process of RNA synthesis.
3. Explain the roles of tRNA, mRNA, and rRNA in protein synthesis.

12. Cellular respiration (introduction)

1. Define the term cellular respiration.
2. Explain the process by which glucose is converted through metabolic pathways to carbon dioxide and water (e.g., glycolysis, citric acid [Krebs or tricarboxylic acid] cycle, electron transport chain).

13. Cell cycle

1. Describe the general phases (e.g., G phases, S phase, cellular division) of the cell cycle.
2. Compare and contrast somatic cell division (mitosis) and reproductive cell division (meiosis).
3. Describe DNA replication.
4. Compare and contrast chromatin, chromosomes, and chromatids.
5. Describe the events that take place during mitosis and cytokinesis.

HAPS Anatomy & Physiology Learning Outcomes
MODULE D: Histology

Topic from HAPS Guidelines (in bold font)
Learning Outcomes (indented, regular font)[4]

Note: HAPS recognizes that there is a great deal of variability in length and depth of coverage of histology (microscopic anatomy). The learning outcomes listed below are for those courses that include a significant histology component in their human anatomy and physiology class.

1. **Overview of histology and tissue types**
    1. Define the term histology.
    2. List the four major tissue types.
    3. Compare and contrast the general features of the four major tissue types.

2. **Microscopic anatomy, location, and functional roles of epithelial tissue**
    1. Describe the structural characteristics common to all types of epithelia.
    2. Classify different types of epithelial tissues based on structural characteristics.
    3. Describe the microscopic anatomy, location, and function of each epithelial tissue type.
    4. Identify examples of each type of epithelial tissue.
    5. Compare and contrast exocrine and endocrine glands, structurally and functionally.
    6. Compare and contrast the different kinds of exocrine glands based on structure, method of secretion, and locations in the body.

3. **Microscopic anatomy, location, and functional roles of connective tissue**
    1. Describe mesenchyme and explain its role in the classification of all types of connective tissue.
    2. Describe the structural characteristics common to all types of connective tissue.
    3. Classify different types of connective tissue based on their structural characteristics, functions, and locations in the body.
    4. Identify examples of each type of connective tissue.

4. **Microscopic anatomy, location, and functional roles of muscle tissue**
    1. Describe the structural characteristics common to all types of muscle tissue.
    2. Classify different types of muscle tissue based on structural characteristics, functions, and locations in the body.
    3. Identify examples of each type of muscle tissue.

5. **Microscopic anatomy, location, and functional roles of nervous tissue**
    1. Recognize the cells of nervous tissue.

[4] An asterisk (*) preceding a learning outcome designates it as an optional, advanced learning outcome. The HAPS A&P Comprehensive Exam does not address these optional learning outcomes.

2. Compare and contrast neurons and glial cells with respect to cell structure and function.

6. Membranes (mucous, serous, cutaneous, and synovial)

1. Describe the structure and function of mucous, serous, cutaneous, and synovial membranes.
2. Describe locations in the body where each type of membrane can be found.

7. Intercellular connections (cell junctions)

1. Compare and contrast the types of intercellular connections (cell junctions) with respect to structure and function.

8. Tissue growth, modification, and repair

1. Define the following terms: hypertrophy, hyperplasia, atrophy, necrosis, apoptosis, metaplasia, regeneration, fibrosis, and dysplasia.
2. Describe tissue repair following an injury.

HAPS Anatomy & Physiology Learning Outcomes
MODULE E: Integumentary System

Topic from HAPS Guidelines (in bold font)
Learning Outcome (indented, regular font)[5]

1. **General composition and functions of the integumentary system and the subcutaneous layer (hypodermis or superficial fascia)**
    1. List the components of the integumentary system.
    2. Describe the general functions of the integumentary system and the subcutaneous layer.

2. **Gross and microscopic anatomy of the integument and subcutaneous layer (hypodermis or superficial fascia)**
    1. Identify and describe the tissue type making up the epidermis.
    2. Identify and describe the layers of the epidermis, indicating which are found in thin skin and which are found in thick skin.
    3. Compare and contrast thin and thick skin with respect to location and function.
    4. Describe the processes of growth and keratinization of the epidermis.
    5. Identify and describe the dermis and its layers, including the tissue types making up each dermal layer.
    6. Identify and describe the subcutaneous layer, including the tissue types.
    7. Describe the factors that contribute to skin color.

3. **Roles of specific tissue layers of skin and the subcutaneous layer (hypodermis or superficial fascia)**
    1. Describe the functions of the epidermis.
    2. Explain how each of the five layers, as well as each of the following cell types and substances, contributes to the functions of the epidermis: stem cells of the stratum basale, keratinocytes, melanocytes, epidermal dendritic (Langerhans) cells, tactile (Merkel) cells and discs, keratin, and extracellular lipids.
    3. Describe the functions of the dermis, including the specific function of each dermal layer.
    4. Describe the functions of the subcutaneous layer.
    5. Describe the thermoregulatory role played by adipose tissue in the subcutaneous layer.

4. **Structure and function of epidermal derivatives (accessory structures of the integument)**
    1. List the epidermal derivatives of the integument.
    2. Describe the structure and function of hair.
    3. Describe the structure and function of nails.

[5] An asterisk (*) preceding a learning outcome designates it as an optional, advanced learning outcome. The HAPS A&P Comprehensive Exam does not address these optional learning outcomes.

4. Describe the structure and function of exocrine glands of the integumentary system.
5. Describe the growth cycles of hair follicles and the growth of hair.
6. Explain the physiological significance of the presence or absence of sebaceous (oil) glands, sudoriferous (sweat) glands, and hair in the skin of the palms and fingers.

5. Application of homeostatic mechanisms

1. Explain how the integumentary system maintains homeostasis with respect to thermoregulation and water conservation.
2. Explain how the integumentary system relates to other body systems to maintain homeostasis.

6. Predictions related to disruption of homeostasis

1. Given a factor or situation (e.g., second-degree burns [partial-thickness burns]), predict the changes that could occur in the integumentary system and the consequences of those changes (i.e., given a cause, state a possible effect).
2. *Given a disruption in the structure or function of the integumentary system (e.g., blisters), predict the possible factors or situations that might have caused that disruption (i.e., given an effect, predict possible causes).

HAPS Anatomy & Physiology Learning Outcomes
MODULE F: Skeletal System & Articulations

Topic from HAPS Guidelines (in bold font)
Learning Outcomes (indented, regular font)[6]

1. General functions of the skeletal system
1. Describe the major functions of the skeletal system.

2. Structural components -- microscopic anatomy
1. List and describe the cellular and extracellular components of bone tissue.
2. Identify the microscopic structure of compact bone and spongy bone.
3. Using microscopic images, distinguish between the three different types of cartilage.
4. Describe the roles of dense regular and dense irregular connective tissue in the skeletal system.

3. Structural components -- gross anatomy
1. Classify bones of the skeleton based on their shape.
2. Identify and describe the structural components of a long bone, and explain their functions.
3. Define common bone marking terms (e.g., condyle, tubercle, foramen, canal).
4. Describe the locations of the three types of cartilage in the skeletal system.
5. Describe how the location and distribution of red and yellow bone marrow varies during a lifetime.

4. Physiology of embryonic bone formation (ossification or osteogenesis)
1. Explain the roles that specific bone cells play in the formation of bone tissue.
2. Compare and contrast intramembranous and endochondral (intracartilaginous) bone formation.

5. Physiology of bone growth, repair, and remodeling
1. Compare and contrast the function of osteoblasts and osteoclasts during bone growth, repair, and remodeling.
2. Compare and contrast interstitial (lengthwise) and appositional (width or circumferential) growth.
3. Explain the hormonal regulation of skeletal growth.
4. Explain the roles of parathyroid hormone, calcitriol, and calcitonin in plasma calcium regulation and bone remodeling.
5. Describe the bone repair and remodeling process and how it changes as humans age.
6. Explain the steps involved in fracture repair.

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6. **Organization of the skeletal system**
    1. Distinguish between the axial and appendicular skeletons and list the major bones contained within each.

7. **Bones of the skeleton**
    1. Identify individual bones and their locations within the body.
    2. Identify major bone markings (e.g., spines, processes, foramina) on individual bones.
    3. Compare and contrast a fetal skull with an adult skull.
    4. Compare and contrast the adult male and female skeletons.

8. **Classification, structure, and function of joints (articulations)**
    1. Describe the anatomical classification of joints based on structure: fibrous (i.e., gomphosis, suture, syndesmosis), cartilaginous (i.e., symphysis, synchondrosis), and synovial (i.e., planar/gliding, hinge, pivot, condylar, saddle, ball-and-socket), and provide examples of each type.
    2. Describe the functional classification of joints (e.g., synarthrosis, diarthrosis) based on the amount of movement permitted, and provide examples of each type.
    3. Explain the relationship between the anatomical classification and the functional classification of joints.
    4. Identify and describe the major structural components of a typical synovial joint.
    5. For each of the six structural types of synovial joints, describe its anatomic features, identify locations in the body, and predict the kinds of movement each joint allows.
    6. Define the movements that typically occur at a joint (e.g., flexion, extension, abduction, adduction, rotation, circumduction, inversion, eversion, protraction, retraction).

9. **Application of homeostatic mechanisms**
    1. Explain how the skeletal system participates in homeostasis of plasma calcium levels.

10. **Predictions related to disruption of homeostasis**
    1. Given a factor or situation (e.g., osteoporosis), predict the changes that could occur in the skeletal system and the consequences of those changes (i.e., given a cause, state a possible effect).
    2. *Given a disruption in the structure or function of the skeletal system (e.g., osteoarthritis), predict the possible factors or situations that might have caused that disruption (i.e., given an effect, predict the possible causes).

HAPS Anatomy & Physiology Learning Outcomes
MODULE G: Muscular System

Topic from HAPS Guidelines (in bold font)
Learning Outcomes (indented, regular font)[7]

1. General functions of muscle tissue
1. Describe the major functions of muscle tissue.

2. Identification, general location, and comparative characteristics of skeletal, smooth, and cardiac muscle tissue
1. Describe the structure, location in the body, and function of skeletal, cardiac, and smooth muscle.
2. Compare and contrast the general microscopic characteristics of skeletal, cardiac, and smooth muscle.

3. Detailed gross and microscopic anatomy of skeletal muscle
1. Describe the organization of skeletal muscle, from cell (skeletal muscle fiber) to whole muscle.
2. Name the connective tissue layers that surround each skeletal muscle fiber, fascicle, entire muscle, and group of muscles and indicate the specific type of connective tissue that composes each of these layers.
3. Describe the components within a skeletal muscle fiber (e.g., sarcolemma, transverse [T] tubules, sarcoplasmic reticulum, myofibrils, thick [myosin] myofilaments, thin [actin] myofilaments, troponin, tropomyosin).
4. Define sarcomere.
5. Describe the arrangement and composition of the following components of a sarcomere: A-band, I-band, H-zone, Z-disc (line), and M-line.
6. Describe the structure of the neuromuscular junction.

4. Physiology of skeletal muscle contraction and relaxation
1. Define the sliding filament theory of skeletal muscle contraction.
2. Describe the sequence of events involved in the contraction of a skeletal muscle fiber, including events at the neuromuscular junction, excitation-contraction coupling, and cross-bridge cycling.
3. Describe the sequence of events involved in skeletal muscle relaxation.

5. Skeletal muscle metabolism
1. Describe the sources of ATP (e.g., glycolysis, oxidative phosphorylation, creatine phosphate) that muscle fibers use for skeletal muscle contraction.
2. Explain the factors that are believed to contribute to skeletal muscle fatigue.

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3. Describe the events that occur during the recovery period from skeletal muscle activity.
4. Compare and contrast the metabolism of skeletal muscle with that of cardiac and smooth muscle.
5. Compare and contrast the anatomical and metabolic characteristics of slow oxidative (Type I), fast oxidative (Type IIa, intermediate, or fast twitch oxidative glycolytic), and fast glycolytic (Type IIb/IIx or fast twitch anaerobic) skeletal muscle fibers.

6. Principles and types of whole muscle contraction

1. Define the following terms: tension, contraction, twitch, motor unit, and myogram.
2. Interpret a myogram of a twitch contraction with respect to the duration of the latent, contraction, and relaxation periods and describe the events that occur in each period.
3. Interpret a myogram or graph of tension versus stimulus frequency and explain the physiological basis for the phenomena of treppe, summation, and tetanus.
4. Interpret a myogram or graph of tension versus stimulus intensity and explain the physiological basis for the phenomenon of recruitment.
5. Interpret a graph of the length-tension relationship and describe the anatomical basis for that relationship.
6. Compare and contrast isotonic and isometric contraction.
7. Compare and contrast concentric and eccentric contraction.

7. Nomenclature of skeletal muscles

1. Explain how the name of a muscle can help identify its action, appearance, or location.

8. Location, general attachments, and actions of the major skeletal muscles

1. Identify the location, general attachments, and actions of the major skeletal muscles.
2. Describe similar actions (functional groupings) of muscles in a particular compartment (e.g., anterior arm) or region (e.g., deep back).

9. Group actions of skeletal muscles

1. Define the terms prime mover (agonist), antagonist, synergist, and fixator.
2. For a given movement, differentiate specific muscles that function as prime mover, antagonist, synergist, or fixator.

10. Lever systems

1. *Compare and contrast the classes of levers in terms of the relative position of fulcrum, effort, and load, and describe examples of each in the human body (comparisons may include relative power and range of motion).

11. Smooth muscle

1. Describe the sources of calcium in smooth muscle contraction and explain how an increase in cytoplasmic calcium initiates contraction.

2. Compare the signals that initiate smooth muscle contraction to the signal that initiates skeletal muscle contraction.

12. Application of homeostatic mechanisms

1. Explain how the muscular system contributes to thermoregulation.

13. Predictions related to disruption of homeostasis

1. Given a factor or situation (e.g., muscular dystrophy), predict the changes that could occur in the muscular system and the consequences of those changes (i.e., given a cause, state a possible effect).
2. *Given a disruption in the structure or function of the muscular system (e.g., skeletal muscle atrophy), predict the possible factors or situations that might have caused that disruption (i.e., given an effect, predict possible causes).

HAPS Anatomy & Physiology Learning Outcomes
MODULE H: Nervous System

Topic from HAPS Guidelines (in bold font)
Learning Outcomes (indented, regular font)[8]

1. General functions of the nervous system
1. Describe the general functions of the nervous system.

2. Organization of the nervous system
1. Compare and contrast the central nervous system (CNS) and the peripheral nervous system (PNS) with respect to structure and function.
2. Differentiate between the motor (efferent) and sensory (afferent) components of the nervous system.
3. Describe the nervous system as a control system with the following components: sensory receptors, afferent pathways, control (integrating) center, efferent pathways, and effector (target) organs.
4. Compare and contrast the somatic motor and autonomic motor divisions of the nervous system.
5. Compare and contrast the somatic sensory and visceral sensory divisions of the nervous system.

3. General anatomy of the nervous system
1. Describe the composition and arrangement of the gray and white matter in the CNS.
2. Describe the structure of a typical nerve, including the motor and sensory neuronal elements, neuroglial elements, and connective tissue wrappings.
3. Compare and contrast the structure and location of a nucleus and ganglion.
4. Compare and contrast the structure and location of a tract and nerve.

4. Protective roles of cranial bones and vertebral column, meninges, and cerebrospinal fluid (CSF)
1. Describe how the cranial bones and the vertebral column protect the CNS.
2. Identify the layers of the meninges and describe their anatomical and functional relationships to the CNS (brain and spinal cord).
3. Compare and contrast the structure of the dura mater surrounding the brain and the spinal cord.
4. Describe the structure and location of the dural venous sinuses, and explain their role in drainage of blood from the brain.
5. Identify and describe the structure and function of the cranial dural septa.
6. Identify and describe the epidural space, subdural space and subarachnoid space associated with the brain and the spinal cord, and identify which space contains cerebrospinal fluid.

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7. Describe the general functions of cerebrospinal fluid (CSF).
8. Describe the production, flow, and reabsorption of cerebrospinal fluid (CSF), from its origin in the ventricles to its eventual reabsorption into the dural venous sinuses.

5. Neurons

1. Identify and describe the major components of a typical neuron (e.g., cell body, nucleus, nucleolus, chromatophilic substance [Nissl bodies], axon hillock, dendrites, and axon) and indicate which parts receive input signals and which parts transmit output signals.
2. Compare and contrast the three structural types of neurons (i.e., unipolar [pseudounipolar], bipolar, and multipolar) with respect to their structure, location, and function.
3. Compare and contrast the three functional types of neurons (i.e., sensory [afferent] neurons, interneurons [association neurons], and motor [efferent] neurons) with respect to their structure, location, and function.

6. Neuroglial (glial) cells

1. Describe the structure, location, and function of each of the six types of neuroglial (glial) cells.
2. Define myelination and describe its function, including comparing and contrasting how myelination occurs in the CNS and PNS.

7. Neurophysiology

1. List the major ion channels of neurons and describe them as leak (leakage or passive) or voltage-gated channels, mechanically gated channels, or ligand-gated (chemically-gated) channels, and identify where they typically are located on a neuron.
2. Describe the physiological basis of the resting membrane potential (RMP) in a neuron including the ion channels involved, the relative ion concentrations, and the electrochemical gradient.
3. Describe the role of the sodium-potassium ATPase pump in maintaining the resting membrane potential.
4. Define and describe depolarization, repolarization, hyperpolarization, and threshold.
5. Compare and contrast graded potentials and action potentials, with particular attention to their locations in the neuron and the ions and ion channels involved in each.
6. Label a voltage-versus-time diagram of an action potential with the ions involved in each phase, the direction of their movement across the membrane, and the terms depolarize, repolarize, and hyperpolarize.
7. Describe the physiological process involved in the conduction (propagation)[9] of an action potential, including the types and locations of the ion channels involved.

[9] The preferred term for neurophysiologists is conduction (not propagation) and we recommend using conduction to be consistent with the neurophysiologists.

8. Describe the importance of voltage-gated channels in the conduction (propagation) of an action potential.
9. Explain how axon diameter and myelination affect conduction velocity.
10. Explain the role of myelin in saltatory conduction.
11. Compare action potential conduction (propagation) in an unmyelinated versus a myelinated axon.[10]
12. Distinguish between absolute and relative refractory periods and compare the physiological basis of each.
13. Explain the impact of absolute and relative refractory periods on the activity of a neuron.

8. Neurotransmitters, neuromodulators, and synaptic transmission

1. Define a synapse, and explain the difference between an electrical synapse and a chemical synapse.
2. *Explain the difference between a neurotransmitter and a neuromodulator.
3. Describe the structures involved in a typical chemical synapse (e.g., axon terminal [synaptic knob], voltage-gated calcium channels, synaptic vesicles of presynaptic cell, synaptic cleft, neurotransmitter receptors of the postsynaptic cell).
4. Describe the events of synaptic transmission in proper chronological order from the release of neurotransmitter by synaptic vesicles to the effect of the neurotransmitter on the postsynaptic cell.
5. Describe the difference between fast synaptic responses (ion channel [ionotropic] receptors) and slow synaptic responses (second messenger-linked metabotropic receptors).
6. Define excitatory postsynaptic potential (EPSP) and inhibitory postsynaptic potential (IPSP) and interpret graphs showing the voltage-versus-time relationship of an EPSP and an IPSP.
7. Explain how a single neurotransmitter can elicit different responses at different postsynaptic cells.
8. List the most common excitatory and inhibitory neurotransmitter(s) used in the nervous system.
9. Explain temporal and spatial summation of postsynaptic potentials.
10. Describe the different mechanisms (e.g., reuptake, enzymatic breakdown, diffusion) by which neurotransmitter activity at a synapse can be terminated.

9. Integration of neural information

1. Define neural (neuronal) circuit.[11]
2. Compare and contrast the different types of neural circuits (e.g., converging, diverging).

[10] All action potential conduction is continuous. We have intentionally omitted the term “continuous conduction” from the comparison of conduction in myelinated and unmyelinated axons because saltatory conduction is also continuous -- it only appears to jump from node to node.
[11] The preferred term is neural circuit rather than neural or neuronal pool.

3. Define neural plasticity.

10. Structural and functional organization of the brain

1. Identify and describe the 3 primary brain vesicles formed from the neural tube.
2. Identify and describe the 5 secondary brain vesicles formed from the neural tube and name the parts of the adult brain arising from each.
3. Identify and define the general terms gyrus, sulcus, and fissure.
4. Identify and describe the four major parts of the adult brain (i.e., cerebrum, diencephalon, brainstem, cerebellum).
5. Identify and describe the ventricular system components.
6. Describe the blood-brain barrier (BBB) and its significance.

For the cerebrum:

7. Identify and describe the cerebral hemispheres and the five lobes of each (i.e., frontal, parietal, temporal, occipital, insula).
8. Identify and describe the major landmarks of the cerebrum (e.g., longitudinal fissure, lateral sulcus [fissure], central sulcus, transverse fissure, precentral gyrus, postcentral gyrus).
9. Identify and describe the three major cerebral regions (i.e., cortex, white matter, cerebral nuclei [basal nuclei]).
10. Identify and describe the primary functional cortical areas of the cerebrum (e.g., primary motor cortex, primary somatosensory cortex, primary auditory cortex, primary visual cortex, primary olfactory cortex, primary gustatory cortex).
11. Compare and contrast the cerebral location and function of the motor speech area (Broca area) and Wernicke area.
12. Compare and contrast the three cerebral white matter tracts (i.e., association, commissural, projection).

For the diencephalon:

13. Name the major components of the diencephalon.
14. Describe the structure, location, and major functions of the thalamus.
15. Describe the structure, location, and major functions of the hypothalamus, including its relationship to the autonomic nervous system and the endocrine system.
16. Describe and identify the epithalamus, including the pineal gland and its function.

For the brainstem:

17. Name the three subdivisions of the brainstem.
18. Describe the structure, location, and major functions of the midbrain (mesencephalon), including the cerebral peduncles, superior colliculi, and inferior colliculi.
19. Describe the structure, location, and major functions of the pons.

20. Describe the structure, location, and major functions of the medulla oblongata (medulla), including the pyramids and decussation of the pyramids.

For the cerebellum:

21. Describe the structure, location, and major functions of the cerebellum.
22. Identify and describe the cerebellar hemispheres, vermis, arbor vitae (cerebellar white matter), cerebellar peduncles, and cerebellar cortex (folia, cerebellar gray matter).

23. Describe the major components and functions of the limbic system.
24. Describe the major components and functions of the reticular activating system (RAS).

11. Cranial nerves

1. List and identify the cranial nerves by name and number.
2. Describe the major functions of each cranial nerve and identify each cranial nerve as predominantly sensory, motor, or mixed (i.e., sensory and motor).
3. List the cranial nerves that have parasympathetic (ANS) components.

12. Structural and functional organization of the spinal cord

1. Identify and describe the gross anatomy of the spinal cord, including its enlargements (i.e., cervical and lumbar), conus medullaris, cauda equina, and filum terminale.
2. Compare and contrast the location, composition, and function of the anterior (ventral) roots, posterior (dorsal) roots, and posterior (dorsal) root ganglion with respect to the spinal cord.
3. Identify and describe the anatomical features seen in a cross-sectional view of the spinal cord (e.g., anterior horn, lateral horn, posterior horn, gray commissure, central canal, anterior funiculus [column[12]], lateral funiculus [column], posterior funiculus [column]).
4. Describe the structure, location, and function of ascending and descending spinal cord tracts.

13. Spinal nerves

1. Identify and describe the formation, structure, and branches of a typical spinal nerve, including the roots and the rami (e.g., anterior [ventral], posterior [dorsal]).
2. List the number of spinal nerve pairs emerging from each spinal cord region (i.e., cervical, thoracic, lumbar, sacral, coccygeal).
3. Describe the concept of a dermatome and its clinical significance.
4. Define a spinal nerve plexus.

[12] Terminologia Anatomica (TA) states that the term funiculus should be used to describe the white matter regions, whereas 'column' should refer to structures within the gray matter of the spinal cord. We include column in parentheses because we recognize the prevalence of the use of the term 'column' relating the white matter.

5. For the cervical, brachial, lumbar, and sacral nerve plexuses, list the spinal nerves that form each plexus, describe the plexus' major motor and sensory distributions, and list the major named nerves that originate from each plexus.

14. Reflexes and their roles in nervous system function

1. Define the term reflex.
2. Describe reflex responses in terms of the major structural and functional components of a reflex arc.
3. Distinguish between each of the following pairs of reflexes: intrinsic versus learned, somatic versus visceral, monosynaptic versus polysynaptic, and ipsilateral versus contralateral.
4. Describe the following reflexes and name all components of each reflex arc: stretch reflex, (Golgi) tendon reflex, flexor (withdrawal) reflex, and crossed-extensor reflex.

15. Structure and function of sensory and motor pathways

1. Describe the locations and functions of the first-, second- and third-order neurons in a sensory pathway.
2. Describe the locations and functions of the upper and lower motor neurons in a motor pathway.
3. Describe the concept of decussation and its functional implications.

16. Autonomic nervous system (ANS)

1. Compare and contrast the autonomic nervous system (ANS) to the somatic nervous system (SNS) with respect to site of origination, number of neurons involved in the pathway, effectors, receptors, and neurotransmitters.
2. Name the two main divisions of the ANS and compare and contrast the major functions of each division, their neurotransmitters, the origination of the division in the CNS, the location of their preganglionic and postganglionic (ganglionic) cell bodies, and the length of the preganglionic versus postganglionic axons.
3. Describe the major components of the sympathetic and parasympathetic divisions (e.g., sympathetic trunk [chain], white and gray rami communicantes, splanchnic nerves, pelvic splanchnic nerves, CN III, CN VII, CN IX, CN X) and the major ganglia of each division (e.g., terminal ganglia, intramural ganglia, sympathetic trunk [chain] ganglia, prevertebral [collateral] ganglia).
4. Describe the different anatomical pathways through which sympathetic and parasympathetic neurons reach target effectors.
5. Compare and contrast the effects (or lack thereof) of sympathetic and parasympathetic innervation on various effectors (e.g., heart, airways, gastrointestinal tract, iris of the eye, blood vessels, sweat glands, arrector pili muscles).
6. Explain the relationship between chromaffin cells in the adrenal medulla and the sympathetic division of the nervous system.
7. Describe visceral reflex arcs, including structural and functional details of sensory and motor (autonomic) components.

8. Compare and contrast cholinergic and adrenergic receptors with respect to neurotransmitters that bind to them, receptor subtypes, receptor locations, target cell response (i.e., excitatory or inhibitory), and examples of drugs, hormones, and other substances that interact with these receptors.

17. Application of homeostatic mechanisms

1. Explain the role of the nervous system in the maintenance of homeostasis and give examples of how the nervous system interacts with other body systems to accomplish this.

18. Predictions related to disruption of homeostasis

1. Given a factor or situation (e.g., a demyelinating disease), predict the changes that could occur in the nervous system and the consequences of those changes (i.e., given a cause, state a possible effect).
2. *Given a disruption in the structure or function of the nervous system (e.g., decreased neurotransmitter release), predict the possible factors or situations that might have caused that disruption (i.e., given an effect, predict the possible causes).

HAPS Anatomy & Physiology Learning Outcomes
MODULE I: General & Special Senses

Topic from HAPS Guidelines (in bold font)
Learning Outcomes (indented, regular font)[13]

1. Sensory receptors
1. Define sensory receptor.
2. Define transduction, perception, sensation, and adaptation.
3. Distinguish between tonic and phasic receptors.
4. Compare and contrast the three types of sensory receptors, based on their stimulus origin (i.e., exteroceptors, interoceptors [visceroceptors], proprioceptors).
5. Compare and contrast the types of sensory receptors based on the type of stimulus (i.e., thermoreceptor, photoreceptor, chemoreceptor, baroreceptor, nociceptor [pain receptor], mechanoreceptor).
6. Compare and contrast a general sense receptor and a special sense (complex) receptor.

2. Tactile receptors
1. Compare and contrast the location, structure, and function of the different types of tactile receptors (e.g., tactile [Merkel] corpuscle, lamellated [Pacinian] corpuscle).

3. Gross and microscopic anatomy of the eye
1. Identify the tunics of the eye and their major components (e.g., cornea, sclera, iris, ciliary body), and describe the structure and function of each.
2. Identify and describe the anterior and posterior cavities of the eye and their associated humors.
3. Describe the lens and its role in vision.
4. Identify and describe the actions of the extrinsic eye muscles.
5. Identify and describe the accessory eye structures (e.g., conjunctiva and lacrimal apparatus).

4. Visual pathways
1. Trace the path of light as is passes through the eye to the retina, and describe which structures are responsible for refracting the light rays.
2. Trace the signal pathway from the retina through the optic nerve, optic chiasm, optic tract, and to the various parts of the brain.
3. Explain how the optical system of the eye creates an image on the retina.
4. Describe phototransduction (i.e., how light activates photoreceptors) and explain the process of light and dark adaptation.
5. Compare and contrast the functions and locations of rods and cones.
6. Relate changes in the anatomy of the eye to changes in vision.

[13] An asterisk (*) preceding a learning outcome designates it as an optional, advanced learning outcome. The HAPS A&P Comprehensive Exam does not address these optional learning outcomes.

5. **Olfaction**
    1. Identify and describe the composition and location of the olfactory epithelium.
    2. Classify olfactory receptor cells based on the type of stimulus (i.e., modality).
    3. Explain the process by which odorants activate olfactory receptors.
    4. Trace the path of olfaction from the olfactory receptors, to the initiation of an action potential in the olfactory nerves, through the olfactory bulb, the olfactory tract, and to the various parts of the brain.

6. **Gustation**
    1. Identify and describe the location and structure of taste buds.
    2. Classify gustatory receptor cells based on the type of stimulus (i.e., modality).
    3. Explain the process by which tastants activate gustatory receptors.
    4. Trace the path of gustation from gustatory receptors through specific cranial nerves to various parts of the brain.
    5. Describe the primary taste sensations.

7. **Gross and microscopic anatomy of the ear**
    1. Identify the macroscopic structures of the outer (external), middle, and inner (internal) ear and their major components (e.g., auditory ossicles, auditory [pharyngotympanic] tube), and describe the structure and function of each.
    2. Identify and describe the microscopic structures within the inner (internal) ear (e.g., maculae, cristae ampullares, spiral organ [of Corti]).

8. **Auditory pathways**
    1. Classify the receptor cells for hearing based on the type of stimulus (i.e., modality).
    2. Trace the path of sound from the external ear to the inner ear, including where sound is amplified.
    3. Explain the process by which an action potential is generated at the spiral organ (of Corti).
    4. Trace the signal path from the spiral organ (of Corti) to the cochlear branch of the vestibulocochlear nerve (CN VIII) and to the various parts of the brain.
    5. Explain how the structures of the ear enable differentiation of pitch, intensity (loudness), and localization of sounds.

9. **Equilibrium**
    1. Classify the receptor cells for equilibrium based on the type of stimulus (i.e., modality).
    2. Compare and contrast static and dynamic equilibrium.
    3. Describe the structure of a macula and its function in static equilibrium.
    4. Describe the structure of a crista ampullaris and its function in dynamic equilibrium.
    5. Trace the signal path from the maculae and cristae ampullares to the vestibular branch of the vestibulocochlear nerve (CN VIII) and to the various parts of the brain.

10. Application of homeostatic mechanisms

1. Explain how the sense organs relate to other body organs and systems to maintain homeostasis.

11. Predictions related to disruption of homeostasis

1. Given a factor or situation (e.g., macular degeneration), predict the changes that could occur in the affected sense and the consequences of those changes (i.e., given a cause, state a possible effect).
2. *Given a disruption in the structure or function of one of the senses, (e.g., vertigo), predict the possible factors or situations that might have caused that disruption (i.e., given an effect, predict the possible causes).

HAPS Anatomy & Physiology Learning Outcomes
MODULE J: Endocrine System

Topic from HAPS Guidelines (in bold font)
Learning Outcomes (indented, regular font)[14]

1. General functions of the endocrine system
1. Describe the major functions of the endocrine system.
2. Define the terms hormone, endocrine gland, endocrine tissue (organ), and target cell.
3. Compare and contrast how the nervous and endocrine systems control body functions, the anatomical pathways by which the signals reach their targets, what determines the target of the pathway, the speed of the target response(s), the duration of the response, and how signal intensity is coded.
4. *Explain the difference between classic hormones and neurohormones.

2. Chemical classification of hormones and mechanism of hormone actions at receptors
1. List the three major chemical classes of hormones (i.e., steroid, peptide, amino acid-derived [amine]) found in the human body.
2. Compare and contrast how steroid and peptide hormones are produced and stored in the endocrine cell, released from the endocrine cell, and transported in the blood.
3. Compare and contrast the locations of target cell receptors for steroid and peptide hormones.
4. Compare and contrast the mechanisms of action of plasma membrane hormone receptors and intracellular hormone receptors, including the speed of the response.

3. Control of hormone secretion
1. Describe the various signals that initiate hormone production and secretion (e.g., monitored variables, direct innervation, neurohormones, other hormones).
2. Describe a simple endocrine pathway in which the response is the negative feedback signal (e.g., parathyroid hormone, insulin).

4. Endocrine control by the hypothalamus and pituitary gland
1. Describe the locations and the anatomical relationships of the hypothalamus, anterior pituitary, and posterior pituitary, including the hypothalamic-hypophyseal portal system.
2. Compare and contrast negative feedback for hypothalamic-anterior pituitary-peripheral endocrine gland pathways to negative feedback for most simple endocrine pathways.
3. Describe major hormones secreted by the anterior pituitary, their control pathways, and their primary target(s) and effects.
4. Explain the role of hypothalamic neurohormones (regulatory hormones) in the release of anterior pituitary hormones.
5. Name the two hormones produced by the hypothalamus that are stored in the

[14] An asterisk (*) preceding a learning outcome designates it as an optional, advanced learning outcome. The HAPS A&P Comprehensive Exam does not address these optional learning outcomes.

posterior pituitary, and the hormones' primary targets and effects.
6. Explain the role of the hypothalamus in the release of hormones from the posterior pituitary.

5. Endocrine structures and their hormones

1. Describe the anatomy of the thyroid gland, its location, the major hormones secreted, the control pathway(s) for hormone secretion, and the hormones' primary targets and effects.
2. Describe the anatomy of the parathyroid glands, their location, the major hormone secreted, the control pathway(s) for hormone secretion, and the hormone's primary targets and effects.
3. Describe the anatomy of the adrenal cortex, its location, the major hormones secreted, the control pathway(s) for hormone secretion, and the hormones' primary targets and effects.
4. Describe the anatomy of the pancreas, its location, the major hormones secreted, the control pathway(s) for hormone secretion, and the hormones' primary targets and effects.
5. Describe the anatomy of the thymus gland, its location, the major hormones secreted, the control pathway(s) for hormone secretion, and the hormones' primary targets and effects.
6. Provide some examples of hormones that are secreted from diffuse endocrine tissues or single endocrine cells.

6. Local chemical messengers

1. Define the terms paracrine and autocrine.
2. List two major types of eicosanoids and describe their functions.
3. Describe the function of growth factors.
4. *Describe the major functions of nitric oxide (NO) and its half-life.
5. Compare and contrast classic hormones with paracrines, autocrines, growth factors, and cytokines.

7. **Hormonal response to stress**
    1. Describe the general adaptation syndrome in response to stress.
    2. *List the hormones released during short-term stress and describe their actions.
    3. *List the hormones released during long-term stress and describe their actions.

8. **Application of homeostatic mechanisms**
    1. Describe examples of how the endocrine organs interact with other body organs and systems to maintain homeostasis.

9. **Predictions related to disruption of homeostasis**
    1. Given a factor or situation (e.g., lack of iodine in the diet), predict the changes that could occur in the endocrine system and the consequences of those changes (i.e., given a cause, state a possible effect).
    2. *Given a disruption in the structure or function of the endocrine system (e.g., hypothyroidism), predict the possible factors or situations that might have caused that disruption (i.e., given an effect, predict possible causes).

HAPS Anatomy & Physiology Learning Outcomes
MODULE K: Cardiovascular System

Topic from HAPS Guidelines (in bold font)
Learning Outcomes (indented, regular font)[15]

1. General functions of the cardiovascular system

1. Describe the major functions of each component of the cardiovascular system (i.e., blood, heart, blood vessels).

2. Composition of blood

1. Describe the general composition of blood (e.g., plasma, formed elements).
2. Describe the composition of blood plasma.
3. List the major types of plasma proteins, their functions, and sites of production.
4. Compare and contrast the morphological features and general functions of the formed elements (i.e., erythrocytes, leukocytes, platelets).
5. List the five types of leukocytes in order of their relative prevalence in normal blood, and describe their major functions.
6. Describe the structure and function of hemoglobin, including its breakdown products.
7. Define hematocrit and state the normal ranges for adult males and females.
8. *State the normal ranges for erythrocyte counts in adult males and females, total leukocyte count, and platelet count.

3. Hematopoiesis (hemopoiesis)[16]

1. Describe the locations of hematopoiesis (hemopoiesis) and the significance of the hematopoietic stem cell (HSC or hemocytoblast).
2. Explain the basic process of erythropoiesis, the significance of the reticulocyte, and regulation through erythropoietin (EPO).
3. Explain the basic process of leukopoiesis.
4. Explain the basic process of thrombopoiesis.

4. Hemostasis

1. Describe the vascular phase of hemostasis, including the role of endothelial cells.
2. Describe the role of platelets in hemostasis and the steps involved in the formation of the platelet plug.
3. Describe the basic steps of coagulation resulting in the formation of the insoluble fibrin clot.

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[15] An asterisk (*) preceding a learning outcome designates it as an optional, advanced learning outcome. The HAPS A&P Comprehensive Exam does not address these optional learning outcomes.

[16] Hematology and medical books define *hematopoiesis* as the production/formation of all blood cells beginning in the embryo, and *hemopoiesis* as the formation of new cellular components of blood in myeloid and lymphoid tissue. Therefore, hematopoiesis is inclusive of hemopoiesis, (but not vice versa).

4. Differentiate among the intrinsic (contact activation), extrinsic (cell injury), and common pathways of the coagulation cascade.
5. Explain how the positive feedback loops in the platelet and coagulation phases promote hemostasis.
6. Explain the role of vitamin K in blood clotting.
7. Describe the process of fibrinolysis, including the roles of plasminogen, tissue plasminogen activator, and plasmin.

5. ABO and Rh blood grouping

1. Explain the role of surface antigens on erythrocytes in determining blood groups.
2. List the type of antigen and the type of antibodies present in each ABO blood type.
3. Describe how the presence or absence of Rh antigen results in blood being classified as positive or negative.
4. Describe the development and clinical significance of anti-Rh antibodies.
5. Predict which blood types are compatible and what happens when the incorrect ABO or Rh blood type is transfused.

6. Gross and microscopic anatomy of the heart

1. Describe the position of the heart in the thoracic cavity.
2. Identify and describe the location, structure, and function of the fibrous pericardium, parietal and visceral layers of the serous pericardium, serous fluid, and the pericardial cavity.
3. Explain the structural and functional differences between atria and ventricles.
4. On the external surface of the heart identify the 4 chambers, the coronary (atrioventricular) sulcus, anterior interventricular sulcus, posterior interventricular sulcus, apex and base.
5. Identify and describe the structure and function of the primary internal structures of the heart, including chambers, septa, valves, papillary muscles, chordae tendineae, fibrous skeleton, and venous and arterial openings.
6. Describe the blood flow to and from the heart wall, including the location of the openings for the left and right coronary arteries, left coronary artery and its major branches, right coronary artery and its major branches, cardiac veins, and coronary sinus.
7. Describe the structure and functions of each layer of the heart wall (i.e., epicardium, myocardium, endocardium).
8. Describe the microscopic anatomy of the myocardium, including the location and function of the intercalated discs.

7. Physiology of cardiac muscle contraction

1. List the phases of contractile and autorhythmic cardiac muscle action potentials and explain the ion movements that occur in each phase.
2. Contrast the initiation of action potentials in cardiac autorhythmic cells, in cardiac contractile cells, and in skeletal muscle cells.

3. Explain the significance of the plateau phase in the action potential of a cardiac contractile cell.
4. Compare and contrast the molecular events of cardiac muscle contraction/relaxation and skeletal muscle contraction/relaxation.
5. Compare and contrast the role of autonomic innervation in the depolarization of cardiac pacemaker cells, ventricular contractile cells, and skeletal muscle cells.
6. Compare the refractory periods of cardiac contractile muscle and skeletal muscles.
7. Explain the role of calcium in determining the force of myocardial contraction (contractility).

8. Blood flow through the heart

1. Trace the path of blood through the right and left sides of the heart, including its passage through the heart valves, and indicate whether the blood is oxygen-rich or oxygen-poor.

9. Electrical conduction system of the heart and the electrocardiogram

1. List the parts of the electrical conduction system of the heart in the correct sequence for one contraction and explain how the electrical conduction system functions.
2. Explain why the SA node normally paces the heart.
3. Explain how the cardiac conduction system produces coordinated heart chamber contractions.
4. Name the waveforms in a normal electrocardiogram (ECG or EKG) and explain the electrical events represented by each waveform.

10. Cardiac cycle

1. Define cardiac cycle, systole, and diastole.
2. Describe the phases of the cardiac cycle including ventricular filling, isovolumic (isovolumetric)[17] contraction, ventricular ejection, and isovolumic (isovolumetric) relaxation.
3. Relate the electrical events represented on an electrocardiogram (ECG or EKG) to the normal mechanical events of the cardiac cycle.
4. Explain how atrial systole is related to ventricular filling.
5. Relate the opening and closing of specific heart valves in each phase of the cardiac cycle to pressure changes in the heart chambers and the great vessels (i.e., blood vessels entering and leaving the heart).
6. Relate the heart sounds to the events of the cardiac cycle.
7. Define systolic and diastolic blood pressure and interpret a graph of aortic pressure versus time during the cardiac cycle.
8. Compare and contrast pressure and volume changes of the left and right ventricles

[17] The more appropriate term is isovolumic (and not isovolumetric) because the volume within the ventricles remains constant, while the length of the cardiac muscle fibers change. We have included isovolumetric in parentheses because many people use that term, but we strongly suggest people switch to the accurate term.

during one cardiac cycle.
9. Given the heart rate, calculate the length of one cardiac cycle.

11. Regulation of cardiac output (CO), stroke volume (SV), and heart rate (HR)

1. Define cardiac output (CO) and state its units of measurement.
2. Calculate cardiac output, given stroke volume and heart rate.
3. Predict how changes in heart rate (HR) and/or stroke volume (SV) will affect cardiac output (CO).
4. Describe the concepts of ejection fraction and cardiac reserve.
5. Define end diastolic volume (EDV) and end systolic volume (ESV), and calculate stroke volume (SV) given values for EDV and ESV.
6. Define venous return, preload, and afterload, and explain the factors that affect them.
7. Explain how venous return, preload, and afterload each affect end diastolic volume (EDV), end systolic volume (ESV), and stroke volume (SV).
8. State the Frank-Starling Law of the heart and explain its significance.
9. Explain the influence of positive and negative inotropic agents on stroke volume (SV).
10. Describe the influence of positive and negative chronotropic agents on HR.
11. Explain the relationship between changes in HR and changes in filling time and EDV.
12. Describe the role of the autonomic nervous system in the regulation of cardiac output.

12. Anatomy and functional roles of the different types of blood vessels

1. Define the terms artery, capillary, and vein.
2. List the three tunics associated with most blood vessels and describe the composition of each tunic.
3. Compare and contrast tunic thickness, composition, and lumen diameter among arteries, capillaries, and veins.
4. Identify and describe the structure and function of specific types of blood vessels (i.e., elastic [conducting] arteries, muscular [distributing] arteries, arterioles, capillaries, venules, veins).
5. Define vasoconstriction and vasodilation.
6. List types of capillaries, state where in the body each type is located, and correlate their anatomical structures with their functions.
7. Describe the functional significance of the venous reservoir.
8. Define anastomosis and explain its functional significance (e.g., cerebral arterial circle [Circle of Willis]).

13. Systemic and pulmonary circuits (circulations)

1. Describe the systemic and pulmonary circuits (circulations) and explain the functional significance of each.
2. Identify the major arteries and veins of the pulmonary circuit.
3. Identify the major arteries and veins of the systemic circuit.
4. Define a portal system.

5. Describe the structure and functional significance of the hepatic portal system.

14. Fetal (prenatal) versus postnatal circulation

1. Describe the role of the placenta, umbilical vessels, ductus venosus, foramen ovale, and ductus arteriosus in fetal circulation.
2. Trace the pathway of blood flow from the placenta, through the fetal heart and body, and back to the placenta.
3. Describe the changes in major fetal cardiovascular structures (i.e., umbilical vessels, ductus venosus, ductus arteriosus, foramen ovale) that typically occur beginning at birth, and the ultimate postnatal remnants (fates) of these structures.

15. Blood pressure and its functional interrelationships with cardiac output (CO), peripheral resistance, and hemodynamics

1. Define blood flow, blood pressure, and peripheral resistance.
2. State and interpret the equation that relates fluid-flow to pressure and resistance.
3. Describe the role of arterioles in regulating tissue blood flow and systemic arterial blood pressure.
4. List the local, hormonal and neural factors that affect peripheral resistance and explain the importance of each.
5. Interpret relevant graphs to explain the relationships between vessel diameter, cross-sectional area, blood pressure, and blood velocity.
6. Using a graph of pressures within the systemic circuit, interpret the pressure changes that occur in the arteries, capillaries, and veins.
7. Given values for systolic and diastolic blood pressure, calculate pulse pressure (PP) and mean arterial pressure (MAP).
8. State the equation relating mean arterial pressure (MAP) to cardiac output (CO) and total peripheral resistance (TPR).
9. Predict and describe how mean arterial pressure (MAP) would be affected by changes in total peripheral resistance (TPR) or by changes in cardiac output (CO) or any of its components - heart rate (HR), stroke volume (SV) or preload.
10. Explain the mechanisms of capillary exchange of gases, nutrients, and wastes.
11. Describe the forces that create capillary filtration and reabsorption.
12. Explain how changes in net filtration pressure (NFP) can result in edema and how a functional lymphatic system normally prevents edema.
13. Describe how muscular compression and the respiratory pump aid venous return.
14. Explain how local control mechanisms and myogenic autoregulation influences blood flow to tissues.
15. Explain the role of the precapillary sphincter in autoregulation.
16. List some chemicals that cause either vasodilation or vasoconstriction and explain the circumstances in which they are likely to be active.[18]
17. Explain the steps of the baroreceptor reflex and describe how this reflex maintains

[18] Some chemicals that cause vasoconstriction or vasodilation, such as natriuretic peptides and those created by the renin-angiotensin system, will be included in the Fluid/Electrolyte Module (Module Q.3)..

blood pressure homeostasis when blood pressure changes.

18. Explain the role of the autonomic nervous system in regulation of blood pressure and volume.

16. Application of homeostatic mechanisms

1. Provide specific examples to demonstrate how the cardiovascular system maintains blood pressure homeostasis in the body.

17. Predictions related to disruption of homeostasis

1. Given a factor or situation (e.g., left ventricular failure), predict the changes that could occur in the cardiovascular system and the consequences of those changes (i.e., given a cause, state a possible effect).
2. *Given a disruption in the structure or function of the cardiovascular system (e.g., pulmonary edema), predict the possible factors or situations that might have created that disruption (i.e., given an effect, predict possible causes).

HAPS Anatomy & Physiology Learning Outcomes
MODULE L: Lymphatic system & Immunity

Topic from HAPS Guidelines (in bold font)
Learning Outcomes (indented, regular font)[19]

1. General functions of the lymphatic system
1. Describe the major functions of the lymphatic system.

2. Lymph and lymphatic vessels
1. Compare and contrast whole blood, plasma, interstitial fluid, and lymph.
2. Compare and contrast lymphatic vessels and blood vessels in terms of structure and function.
3. Describe the path of lymph circulation.
4. Describe the mechanisms of lymph formation and circulation.

3. Lymphatic cells, tissues, and organs
1. Describe the basic structure and cellular composition of lymphatic tissue and correlate them to the overall functions of the lymphatic system.
2. Describe the structure, function, and major locations of lymphatic nodules (e.g., mucosa-associated lymphoid tissue [MALT], tonsils).
3. Describe the structure, functions, and major locations of the following lymphatic organs: lymph nodes, thymus, and spleen.

4. Introduction to innate (nonspecific) and adaptive (specific) immune responses
1. Compare and contrast innate (nonspecific) with adaptive (specific) defenses.
2. Define immunity and the immune system.
3. Describe the roles of various types of leukocytes in innate (nonspecific) and adaptive immune responses.
4. Explain ways in which the innate (nonspecific) and adaptive (specific) immune responses cooperate to enhance the overall resistance to disease.

5. Innate (nonspecific) defenses
1. Name surface membrane barriers and describe their physical, chemical, and microbiological mechanisms of defense.
2. Define diapedesis, chemotaxis, opsonization, and membrane attack complex, and explain their importance for innate defenses.
3. Describe the steps involved in phagocytosis and provide examples of important phagocytic cells in the body.
4. Describe the functions of natural killer cells.
5. Explain how complement and interferon function as antimicrobial chemicals.

[19] An asterisk (*) preceding a learning outcome designates it as an optional, advanced learning outcome. The HAPS A&P Comprehensive Exam does not address these optional learning outcomes.

6. Explain the role of pattern-recognition receptors in innate defenses.
7. Describe the mechanisms that initiate inflammation.
8. Summarize the cells and chemicals involved in the inflammatory process.
9. List and explain the causes of the four cardinal signs of inflammation.
10. Explain the benefits of inflammation.
11. Describe the mechanism of fever, including the role of pyrogens.
12. Explain the benefits of fever.

6. Overview of adaptive (specific) immunity

1. Compare and contrast antibody-mediated (humoral) and cell-mediated (cellular) immunity.
2. Describe the immunological memory (anamnestic) response.

7. Antigens and antigen processing

1. Define antigen, self-antigen, and antigen receptor.
2. *Distinguish among complete antigens, haptens, antigenic determinants, and self-antigens.
3. Define major histocompatibility complex (MHC).
4. Describe where class I and class II major histocompatibility complex (MHC) proteins are found.
5. Explain the functions of class I and class II major histocompatibility complex (MHC) proteins in adaptive (specific) immunity.
6. State that the genetic code is the source of antigen receptor diversity.
7. Explain the roles of antigen-presenting cells (APCs) and provide examples of cells that function as APCs.

8. Lymphocytes and their role in adaptive (specific, acquired) immunity

1. Describe the general structure and functions of the various types of lymphocytes (e.g., helper T cells, cytotoxic T cells, regulatory [suppressor] T cells, B cells, plasma cells, memory cells).
2. Define immunocompetence and self tolerance, and distinguish between naive and activated immune cells.
3. Describe where B and T cells originate, and contrast where they attain their immunocompetence.
4. Compare and contrast the primary locations of immunocompetent cells in the body.
5. Compare and contrast the mechanisms of antigen challenge and the clonal selection processes of B and T cells, including effector cells, helper cells, memory cells, and important cytokines.
6. Compare and contrast the defense mechanisms and functions of B and T cells.
7. Describe the contribution of clonal deletion to immunity.

9. Antibodies and their role in adaptive (specific) immunity

1. Describe antibody structure.
2. Describe mechanisms of antibody action and correlate mechanisms with effector

functions.
3. Compare and contrast the structure and functions of the classes of antibodies.
4. Interpret a graph of the primary and secondary immune response, in terms of the relative concentrations of different classes of antibodies produced over time.

10. Applied immunology

1. Distinguish between active and passive immunity.
2. Describe natural and artificial examples of both active and passive immunity.

11. Application of homeostatic mechanisms

1. Provide specific examples to demonstrate how the lymphatic system responds to maintain homeostasis in the body.
2. Explain how the lymphatic system relates to other body systems to maintain homeostasis.

12. Predictions related to disruption of homeostasis

1. Given a factor or situation (e.g., elephantiasis), predict the changes that could occur in the lymphatic or immune system and the consequences of those changes (i.e., given a cause, state a possible effect).
2. *Given a disruption in the structure or function of the lymphatic or immune system (e.g., destruction of helper T-cells), predict the possible factors or situations that might have caused that disruption (i.e., given an effect, predict the possible causes).

HAPS Anatomy & Physiology Learning Outcomes
MODULE M: Respiratory System

Topic from HAPS Guidelines (in bold font)
Learning Outcomes (indented, regular font)[20]

1. General functions of the respiratory system

1. Describe the major functions of the respiratory system.
2. Describe the processes associated with the respiratory system (i.e., ventilation, pulmonary gas exchange [gas exchange between alveoli and blood], transport of gases in blood, tissue gas exchange [gas exchange between blood and body tissues]).[21]

2. Gross and microscopic anatomy of the respiratory tract and related organs

1. Compare and contrast the general locations and functions of the conducting and respiratory portions (zones) of the respiratory tract.
2. Identify the anatomical division of the upper versus lower respiratory tract.
3. List, in order, the respiratory structures that air passes through during inspiration and expiration.
4. Describe the major functions, gross anatomical features, and epithelial lining of the nasal cavity, paranasal sinuses, and pharynx.

Larynx:

5. Describe the major functions of the larynx.
6. Describe the anatomical features of the larynx, including the laryngeal cartilages.
7. Compare and contrast the location, composition, and function of the vestibular folds (false vocal cords) and vocal folds (true vocal cords).
8. Briefly explain how the vocal folds and the larynx function in phonation.

Trachea:

9. Describe the major functions of the trachea.
10. Describe the gross anatomical features of the trachea, including its positioning with respect to the esophagus.
11. Describe the microscopic anatomy of the trachea, including the significance of the C-shaped hyaline cartilage rings.

Lungs, pleura, and bronchial tree:

[20] An asterisk (*) preceding a learning outcome designates it as an optional, advanced learning outcome. The HAPS A&P Comprehensive Exam does not address these optional learning outcomes.
[21] We are not using the terms "*external respiration*" and "*internal respiration*" because these terms have different meanings to different people and because of confusion between internal respiration and cellular respiration. We strongly encourage A&P instructors to adopt the terminology listed in LO 1.2 instead.

12. Compare and contrast the main anatomical differences between bronchi and bronchioles.
13. Identify and describe the anatomic features of the bronchial tree (e.g., main [primary] bronchi, lobar [secondary] bronchi, segmental [tertiary] bronchi, smaller bronchi, bronchioles, terminal bronchioles, respiratory bronchioles, alveolar ducts, alveolar sacs, and alveoli).
14. Pair each bronchus (e.g., main, lobar, segmental) with the general portion of lung it supplies (e.g., lung, lobe, bronchopulmonary segment).
15. Identify and describe the respiratory membrane, and explain its function.
16. Describe the histological changes that occur along the bronchial tree from larger to smaller air passageways.
17. Identify and describe the location, structure, and function of the visceral and parietal pleura, serous fluid, and the pleural cavity.
18. Compare and contrast the gross anatomic features of the left and right lungs, and explain the reasons for these differences.
19. *Identify and describe the bronchopulmonary segments and their clinical significance.

3. Mechanisms of pulmonary ventilation

1. Define pulmonary ventilation, inspiration (inhalation), and expiration (exhalation).
2. Identify the muscles used during quiet inspiration, deep inspiration, and forced expiration.
3. Identify the nerves responsible for ventilation.
4. Define atmospheric pressure, intrapulmonary pressure, intrapleural pressure, and transpulmonary pressure.
5. Explain the relationship of intrapleural pressure, transpulmonary pressure, and intrapulmonary pressure relative to atmospheric pressure during ventilation.
6. Explain the inverse relationship between gas pressure and volume of the gas (i.e., Boyle's Law) and apply this relationship to explain airflow during inspiration and expiration.
7. Explain how pulmonary ventilation is affected by bronchiolar smooth muscle contractions (bronchoconstriction), lung and thoracic wall compliance, and pulmonary surfactant and alveolar surface tension.
8. Describe the forces that tend to collapse the lungs and those that normally oppose or prevent collapse (e.g., elastic recoil of the lung versus subatmospheric intrapleural pressure).

4. Pulmonary air volumes and capacities

1. Define, identify, and determine values for the pulmonary volumes (inspiratory reserve volume [IRV], tidal volume [TV], expiratory reserve volume [ERV], and residual volume [RV]) and the pulmonary capacities (inspiratory capacity [IC], functional residual capacity [FRC], vital capacity [VC], and total lung capacity [TLC]).
2. Define anatomical dead space.
3. Explain the effect of anatomical dead space on alveolar ventilation and on the

composition of alveolar and expired air.
4. Define and calculate minute ventilation and alveolar ventilation.

5. Mechanisms of gas exchange in the lungs and tissues

1. Explain the relationship between the total pressure of gases in a mixture and the partial pressure of an individual gas (i.e., Dalton's Law).
2. Explain the relationship between the partial pressure of a gas in air, the solubility of that gas in water, and the amount of the gas that can dissolve in water.
3. Compare and contrast the solubility of oxygen and carbon dioxide in plasma.
4. Describe oxygen and carbon dioxide concentration gradients and net gas movements between the alveoli and the pulmonary capillaries.
5. Analyze how oxygen and carbon dioxide movements are affected by changes in partial pressure gradients (e.g., at high altitude), area of the exchange surface, permeability of the exchange surface, and diffusion distance.
6. Explain the effects of local changes in oxygen and carbon dioxide concentrations on the diameters of pulmonary arterioles and bronchioles.
7. Use the mechanisms of ventilation-perfusion coupling to predict the effect that reduced alveolar ventilation has on the distribution of pulmonary blood flow and to predict the effect that reduced pulmonary blood flow has on bronchiole diameter.
8. Describe oxygen and carbon dioxide concentration gradients and net gas movements between systemic capillaries and the body tissues.
9. Explain the influence of cellular respiration on oxygen and carbon dioxide gradients that govern gas exchange between blood and body tissues.

6. Mechanisms of gas transport in the blood

1. Describe the ways in which oxygen is transported in blood, and explain the relative importance of each to total oxygen transport.
2. State the reversible chemical equation for oxygen binding to hemoglobin and predict how raising or lowering the partial pressure of oxygen will shift the equilibrium.
3. Interpret the oxygen-hemoglobin saturation curve at low and high partial pressures of oxygen.
4. Explain the changes in hemoglobin affinity for oxygen when the curve shifts to the right or the left.
5. List factors that shift the oxygen-hemoglobin saturation curve to the right, and explain how this results in increased oxygen release at the tissues.
6. List factors that shift the oxygen-hemoglobin saturation curve to the left, and explain how this facilitates oxygen binding to hemoglobin in the lungs.
7. *Describe the oxygen-fetal hemoglobin saturation curve and its impact on oxygen delivery to fetal tissues.
8. Describe the ways in which carbon dioxide is transported in blood and explain the relative importance of each to total carbon dioxide transport.
9. State the reversible chemical equation for the reaction of carbon dioxide and water to carbonic acid and then to hydrogen ion and bicarbonate ion.
10. Explain the relationship between pH and hydrogen ion concentration.

11. Predict how changing the partial pressure of carbon dioxide will affect the pH and the concentration of bicarbonate ions in the plasma.
12. Predict how changing the pH or the concentration of bicarbonate ions will affect the partial pressure of carbon dioxide in the plasma.
13. State the reversible chemical equation for carbon dioxide binding to deoxyhemoglobin.
14. Explain the role of each of the following in carbon dioxide transport: carbonic anhydrase, hydrogen ions binding to hemoglobin, the chloride shift, and oxygen-hemoglobin saturation level.

7. Control of pulmonary ventilation

1. Describe the locations and functions of the brainstem respiratory centers.
2. List and describe the major chemical and neural stimuli to the respiratory centers.
3. Compare and contrast the central and peripheral chemoreceptors.
4. Define hyperventilation, hypoventilation, panting, eupnea, hyperpnea, and apnea.
5. Explain why it is possible to hold one's breath longer after hyperventilating than after eupnea.

8. Application of homeostatic mechanisms

1. Provide specific examples to demonstrate how the respiratory system responds to maintain homeostasis in the body.
2. Explain how the respiratory system relates to other body systems to maintain homeostasis.

9. Predictions related to homeostatic imbalance

1. Given a factor or situation (e.g., pulmonary fibrosis), predict the changes that could occur in the respiratory system and the consequences of those changes (i.e. given a cause, state a possible effect).
2. *Given a disruption in the structure or function of the respiratory system (e.g., atelectasis), predict the possible factors or situations that might have created the disruption (i.e. given an effect, predict possible causes).

HAPS Anatomy & Physiology Learning Outcomes
MODULE N: Digestive system

Topic from HAPS Guidelines (in bold font)
Learning Outcomes (indented, regular font)[22]

1. **Structure and functions of the digestive system**
    1. Describe the major functions of the digestive system.
    2. Explain the differences between the gastrointestinal (GI) tract (alimentary canal) and the accessory digestive organs.
    3. Compare and contrast mechanical digestion and chemical digestion, including where they occur in the digestive system.
    4. Define peristalsis.
    5. Trace the pathway of ingested substances through the gastrointestinal (GI) tract.

2. **General gross and microscopic anatomy of the gastrointestinal (GI) tract**
    1. List and identify the organs that compose the gastrointestinal (GI) tract.
    2. Identify and describe the gross anatomic and microscopic structure and function of each of the gastrointestinal (GI) tract tunics (layers): mucosa, submucosa, muscularis (muscularis externa), and serosa or adventitia.

3. **Peritoneum and mesenteries**
    1. Identify and describe the location, structure, and function of the visceral and parietal peritoneum, serous fluid, and the peritoneal cavity.
    2. Define mesentery and explain its function.
    3. Compare and contrast the locations of the mesenteries (e.g., mesentery proper, mesocolon, lesser omentum, greater omentum).
    4. Explain the difference between an intraperitoneal and a retroperitoneal organ.
    5. Identify which digestive system organs are intraperitoneal or retroperitoneal.

4. **Oral cavity**
    1. Identify and describe the boundaries of the oral cavity.
    2. Define mastication.
    3. Compare and contrast the composition and functions of the hard palate, soft palate, and uvula.
    4. Identify and describe the structures (e.g., taste buds, papillae) and the functions of the tongue.
    5. Describe the structure and function of teeth.
    6. Describe the structure and function of the salivary glands.
    7. Describe the composition and functions of saliva.

[22] An asterisk (*) preceding a learning outcome designates it as an optional, advanced learning outcome. The HAPS A&P Comprehensive Exam does not address these optional learning outcomes.

5. **Anatomy of the pharynx**
    1. Identify and describe the different regions of the pharynx with respect to the passage of air and/or food.

6. **Gross and microscopic anatomy of the esophagus**
    1. Identify and describe the gross anatomy of the esophagus, including its location relative to other body structures.
    2. Describe the general functions of the esophagus.
    3. Describe the anatomic specializations of the esophageal tunics (e.g., composition of the mucosa and muscularis [muscularis externa]) compared to the tunics of the rest of the GI tract.
    4. Relate the anatomic specializations of the esophagus to the organ's functions.

7. **Gross and microscopic anatomy of the stomach**
    1. Identify and describe the gross anatomy of the stomach, including its location relative to other body structures.
    2. Describe the general functions of the stomach.
    3. Describe the anatomic specializations of the stomach tunics compared to the tunics of the rest of the GI tract.
    4. Relate the anatomic specializations of the stomach tunics (e.g., number of layers of muscle in the muscularis [muscularis externa]) to the organ's functions.
    5. Identify and describe the gastric glands, including their cells (e.g., parietal cells, chief cells).
    6. Describe the compositions, locations, and functions of the inferior esophageal (cardiac, lower esophageal) sphincter and the pyloric sphincter.
    7. Identify gastric folds (rugae) and discuss their functional significance.

8. **Gross and microscopic anatomy of the small intestine**
    1. Identify and describe the gross anatomy of the small intestine, including its location relative to other body structures.
    2. Describe the general functions of the small intestine.
    3. Identify the specific segments of the small intestine (i.e., duodenum, jejunum, ileum), including their relative length.
    4. Describe the anatomic specializations of the small intestine tunics (e.g., circular folds [plicae circulares], villi, microvilli) compared to the tunics of the rest of the GI tract.
    5. Relate the anatomic specializations of the small intestine tunics (e.g., circular folds [plicae circulares], villi, microvilli) to the organ's functions.
    6. Identify and describe the function of the following small intestine structures: duodenal glands (Brunner glands), intestinal glands (crypts of Lieberkuhn), and Peyer patches (lymphoid [lymphatic] nodules).

9. **Gross and microscopic anatomy of the large intestine, rectum, and anal canal**

1. Identify and describe the gross anatomy of the large intestine, rectum and anal canal, including their location relative to other body structures.
2. Identify the specific segments and related flexures of the large intestine.
3. Describe the general functions of the large intestine, rectum, and anal canal.
4. Describe the specializations of the large intestine tunics (e.g., composition of the muscularis [muscularis externa]) compared to the tunics of the rest of the GI tract.
5. Relate the specializations of the large intestine tunics (e.g., composition of the muscularis [muscularis externa]) to the organ's functions.
6. Compare and contrast the location, composition, and innervation (i.e., somatic versus autonomic) of the internal and external anal sphincters.

10. Gross and microscopic anatomy of the accessory digestive organs

Liver:

1. Describe the general functions of the liver.
2. Identify and describe the structure of the liver, including the individual lobes, ligaments (e.g., coronary ligament, falciform ligament, round ligament [ligamentum teres]), and the porta hepatis.
3. Describe the location of the liver relative to other body structures.
4. Identify and describe the histological components of the classic hepatic lobule.

Gallbladder:

5. Identify and describe the structure and functions of the gallbladder.
6. Describe the location of the gallbladder relative to other body structures.

Pancreas:

7. Identify and describe the structure and functions of the pancreas.
8. Describe the location of the pancreas relative to other body structures.
9. Identify and describe the major histological components of the pancreas (pancreatic acini and pancreatic islets [islets of Langerhans]) and discuss their major functions.

Biliary Apparatus:

10. Describe the major functions of the biliary apparatus.
11. Identify and describe the biliary apparatus components (i.e., left and right hepatic ducts, common hepatic duct, cystic duct, common bile duct, main pancreatic duct, hepatopancreatic ampulla [ampulla of Vater], hepatopancreatic sphincter [sphincter of Oddi], major duodenal papilla).
12. Trace the path of bile and pancreatic juice through the biliary apparatus.

11. Motility in the gastrointestinal (GI) tract

1. List the structures involved in deglutition and explain the process of deglutition, including the changes in position of the glottis and larynx that prevent aspiration.
2. Compare and contrast the following: peristalsis, mixing waves, segmentation, and mass movement.
3. Explain how volume, chemical composition, and osmolarity of chyme affect motility in

the stomach and in the duodenum.
4. Describe the defecation reflex and how it is affected by somatic and autonomic innervation.

12. Physiology of digestion

1. List the enzymes, their sources, their substrates, and their products of chemical digestion (enzymatic hydrolysis).
2. Identify the locations of chemical digestion of macromolecules (e.g., carbohydrates, proteins, lipids). Define zymogen and describe its importance in chemical digestion.
3. Describe the functions, production, and regulation of secretion of hydrochloric acid (HCl).
4. Define emulsification, and explain how and where bile salts facilitate fat digestion.
5. Describe the role of bacteria (microbiome) in digestion.

13. Processes of absorption

1. List the organs and specific structures that facilitate the absorption of nutrients (e.g., monosaccharides, amino acids, fatty acids, monoglycerides).
2. Explain the transport processes involved in the absorption of various nutrients.
3. Describe the absorption of minerals (e.g., calcium, iron) and vitamins (e.g., fat-soluble, water-soluble, B12) in the gastrointestinal (GI) tract.
4. Describe bile salt recycling.
5. Describe the process of water absorption in the gastrointestinal (GI) tract.

14. Hormonal and neural regulation of digestive processes

1. Describe the enteric nervous system (ENS) and explain its role in controlling digestive system function.
2. Compare and contrast sympathetic and parasympathetic innervation effects on the digestive system.
3. *List the components of a short reflex and a long reflex in the digestive system.
4. Explain the effects of the cephalic phase, gastric phase, and intestinal phase of digestion on various parts of the gastrointestinal (GI) tract.
5. Describe the source, stimuli for release, targets, and actions of gastrointestinal (GI) tract hormones - (e.g., gastrin, cholecystokinin, secretin).

15. Application of homeostatic mechanisms

1. Describe mass balance in the digestive system (e.g., fluid intake, digestive secretions, fluid absorption, excretion) and its relationship to body fluid homeostasis.
2. Explain how the digestive system relates to other body systems to maintain homeostasis.

16. Predictions related to homeostatic imbalance

1. Given a factor or situation (e.g., surgical removal of part of the stomach), predict the changes that could occur in the digestive system and the consequences of those changes (i.e., given a cause, state possible effects).

2. *Given a disruption in the structure or function of the digestive system (e.g., diarrhea), predict the possible factors or situations that might have created that disruption (i.e., given an effect, predict possible causes).

HAPS Anatomy & Physiology Learning Outcomes
MODULE O: Nutrients[23] & Metabolism

Topic from HAPS Guidelines (in bold font)
Learning Outcomes (indented, regular font)[24]

Note: HAPS recognizes that there is a great deal of variability in length and depth of coverage of nutrients and metabolism. The learning outcomes listed below are for those courses that include a significant nutrients and metabolism component in their human anatomy and physiology class.

1. Nutrients

1. Define nutrient, essential nutrient, and non-essential nutrient.
2. Describe common uses in the body for carbohydrates, fats, and proteins.
3. Classify vitamins as either fat-soluble or water-soluble, and describe the major uses in the body of each vitamin.
4. Name the major minerals (e.g., calcium, sodium, potassium) and trace elements (e.g., iron, iodine, zinc) and their roles within various physiological processes in the body.
5. Explain the significance of protein intake to nitrogen balance.

2. Introduction to metabolism

1. Define metabolism, anabolism, and catabolism, and provide examples of anabolic and catabolic reactions.
2. Compare and contrast the roles of enzymes and cofactors in metabolic processes.
3. Explain the roles of coenzyme A, nicotinamide adenine dinucleotide (NAD), and flavin adenine dinucleotide (FAD) in metabolism.
4. Describe the processes of oxidation, reduction, decarboxylation, deamination, and phosphorylation.

3. Cellular respiration and metabolism of carbohydrates, fats, and proteins

1. Describe the processes of aerobic respiration (e.g., citric acid [Krebs, tricarboxylic acid or TCA] cycle, electron transport chain) in the oxidation of glucose to generate ATP.

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[23] The HAPS Learning Outcome task force made a conscious decision to focus this module on nutrients, rather than diet. Hence, we limit our discussion to nutrients, and rename this module as nutrients and metabolism (rather than nutrition and metabolism).

[24] An asterisk (*) preceding a learning outcome designates it as an optional, advanced learning outcome. The HAPS A&P Comprehensive Exam does not address these optional learning outcomes.

2. Describe the processes of anaerobic respiration (e.g., glycolysis) in the oxidation of carbohydrates to generate ATP.
3. Describe metabolic pathways that produce or store glucose (e.g., glycogenesis, glycogenolysis, gluconeogenesis).
4. Describe the anabolic and catabolic processes of fat metabolism (e.g., lipolysis, lipogenesis) and how these processes interact with carbohydrate metabolism.
5. Describe the anabolic and catabolic processes of protein metabolism (e.g., deamination, transamination) and how these processes interact with carbohydrate metabolism.
6. Compare and contrast carbohydrate, fat, and protein metabolism in the fed (absorptive) and fasted (post-absorptive) states[25].
7. Describe the effects of hormones (e.g., cortisol, growth hormone, thyroid hormone, insulin, glucagon) on the anabolic and catabolic metabolism of carbohydrates, fats, and proteins.

4. Energy balance and thermoregulation

1. Define metabolic rate and describe the conditions under which basal metabolic rate is measured.
2. Describe factors that affect metabolic rate.
3. Describe the roles of the liver, adipose tissue, and skeletal muscle in metabolism.
4. Define calorie and kilocalorie.
5. Describe energy yields per gram for carbohydrates, fats, and proteins.
6. Describe the neural and chemical control of appetite and food intake.
7. Explain the importance of thermoregulation in the body.
8. Explain how various organ systems and behaviors participate in thermoregulation.

5. Application of homeostatic mechanisms

1. Explain how metabolic processes participate in the maintenance of blood glucose and body temperature homeostasis.

6. Predictions related to homeostatic imbalance

1. Given a factor or situation (e.g., cirrhosis of the liver), predict the changes that could occur in metabolism and the consequences of those changes (i.e., given a cause, state a possible effect).

[25] The terms *absorptive* and *post-absorptive* may confuse students because anabolic processes of the fed state continue after nutrients have been absorbed.

2. *Given a disruption in metabolism (e.g., low hemoglobin concentration), predict the possible factors or situations that might have created that disruption (i.e., given an effect, predict possible causes).

HAPS Anatomy & Physiology Learning Outcomes
MODULE P: Urinary System

Topic from HAPS Guidelines (in bold font)
Learning Outcomes (indented, regular font)[26]

1. General functions of the urinary system
1. Describe the major functions of the urinary system and which organs are responsible for those functions.

2. Gross and microscopic anatomy of the kidney
1. Identify and describe the anatomic structure of the kidney, including its coverings.
2. Distinguish histologically between the renal cortex and the renal medulla.
3. Trace the path of blood flow through the kidney, from the renal artery to the renal vein.
4. Identify and describe the structure of a typical nephron, including the renal corpuscle (i.e.,glomerular [Bowman's] capsule, glomerulus) and renal tubule (i.e., proximal convoluted tubule, nephron loop [loop of Henle], distal convoluted tubule).
5. Identify and describe the vascular elements associated with the nephron (i.e., afferent and efferent arterioles, glomerulus, peritubular capillaries, vasa recta).
6. Compare and contrast the anatomic structure of the cortical nephrons and juxtamedullary nephrons.
7. Trace the flow of filtrate from the renal corpuscle through the collecting duct.
8. Identify the location, structures and cells of the juxtaglomerular apparatus (JGA) and discuss its significance.

3. Gross and microscopic anatomy of the urinary tract (i.e., ureters, urinary bladder, urethra)
1. Identify and describe the gross anatomy and location of the ureters, urinary bladder, and urethra.
2. Identify and describe the microscopic anatomy of the ureters, urinary bladder, and urethra.
3. Compare and contrast the anatomy of the male urethra versus the female urethra.
4. Compare and contrast the locations, innervation and functions of the internal urethral sphincter and external urethral sphincter.
5. Trace the path of urine from the collecting duct of the kidney to the external urethral orifice.

4. Functional process of urine formation, including filtration, reabsorption, and secretion
1. Describe the three processes that take place in the nephron (i.e., filtration, reabsorption, and secretion) and explain how the integration of these three processes determines the volume and composition of urine.

[26] An asterisk (*) preceding a learning outcome designates it as an optional, advanced learning outcome. The HAPS A&P Comprehensive Exam does not address these optional learning outcomes.

2. Compare and contrast blood plasma, glomerular filtrate, and urine.
3. For any solute, explain how renal filtration, reabsorption, and secretion determine the excretion rate of that solute.
4. Describe the filtration structures that lie between the lumen of the glomerular capillaries and the capsular (Bowman) space.
5. Define glomerular filtration rate (GFR) and explain the role of blood pressure, capsule fluid pressure, and colloid osmotic (oncotic) pressure in determining GFR.
6. Describe factors that can change blood pressure, capsule fluid pressure, and colloid osmotic (oncotic) pressure and thereby change glomerular filtration rate (GFR).
7. Explain the role of the juxtaglomerular apparatus (JGA) in tubuloglomerular feedback.
8. Compare and contrast tubular reabsorption and secretion with respect to the direction of solute movement and the tubule segments in which each process occurs.
9. Describe specific mechanisms of transepithelial transport that occur in different parts of the nephron (e.g., active transport, osmosis, facilitated diffusion, electrochemical gradients, receptor-mediated endocytosis, transcytosis).
10. Give examples of each type of transepithelial transport, including the substance being transported, any membrane proteins involved, and the direction of movement across the tubule wall (e.g., water is reabsorbed from the collecting duct through aquaporin water channels).
11. For the important solutes of the body (e.g., Na+, K+, glucose, urea), describe how each segment of the nephron handles the solute and compare the filtration rate of the solute to its excretion rate (i.e., the net handling of the solute by the nephron).[27]
12. Explain the difference between clearance of a solute and renal handling of a solute.
13. State the equation for clearance of a solute and explain how inulin and creatinine clearance are used to determine glomerular filtration rate (GFR).
14. Describe the percentage of filtrate that is reabsorbed in each segment of the nephron.
15. Trace the changes in filtrate osmolarity as it passes through the segments of the nephron.
16. Explain the role of the nephron loop (of Henle), its permeability to water, and the high osmolarity of the interstitial fluid in the renal medulla in the formation of dilute urine.[28]
17. Describe the transport processes involved in eliminating drugs (e.g., penicillin), wastes, and foreign substances.
18. Describe the composition of normal urine.

5. Control of sodium, potassium, and water homeostasis

[27] We are choosing to include the renal handling of hydrogen ions and bicarbonate ions in the fluid/electrolyte discussion of acid/base balance (Module Q).

[28] We are intentionally not including the details of the countercurrent mechanisms in these LOs because they are not essential for understanding renal function, and they are no longer taught in many medical physiology courses.

1. For the renin-angiotensin system (RAS), describe the factors that initiate renin release, the pathway from angiotensinogen to angiotensin II (ANGII), and the effects of ANGII on various tissues.
2. Describe the signals that cause release of aldosterone from the adrenal cortex and the effect of aldosterone on the nephron, including the tubule segment involved and the transport mechanisms that are altered by aldosterone.
3. Describe the effect of vasopressin (ADH, antidiuretic hormone) on the nephron and on the final concentration of urine.
4. Describe the factors that cause release of natriuretic peptide hormones, their sites of synthesis, and their effects on the nephron.

6. Additional endocrine activities of the kidney

1. Describe the role of the kidney in vitamin D activation.
2. Describe the role of the kidney in regulating erythropoiesis.
3. Describe the effect of parathyroid hormone (PTH) on renal handling of calcium and phosphate.

7. Micturition (urination)

1. Describe the micturition reflex and the role of the autonomic nervous system in the reflex.
2. Describe voluntary control of micturition.

8. Application of homeostatic mechanisms

1. Provide specific examples to demonstrate how urinary system processes help maintain solute and osmolarity homeostasis in the body.

9. Predictions related to disruption of homeostasis

1. Given a factor or situation (e.g., hyperglycemia), predict the changes that could occur in the urinary system and the consequences of those changes (i.e., given a cause, state a possible effect).
2. *Given a disruption in the structure or function of the urinary system (e.g., blood in the urine), predict the possible factors or situations that might have caused that disruption (i.e., given an effect, predict possible causes).

HAPS Anatomy & Physiology Learning Outcomes
MODULE Q: Fluid/Electrolytes & Acid-Base Balance

Topic from HAPS Guidelines (in bold font)
Learning Outcomes (indented, regular font)[29]

Note: HAPS recognizes that there is a great deal of variability in length and depth of coverage of this topic. The learning outcomes listed below are for those courses that include significant discussion of this topic. In addition, some concepts regarding this topic may be covered instead within another module (e.g., aldosterone's effect on the nephron is covered in Module P - Urinary System).

1. Body fluid compartments

1. Compare and contrast total body water (TBW) volumes in normal adult males and females.
2. Compare and contrast relative volumes and osmolarities of intracellular fluid (ICF) and extracellular fluid (ECF).
3. Explain the subdivision of the extracellular fluid (ECF) compartment into plasma and interstitial fluid (IF), and compare volumes and composition of plasma and IF.
4. Describe the boundary walls that separate different body fluid compartments and list transport mechanisms by which water and other substances move between compartments.

2. Regulation of body osmolarity

1. Describe the normal routes of body water entry and loss, and explain how changes in water intake/loss can disrupt osmolarity homeostasis.
2. Describe behavioral mechanisms that control water intake and loss.
3. Explain the role of hypothalamic osmoreceptors in regulation of body osmolarity.
4. Describe changes to body fluid compartment volumes and osmolarity when a person drinks a large volume of pure water, and then explain the compensatory mechanisms that attempt to restore normal volumes and osmolarity.

3. Homeostasis of blood volume, blood pressure, and body osmolarity

1. Explain what happens to blood pressure when blood volume decreases significantly due to dehydration or hemorrhage.
2. Compare changes in body osmolarity in dehydration and hemorrhage.
3. Explain how the cardiovascular, endocrine, and urinary systems monitor blood volume and/or blood pressure.
4. Explain the integrated responses of the cardiovascular, endocrine, and urinary systems to low blood pressure as a result of dehydration.
5. *Compare and contrast the compensatory mechanisms used to restore blood pressure in dehydration to those used in hemorrhage.

[29] An asterisk (*) preceding a learning outcome designates it as an optional, advanced learning outcome. The HAPS A&P Comprehensive Exam does not address these optional learning outcomes.

4. Potassium and calcium homeostasis

1. Explain the importance of maintaining potassium homeostasis with regards to membrane potential, and provide examples of dysfunction that occur when plasma potassium levels are too high or too low.
2. Describe the integrated responses of the endocrine and urinary systems to disruptions of potassium homeostasis.
3. Explain the importance of maintaining calcium homeostasis, and provide examples of dysfunction that occur when plasma calcium levels are too high or too low.
4. Describe the integrated responses of the endocrine, digestive, skeletal, and urinary systems to disruptions of calcium homeostasis.

5. Acid-base homeostasis and buffer systems

1. State the normal pH range for arterial blood and the pH range that is compatible with life.
2. Explain how changes in pH outside the normal range adversely affect body functions.
3. State the normal ranges for arterial blood P_{CO2} and HCO_3^- .
4. Describe the major buffer systems of the body (e.g., bicarbonate buffer system, protein buffer system) and their locations (e.g., extracellular fluid) in the body.
5. Explain the relationship between transport of carbon dioxide in the blood and the bicarbonate buffer system in the plasma.
6. Using the equation $CO_2 + H_2O \leftrightarrow H^+ + HCO_3^-$, explain what happens to pH when arterial blood P_{CO2} and HCO_3^- concentrations change.

6. Integrated control of acid-base homeostasis

1. Explain the relationship between changes in alveolar ventilation (i.e., hypoventilation and hyperventilation), arterial blood P_{CO2}, arterial blood pH, and arterial blood HCO_3^-.
2. Explain the mechanisms by which the nephron secretes or reabsorbs hydrogen ions.
3. Explain the mechanisms by which the nephron retains filtered bicarbonate ions and makes new bicarbonate ions.
4. Define acidosis and alkalosis.
5. Compare and contrast metabolic and respiratory causes of pH imbalances.
6. Describe the concept of compensation in relation to disruption of pH homeostasis.
7. *Given arterial blood values for P_{CO2}, pH and HCO_3^-, determine whether a patient is in acidosis or alkalosis and whether the cause of the pH disturbance is metabolic or respiratory.

HAPS Anatomy & Physiology Learning Outcomes

MODULE R: Reproductive System

Topic from HAPS Guidelines (in bold font)

Learning Outcomes (indented, in regular font)[30]

1. Overview of the male and female reproductive systems

1. Compare and contrast the major anatomy of the male and female reproductive systems.
2. Identify male and female homologues of various reproductive system structures (e.g., ovary is homologous to the testis).
3. Describe the functions of the hormones involved in the regulation of the reproductive processes (e.g., gonadotropin releasing hormone [GnRH], follicle stimulating hormone [FSH], luteinizing hormone [LH], androgens, inhibin, estrogens, progesterone).

2. Gross and microscopic anatomy of the male reproductive system

1. Identify and describe the gross anatomy, microscopic anatomy, and functions of the testes.
2. Identify and describe the gross anatomy, microscopic anatomy, and functions of the epididymis.
3. Identify and describe the structure and functions of the spermatic cord and male reproductive ducts (e.g., ductus [vas] deferens, ejaculatory duct, urethra).
4. Identify and describe the structure and functions of accessory glands (i.e., seminal glands [seminal vesicles], prostate gland, bulbourethral [Cowper] glands).
5. Identify and describe the structure and functions of the male external genitalia (e.g., scrotum, penis).
6. Describe the pathway of sperm from the seminiferous tubules to the external urethral orifice of the penis.
7. Describe the production, composition, and functions of semen.

3. Gross and microscopic anatomy of the female reproductive system

1. Identify and describe the gross anatomy, microscopic anatomy, and functions of the ovaries.
2. Identify and describe the gross anatomy, microscopic anatomy, and functions of the uterus and uterine (fallopian) tubes.
3. Identify and describe the ligaments of the female reproductive system (e.g., broad ligament, ovarian ligament, suspensory ligament of the ovary, round ligament of the uterus).
4. Identify and describe the structure and function of the vagina.

[30] An asterisk (*) preceding a learning outcome designates it as an optional, advanced learning outcome. The HAPS A&P Comprehensive Exam does not address these optional learning outcomes.

5. Identify and describe the structure and functions of the external genitalia (e.g., mons pubis, labia majora, labia minora, clitoris, greater vestibular glands).
6. Identify and describe the structure and functions of the mammary glands.
7. Describe the pathway of the oocyte from the ovary to the uterus.

4. Spermatogenesis and spermiogenesis

1. Define the processes of spermatogenesis and spermiogenesis.
2. Describe the stages of spermatogenesis in the seminiferous tubule, including the roles of the nurse (sustentacular, Sertoli) cells and interstitial cells (of Leydig).
3. Describe endocrine regulation of spermatogenesis.

5. Oogenesis, folliculogenesis, and the ovarian cycle

1. Define the process of oogenesis (oocyte development).
2. Describe the stages of folliculogenesis (ovarian follicle development).
3. Describe a typical ovarian cycle and explain how the process of folliculogenesis spans multiple ovarian cycles.
4. Define ovulation, and explain the role of luteinizing hormone (LH) in ovulation.
5. Describe endocrine regulation of oogenesis, folliculogenesis, and the ovarian cycle.

6. Comparison of male and female gametogenesis

1. Compare and contrast the timing and number of oocytes produced in oogenesis and sperm produced in spermatogenesis.
2. Compare and contrast endocrine regulation of spermatogenesis and oogenesis.

7. Uterine (menstrual) cycle

1. Name the phases of the uterine (menstrual) cycle, and describe the anatomical changes in the uterine wall that occur during each phase.
2. Describe the correlation between the uterine and ovarian cycles.

8. Lifespan changes within the male and female reproductive systems

1. Define puberty.
2. Compare and contrast the events of female and male puberty.
3. Compare and contrast secondary sex characteristic development in males and females.
4. Compare and contrast female and male physiological sexual responses.
5. Define menopause and describe the physiological changes associated with menopause.
6. Compare and contrast menopause with andropause.
7. Describe examples of how birth control methods disrupt normal reproductive function.

9. Fertilization and pregnancy

1. Define fertilization.
2. Describe the processes that facilitate fertilization (e.g., sperm capacitation,

acrosomal reaction).
3. Describe the three phases of fertilization (i.e., corona radiata penetration, zona pellucida penetration, fusion of the oocyte and sperm plasma membranes).
4. Describe the formation and function of the placenta and extraembryonic membranes.
5. Describe the hormones associated with pregnancy and the effects of these hormones.
6. *Describe the functional changes in the woman's body during pregnancy.

10. Parturition (labor)

1. Define parturition (labor).
2. Explain the hormonal events that initiate and regulate labor.
3. *Describe the three stages of labor.

11. Postpartum changes to the mother

1. *Define the postpartum period.
2. *Describe the hormonal changes that occur after parturition.
3. *Describe the functional changes in the woman's body during the postpartum period.
4. Describe the hormonal regulation of lactation.

12. Predictions related to disruption of the reproductive system

1. Given a factor or situation (e.g., ectopic pregnancy), predict the changes you could see in the reproductive system and the consequences of those changes (i.e., given a cause, state a possible effect).
2. *Given a disruption in the structure or function of the reproductive system (e.g., vasectomy), predict the possible factors or situations that might have caused that disruption (i.e., given an effect, predict possible causes).

HAPS Anatomy & Physiology Learning Outcomes

MODULE S: Introduction to Heredity

Topic from HAPS Guidelines (in bold font)

Learning Outcomes (indented, regular font)

Note: This module is provided for A&P courses that do not have a prerequisite class which includes information about heredity. Content covered by required prerequisite courses does not need to be repeated in Anatomy & Physiology. Due to the variability in coverage, the HAPS Anatomy and Physiology Exam does not ask any questions about heredity.

1. Genetic variability

1. Describe events that lead to genetic variability of gametes.

2. Gene expression and inheritance

1. Define the terms chromosome, gene, allele, homologous, homozygous, heterozygous, genotype and phenotype.
2. Explain the genetic concepts of dominant and recessive alleles, incomplete dominance, codominance, and multiple alleles.
3. Compare and contrast monogenic inheritance and polygenic inheritance.
4. Define epigenetics and explain the impact of environmental factors on gene expression.
5. Describe the role of sex chromosomes in sex determination and sex-linked inheritance.

3. Genetic testing

1. Describe examples of prenatal and postnatal genetic testing.

HAPS Anatomy & Physiology Learning Outcomes
MODULE T: Embryology

Topic from HAPS Guidelines (in bold font)

Learning Outcomes (indented, regular font)[31]

Note: HAPS recognizes that there is a great deal of variability in length and depth of coverage of embryology. The learning outcomes listed below are for those courses that include an embryology component in their human anatomy and physiology class. Due to the variability in coverage, the HAPS Anatomy and Physiology Exam does not ask any questions about the embryology topics listed below.

1. Timeline of human development

1. Define the pre-embryonic period, embryonic period, and fetal period, and describe the main events that occur in each.

2. Conception through week 2 (bilaminar germinal disc)

1. Describe the process and events of fertilization.
2. Describe the changes that occur from zygote to morula to blastocyst.
3. Explain the timing and importance of cleavage.
4. Compare and contrast the locations and end fates of the embryoblast (inner cell mass) and the trophoblast of the blastocyst.
5. Explain the process and timing of implantation.
6. *Describe the process by which the embryoblast transforms into a bilaminar germinal disc.
7. Describe the formation and functions of the extraembryonic membranes (i.e., amnion, yolk sac, allantois, chorion).
8. List the maternal and fetal components of the placenta.

3. Embryonic period

1. Define the process and timing of gastrulation.
2. Identify the three primary germ layers resulting from gastrulation, and the major structures formed from each primary germ layer.
3. Define organogenesis.
4. Define neurulation and state when this process occurs.
5. Describe how a neural plate is transformed into a neural tube and explain how neural crest cells are formed.
6. Compare and contrast the adult fates of the neural tube and the neural crest cells.
7. *Describe the processes of craniocaudal and lateral folding of the embryo.

4. Fetal period

[31] An asterisk (*) preceding a learning outcome designates it as an optional, advanced learning outcome. The HAPS A&P Comprehensive Exam does not address these optional learning outcomes.

1. Describe the major events of the fetal period.

