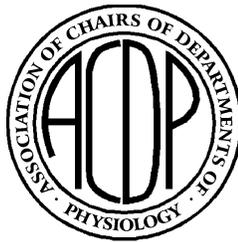


# Medical Physiology Learning Objectives



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# Introduction and Rationale

As medical and other professional schools in the health sciences continue to modify their curricula, a variety of approaches are being utilized to teach the students. These widely diversified approaches range from the traditional and systematic course in physiology and neuroscience to those in which there is not an identifiable course in physiology. While a systematic presentation of physiological concepts under the direction of physiology faculty continues to be the most efficient way to ensure appropriate depth and breadth, physiologically related topics are often spread out over several courses. It is, nevertheless, essential that all medical and health professional students receive sufficient exposure to the physiological concepts that provide the foundations needed for further studies in pharmacology, pathology, pathophysiology, and medicine. The mechanisms of deranged function cannot be appreciated without an in-depth understanding of basic biophysical and physiological mechanisms. The purpose of developing these core competency criteria is to provide guidelines for the breadth and depth of knowledge in the physiological principles and concepts that are considered minimal and essential for further progress in understanding mechanisms of disease and body defenses. Regardless of the specific didactic or educational approach used by any given institution, that institution must develop mechanisms to assure that the students are being inculcated with these basic principles and concepts at appropriate depth of understanding. The development of these core learning objectives will allow all programs to determine if their students are achieving at least this basic level of understanding.

By necessity, the objectives define content to be taught. Not addressed in this document are issues related to the format in which this content should be presented. This will be dictated by factors and constraints (i.e., class size, number of faculty) unique to each institution. Nevertheless, all of the objectives can be attained using multiple teaching formats, and faculty need to the optimum teaching/learning format for their students. The curricular objectives are focused primarily on normal body function. However, it is recognized that this material must be presented in a context that prepares students for their roles as physicians. Accordingly, it is suggested that wherever possible clinical examples can and should be used to illustrate the underlying physiological principles.

This project has been endorsed by The American Physiological Society and the Association of Chairs of Departments of Physiology. The objectives will be revised and updated periodically – readers are asked to see the APS web site <http://www.the-aps.org/MedPhysObj> or the ACDP web site [http://www.acdponline.org/med\\_phys\\_obj.htm](http://www.acdponline.org/med_phys_obj.htm) for future versions of this project. Details on the construction and evaluation of the objectives project are also on the APS web site, published in the journal *Advances in Physiology Education* ([Adv Physiol Educ 25: 2-7, 2001](#)).

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University of Puerto Rico  
University of South Alabama  
University of South Florida  
Vanderbilt University  
Wayne State University

## Learning Objective Format

### Purpose of Learning Objectives

Learning objectives communicate the expectations of the faculty member. Consequently, the learning objectives have to identify the knowledge base, the appropriate depth or detail, and how the students are to use the knowledge. For a traditional 50-minute lecture, usually three to seven learning objectives can be constructed. For integrated courses, the objectives are provided in a group and are expected to be mastered during that block of the course.

### Bloom's Taxonomy

In 1956, Bloom identified six distinct levels of cognitive understanding, and organized them into a taxonomy of objectives in the cognitive domain. From basic to complex, the taxonomy categories are: Knowledge, Comprehension, Application, Analysis, Synthesis, and Evaluation. The taxonomy levels can be coupled with general objectives, and specific outcome action verbs, which lead to that level.

Level of Taxonomy	General Objectives	Specific Outcome Action Verbs
Knowledge	Knows terms Knows specific facts Knows rules Knows classifications and categories Knows criteria Knows methods and procedures Knows principles and generalizations Knows theories and structure	Defines Names States Identifies Describes Distinguishes
Comprehension	Translates communications Interprets relationships Extrapolates from given data	Interprets Converts Explains Predicts Generalizes Infers
Application	Applies principles	Uses Solves Constructs Prepares Demonstrates
Analysis	Analyzes organizations and relationships	Discriminates Outlines Diagrams Differentiates Infers Explains
Synthesis	Produces new arrangements	Designs Organizes Rearranges Compiles Modifies Creates
Evaluation	Judges on the basis of external criteria Judges on the basis of evidence	Appraises Compares Contrasts Discriminates Criticizes Detects

## Learning Objectives and Template

Learning objectives provide a focal point for student learning efforts. Objectives should be constructed so that the student will know:

1. The knowledge base they are expected to learn
2. The depth or detail they are to learn it
3. How they are to use this knowledge

One advantage of learning objectives is that you can use them to direct students to material not covered in class.

### Tips for Constructing Learning Objectives

- Objectives should be stated in terms of student behavior and the level of specificity that is expected
- Objectives should use an action verb that indicates the depth of understanding expected (see table on previous page)
- Objectives should be stated precisely using terms that have uniform meaning and are consistent with their reading resources
- Objectives should be realistic

#### EXAMPLES

The ECU Physiology Department committed to the use of learning objectives for all sections in 1994. Each instructor wrote objectives for the lecture. The objectives were reviewed by four other physiologists, and then the proposed objectives were revised to answer the concerns of the reviewers. The process is cumbersome, but the product is worth the effort. Here are sample objectives proposed for the lecture on microcirculation, followed by reviewers' comments, and finally the revised objectives.

#### Chapter 28 The Microcirculation and Lymphatics

**ORIGINAL 1.** Using Fick's Law for Diffusion, contrast the movement of oxygen and glucose from the plasma to the intracellular space. Based on their chemical properties, predict which of these substances would show diffusion limited movement and which would show flow limited movement.

AUTHOR: I expect the students to review the factors influencing diffusion (presented earlier in the course) and contrast the movement of two different agents from the blood to the cell. I also expect a working definition of flow-limited and diffusion-limited transport.

COMMITTEE: Glucose movement is tissue specific, and entry into the cell by any of a variety of glucose transporters further obscures my intent (transport from the blood to the cell). Identify

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a tissue, and delete intracellular space. Finally transport is a poorly defined term, replace with exchange (the term used in the text).

**REVISED 1.** Using Fick's Law for Diffusion, contrast the movement of oxygen and glucose from the plasma to a skeletal muscle cell. Based on their chemical properties, predict which of these substances would show diffusion limited exchange and which would show flow limited exchange.

**ORIGINAL 2.** Calculate the balance of hydrostatic and osmotic forces controlling fluid movement at the arteriolar and venular ends of a capillary bed. How is this balance altered by pre-capillary arteriolar constriction?

**AUTHOR:** The Starling forces control fluid exchange between the plasma and the interstitial fluid. The drop in arterial pressure along the capillary allows filtration at one area of the microcirculation and reabsorption at the other end of the microcirculation. Any factors that alter capillary pressure will affect this exchange.

**COMMITTEE:** Calculation requires standard values. Reference to the text forces students to use and review the appropriate figure. Replace fluid movement with the more specific transcapillary fluid exchange. Reword last sentence as an objective, with an action verb. Expand the objective to include the effects of venous pressure on capillary fluid exchange, such as occurs in ascites.

**REVISED 2.** Given the estimates in figure 28-7, calculate the balance of hydrostatic and osmotic forces controlling transcapillary fluid exchange at the arteriolar and venular ends of a capillary bed. Predict how this balance is altered by pre-capillary and post-capillary resistance and pressure changes.

**ORIGINAL 3.** List four causes of edema, and describe how each results from the disruption of the balance of microcirculatory fluid exchange and lymph flow.

**AUTHOR:** Disruption of the Starling forces, permeability, or lymphatic drainage each can cause edema.

**COMMITTEE:** OK as written (a minor miracle)

**ORIGINAL 4.** Describe how the theory of metabolic regulation of blood flow accounts for the observed phenomena of autoregulation, active hyperemia, and reactive hyperemia.

**AUTHOR:** Three theories can account for autoregulation. I feel that understanding of the metabolic theory has the most practical advantages, and I want to focus the student's attention on that area.

**COMMITTEE:** OK as written (they must have gotten tired)

# Cardiovascular

(revised 2006; 2011)

## Unique Characteristics of Cardiac Muscle

CV 1. Contrast the duration of the action potential and the refractory period in a cardiac muscle, a skeletal muscle, and a nerve. Sketch the temporal relationship between an action potential in a cardiac muscle cell and the resulting contraction (twitch) of that cell. On the basis of that graph, explain why cardiac muscle cannot remain in a state of sustained (tetanic) contraction.

CV 2. State the steps in excitation-contraction coupling in cardiac muscle. Outline the sequence of events that occurs between the initiation of an action potential in a cardiac muscle cell and the resulting contraction and then relaxation of that cell. Provide specific details about the special role of  $\text{Ca}^{2+}$  in the control of contraction and relaxation of cardiac muscle.

CV 3. Compare cardiac and skeletal muscle with respect to: cell size, electrical connections between cells, and arrangement of myofilaments. Based on ion permeability and electrical resistance describe role of gap junctions in creating a functional syncytium.

CV 4. Identify the role of extracellular calcium in cardiac muscle contraction. Identify other sources of calcium that mediate excitation-contraction coupling, and describe how intracellular calcium concentration modulates the strength of cardiac muscle contraction.

CV 5. Describe the role of Starling's Law of the Heart in keeping the output of the left and right ventricles equal.

CV 6. Describe the difference in the way changes in preload and changes in contractility influence ventricular force development. Compare the energetic consequences of these two separate mechanisms of force modulation.

## Electrophysiology of the Heart

CV 7. Sketch a typical action potential in a ventricular muscle and a pacemaker cell, labeling both the voltage and time axes accurately. Describe how ionic currents contribute to the four phases of the cardiac action potential. Use this information to explain differences in shapes of the action potentials of different cardiac cells.

CV 8. Describe the ion channels that contribute to each phase of the cardiac action potential. How do differences in channel population influence the shape of the action potential in the nodal, atrial muscle, ventricular muscle, and Purkinje fiber cardiac cells?

CV 9. Explain what accounts for the long duration of the cardiac action potential and the resultant long refractory period. What is the advantage of the long plateau of the cardiac action potential and the long refractory period?

CV 10. Beginning in the SA node, diagram the normal sequence of cardiac activation (depolarization) and the role played by specialized cells. Predict the consequence of a failure to conduct the impulse through any of these areas.

CV 11. Explain why the AV node is the only normal electrical pathway between the atria and the ventricles, and explain the functional significance of the slow conduction through the AV node. Describe factors that influence conduction velocity through the AV node.

CV 12. Explain the ionic mechanism of pacemaker automaticity and rhythmicity, and identify cardiac cells that have pacemaker potential and their spontaneous rate. Identify neural and humoral factors that influence their rate.

CV 13. Discuss the significance of “overdrive suppression” and “ectopic pacemaker,” including the conditions necessary for each to occur.

CV 14. Contrast the sympathetic and parasympathetic nervous system influence on heart rate and cardiac excitation in general. Identify which arm of the autonomic nervous system is dominant at rest and during exercise. Discuss ionic mechanisms of these effects on both working myocardium and pacemaker cells.

CV 15. Describe how cell injury, resulting in a less negative resting potential, alters ionic events in depolarization and repolarization.

CV 16. Define the following terms: decremental conduction, reentry, and circus movement.

## **Cardiac Function**

CV 17. Draw and describe the length-tension relationship in a single cardiac cell. Correlate the cellular characteristics of length, tension, and velocity of shortening with the intact ventricle characteristics of end diastolic volume, pressure, and  $dP/dt$ .

CV 18. Define preload and explain why ventricular end-diastolic pressure, atrial pressure and venous pressure all provide estimates of ventricular preload. Explain why ventricular end-diastolic pressure provides the most reliable estimate.

CV 19. Define afterload and explain how arterial pressure influences afterload. Describe a condition when arterial pressure does not provide a good estimate of afterload.

CV 20. Define contractility and explain why  $dp/dt$  is a useful index of contractility. Explain how the calcium transient differs between cardiac and skeletal muscle and how this influences contractility.

CV 21. Define the difference between cardiac performance and cardiac contractility. Describe the impact of changes in preload, afterload, and contractility in determining cardiac performance.

CV 22. Explain how changes in sympathetic activity alter ventricular work, cardiac metabolism, oxygen consumption and cardiac output.

CV 23. Write the formulation of the Law of LaPlace. Describe how it applies to ventricular function in the normal and volume overloaded (failing) ventricle.

CV 24. Draw a ventricular pressure-volume loop and on it label the phases and events of the cardiac cycle (ECG, valve movement).

CV 25. Differentiate between stroke volume and stroke work. Identify stroke volume and stroke work from a pressure-volume loop.

CV 26. Define ejection fraction and be able to calculate it from end diastolic volume, end systolic volume, and/or stroke volume. Predict the change in ejection fraction that would result from a change in a) preload, b) afterload, and c) contractility.

CV 27. Draw the change in pressure-volume loops that would result from changes in a) afterload, b) preload, or c) contractility, for one cycle and the new steady state that is reached after 20 or more cycles.

## **Cardiac Cycle**

CV 28. Understand the basic functional anatomy of the atrioventricular and semilunar valves, and explain how they operate.

CV 29. Draw, in correct temporal relationship, the pressure, volume, heart sound, and ECG changes in the cardiac cycle. Identify the intervals of isovolumic contraction, rapid ejection, reduced ejection, isovolumic relaxation, rapid ventricle filling, reduced ventricular filling and atrial contraction.

CV 30. Know the various phases of ventricular systole and ventricular diastole. Contrast the relationship between pressure and flow into and out of the left and right ventricles during each phase of the cardiac cycle.

CV 31. Understand how and why left sided and right sided events differ in their timing.

## **Physiology of Cardiac Defects (Heart Sounds)**

CV 32. Know the factors that contribute to the formation of turbulent flow.

CV 33. Describe the timing and causes of the four heart sounds.

CV 34. Describe the expected auscultation sounds that define mitral stenosis, mitral insufficiency, aortic stenosis, and aortic insufficiency. Explain how these pathologic changes would affect cardiac mechanics and blood pressure.

## **The Normal Electrocardiogram (ECG) and the ECG in Cardiac Arrhythmias and Myopathies**

CV 35. Define the term dipole. Describe characteristics that define a vector. Describe how dipoles generated by the heart produce the waveforms of the ECG.

CV 36. Describe the electrode conventions used by clinicians to standardize ECG measurements. Know the electrode placements and polarities for the 12 leads of a 12-lead electrocardiogram and the standard values for pen amplitude calibration and paper speed.

CV 37. Name the parts of a typical bipolar (Lead II) ECG tracing and explain the relationship between each of the waves, intervals, and segments in relation to the electrical state of the heart.

CV 38. Explain why the ECG tracing looks different in each of the 12 leads.

CV 39. Define mean electrical vector (axis) of the heart and give the normal range. Determine the mean electrical axis from knowledge of the magnitude of the QRS complex in the standard limb leads.

CV 40. Describe the alteration in conduction responsible for most common arrhythmias: i.e., tachycardia, bradycardia, A-V block, Wolff-Parkinson-White (WPW) syndrome, bundle branch block, flutter, fibrillation.

CV 41. Describe electrocardiographic changes associated respectively with myocardial ischemia, injury, and death. Define injury current and describe how it alters the S-T segment of the ECG.

## **Cardiac Output and Venous Return**

CV 42. Understand the principles underlying cardiac output measurements using the Fick principle, dye dilution, and thermodilution methods.

CV 43. Know how cardiac function (output) curves are generated and how factors which cause changes in contractility in the heart can alter the shape of cardiac function curves.

CV 44. Understand the concept of “mean systemic pressure,” its normal value, and how various factors can alter its value.

CV 45. Define venous return. Understand the concept of “resistance to venous return” and know what factors determine its value theoretically, what factors are most important in practice, and how various interventions would change the resistance to venous return.

CV 46. Construct a vascular function curve. Predict how changes in total peripheral resistance, blood volume, and venous compliance influence this curve.

CV 47. Explain why the intersection point of the cardiac function and vascular function curves represents the steady-state cardiac output and central venous pressure under the conditions represented in the graph.

CV 48 Use the intersection point of the cardiac function curve and vascular function curve to predict how interventions such as hemorrhage, heart failure, autonomic stimulation, and exercise will affect cardiac output and right atrial pressure. Predict how physiological compensatory changes would alter acute changes.

## **Fluid Dynamics**

CV 49. Describe the components of blood (cells, ions, proteins, platelets) giving their normal values. Relate the three red blood cell concentration estimates, red blood cell count, hematocrit, and hemoglobin concentration.

CV 50. Identify the source, stimulus for formation, and function of the hormone erythropoietin. Relate the rate of red blood cell synthesis to the normal red blood cell life span and the percentage of immature reticulocytes in the blood.

CV 51. Describe the functional consequence of the lack of a nucleus, ribosomes, and mitochondria for a) protein synthesis and b) energy production within the red blood cell.

CV 52. Discuss the normal balance of red blood cell synthesis and destruction, including how imbalances in each lead to anemia or polycythemia.

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CV 53. Explain how red blood cell surface antigens account for typing of blood by the A B O system and rhesus factor. Based on these antigens, identify blood type of a “universal donor” and a “universal recipient.”

CV 54. Know the factors that determine the total energy of the flowing blood and the relationship among these factors. Describe the usual reference point for physiological pressure.

CV 55. Be able to differentiate between flow and velocity in terms of units and concept.

CV 56. Understand the relationship between pressure, flow, and resistance in the vasculature and be able to calculate for one variable if the other two are known. Apply this relationship to the arteries, arterioles, capillaries, venules, and veins. Explain how blood flow to any organ is altered by changes in resistance to that organ.

CV 57. Explain how Poiseuille’s Law influences resistance to flow. Use it to calculate changes in resistance in a rigid tube (blood vessel). Explain the deviations from Poiseuille’s law predictions that occur in distensible blood vessels.

CV 58. Understand the relationship between flow, velocity, and cross-sectional area and the influence vascular compliance has on these variables. Explain how hemodynamics in blood vessels, especially microcirculation, deviate from theory due to anomalous viscosity, distensibility, axial streaming and critical closing behavior and the glycocalyx.

CV 59. Define resistance and conductance. Understand the effects of adding resistance in series vs. in parallel on total resistance and flow. Apply this information to solving problems characterized by a) resistances in series and b) resistances in parallel. Apply this concept to the redistribution of flow from the aorta to the tissues during exercise.

CV 60. List the factors that shift laminar flow to turbulent flow. Describe the relationship between velocity, viscosity, and audible events, such as murmurs and bruits.

CV 61. Understand the principles of flow through collapsible tubes, the Starling resistor, and what pressure gradient determines flow for different relative values of inflow, surrounding, and outflow pressures.

## **Arterial Pressure and the Circulation**

CV 62. Describe the organization of the circulatory system and explain how the systemic and pulmonary circulations are linked physically and physiologically.

CV 63. Describe blood pressure measurement with a catheter and transducer and explain the components of blood pressure waveform. Contrast that with the indirect estimation of blood pressure with a sphygmomanometer. Explain how each approach provides estimates of systolic and diastolic pressures. Given systolic and diastolic blood pressures, calculate the pulse pressure and the mean arterial pressure.

CV 64. Describe how arterial systolic, diastolic, mean, and pulse pressure are affected by changes in a) stroke volume, b) heart rate, c) arterial compliance, and d) total peripheral resistance.

CV 65. Contrast pressures and oxygen saturations in the arteries, arterioles, capillaries, venules, and veins of both the systemic and pulmonary circulations. Repeat that process for velocity of blood flow and cross-sectional area, and volume.

CV 66. Identify the cell membrane receptors and second messenger systems mediating the contraction of vascular smooth muscle by norepinephrine, angiotensin II, and vasopressin.

CV 67. Identify the cell membrane receptors and second messenger systems mediating the relaxation of vascular smooth muscle by nitric oxide, bradykinin, prostaglandins, and histamine. Include the role of the endothelial cell.

CV 68. Identify the cell membrane receptors and second messenger systems mediating changes in cardiac performance.

## **The Microcirculation and Lymphatics**

CV 69. Explain how water and solutes traverse the capillary wall. Use Fick's equation for diffusion to identify the factors that will affect the diffusion mediated delivery of nutrients from the capillaries to the tissues. Define and give examples of diffusion-limited and flow-limited exchange.

CV 70. Describe how changes in capillary surface area affect the capacity for fluid exchange.

CV 71. Define the Starling equation and discuss how each component influences fluid movement across the capillary wall.

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CV 72. Describe the pathway for leukocyte migration across the microcirculation, including leukocyte expression of cellular adhesion molecules, and recognition sites in the vascular endothelial cells.

CV 73. Starting at the post capillary venule, describe the process of angiogenesis, including the stimulus that initiates new vessel growth.

CV 74. Describe the Donnan effect and its importance in capillary dynamics.

CV 75. Predict how altering pressure or resistance in pre- and post-capillary regions alters capillary pressure and the consequence of this change on transmural fluid movement.

CV 76. Using the components of the Starling equation, explain why fluid does not usually accumulate in the interstitium of the lungs.

CV 77. Describe how histamine alters the permeability of the post capillary venules and how the loss of albumin into the interstitial space promotes localized edema.

CV 78. Describe the lymphatics, and explain how the structural characteristics of terminal lymphatics allow the reabsorption of large compounds, such as proteins.

CV 79. Contrast the structure of lymphatic capillaries and systemic capillaries, including the significance of the smooth muscle in the walls of the lymphatic vessels.

CV 80. Identify critical functions of the lymphatic system in fat absorption, interstitial fluid reabsorption, and clearing large proteins from the interstitial spaces.

CV 81. Diagram the relationship between interstitial pressure and lymph flow. Explain why edema does not normally develop as interstitial pressure increases.

CV 82. Explain how edema develops in response to: a) venous obstruction, b) lymphatic obstruction, c) increased capillary permeability, d) heart failure, e) tissue injury or allergic reaction, and f) malnutrition.

## **Regulation of Arterial Pressure**

CV 83. List the anatomical components of the baroreceptor reflex.

CV 84. Explain the sequence of events in the baroreflex that occur after an acute increase or decrease in arterial blood pressure. Include receptor response, afferent nerve activity, CNS integration, efferent nerve activity to the SA node, ventricles, arterioles, venules, and hypothalamus.

CV 85. Explain the sequence of events mediated by cardiopulmonary (volume) receptors that occur after an acute increase or decrease in arterial blood pressure. Include receptor response, afferent nerve activity, CNS integration, efferent nerve activity to the heart, kidney, hypothalamus, and vasculature.

CV 86. Explain the sequence of events mediated by cardiopulmonary (volume) receptors that occur after an acute increase or decrease in central venous pressure. Include receptor response, afferent nerve activity, CNS integration, efferent nerve activity to the heart, kidney, hypothalamus, and vasculature.

CV 87. Contrast the sympathetic and parasympathetic nervous system control of heart rate, contractility, total peripheral resistance, and venous capacitance. Predict the cardiovascular consequence of altering sympathetic nerve activity and parasympathetic nerve activity.

CV 88. Contrast the relative contribution of neural and renal mechanisms in blood pressure and blood volume regulation.

CV 89. Outline the cardiovascular reflexes initiated by decreases in blood O<sub>2</sub> and increases in blood CO<sub>2</sub>.

CV 89. Describe the release, cardiovascular target organs, and mechanisms of cardiovascular effects for angiotensin, atrial natriuretic factor, bradykinin, and nitric oxide.

CV 90. Describe the Cushing Reflex and the CNS ischemic pressor response.

## **Local Control of Blood Flow**

CV 91. Define autoregulation of blood flow. Distinguish between short-term and long-term autoregulatory responses and the mechanisms responsible for each.

CV 92. Describe how the theory of metabolic regulation of blood flow accounts for active hyperemia and reactive hyperemia.

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CV 93. Describe the contribution of myogenic tone to blood flow regulation.

CV 94. Identify the role of  $PO_2$ ,  $PCO_2$ , pH, adenosine, and  $K^+$  in the metabolic control of blood flow to specific tissues.

CV 95. Diagram the synthetic pathway for nitric oxide (EDRF, endothelial derived relaxing factor), including substrate and the interplay between endothelium and vascular smooth muscle.

CV 96. Discuss the circumstances and the mechanisms whereby humoral substances contribute to regulation of the microcirculation.

CV97. Discuss the interaction of a) intrinsic (local), b) neural, and c) humoral control mechanisms and contrast their relative dominance in the CNS, coronary, splanchnic, renal, cutaneous, and skeletal muscle vascular beds.

CV 98. Describe the role of angiogenesis in providing a long-term match of tissue blood flow and metabolic need.

### **Fetal and Neonatal Circulation**

CV 99. Describe the progressive changes in maternal blood volume, cardiac output, and peripheral resistance during pregnancy and at delivery.

CV 100. Contrast the blood flow pattern in the fetus with that of a normal neonate, including the source of oxygenated blood.

CV 101. Describe the function in utero of the fetal ductus venosus, foramen ovale, and ductus arteriosus. Explain the mechanisms causing closure of these structures at birth.

CV 102. Discuss the relative differences in oxygen saturation and pressure for blood in the major blood vessels and cardiac chambers of the fetus. Explain how these values change at birth.

CV 103. Describe fetal cardiovascular responses to acute hypoxia.

CV 104. Explain the unfavorable consequences to the neonate if either the ductus arteriosus or the foramen ovale fails to close or if pulmonary vascular resistance fails to decrease.

## **Hemostasis and Injury, Hemorrhage, Shock**

CV 105. Diagram the enzymes and substrates involved in the formation of fibrin polymers, beginning at prothrombin. Contrast the initiation of thrombin formation by intrinsic and extrinsic pathways.

CV 106. Contrast the mechanisms of anticoagulation of a) heparin, b) EGTA, and c) coumadin. Identify clinical uses for each agent.

CV 107. Describe the mechanisms of fibrinolysis by TPA (tissue plasminogen activator) and urokinase.

CV 108. Explain the role of the platelet release reaction on clot formation. Distinguish between a thrombus and an embolus.

CV 109. Explain why the activation of the clotting cascade does not coagulate all of the blood in the body.

CV 110. Describe the direct cardiovascular consequences of the loss of 30% of the circulating blood volume on cardiac output, central venous pressure, and arterial pressure. Describe the compensatory mechanisms activated by these changes.

CV 111. Explain three positive feedback mechanisms activated during severe hemorrhage that may lead to circulatory collapse and death.

CV 112. Contrast the change in plasma electrolytes, hematocrit, proteins, and colloid osmotic pressure following resuscitation from hemorrhage using a) water, b) 0.9% NaCl, c) plasma, and d) whole blood.

## **Coronary Circulation**

CV 113. Describe the phasic flow of blood to the ventricular myocardium through an entire cardiac cycle. Contrast this cyclic variation in myocardial flow a) in the walls of the right and left ventricles and b) in the subendocardium and subepicardium of the left ventricle.

CV 114. Explain how arterio-venous O<sub>2</sub> difference and oxygen extraction in the heart is unique when compared with other body organs.

CV 115. Explain the mechanism whereby coronary blood flow is coupled to myocardial workload, and identify stimuli that cause increases in coronary blood flow to occur.

CV 116. Explain how sympathetic stimulation alters heart rate, contractility, and coronary vascular resistance, as well as both directly and indirectly to change coronary blood flow. Identify the relative importance of the direct and indirect SNS effects in determining coronary blood flow during exercise.

CV 117. Describe what is meant by coronary vascular reserve and the role of collateral blood vessels. Discuss physiological and pathological events that decrease coronary vascular reserve.

### **Cerebral, Splanchnic, and Cutaneous Circulation**

CV 118. Contrast the local and neural control of cerebral blood flow. Discuss the relative importance of O<sub>2</sub>, CO<sub>2</sub>, and pH in regulating cerebral blood flow.

CV 119. Describe the structural components of the blood brain barrier and how this barrier impedes the movement of gases, proteins, and lipids from the blood to neurons. Identify the differences in cerebrospinal fluid and plasma relative to protein concentration, and describe the function of cerebrospinal fluid.

CV 120. Contrast the mechanisms of the two major types of stroke, hemorrhagic and occlusive stroke.

CV 121. Contrast the local and neural control of the splanchnic circulation. Describe the role of the hepatic portal system and the hepatic artery in providing flow and oxygen to the liver.

CV 122: Describe the blood pressure in the hepatic portal vein, hepatic sinusoids, and the vena cava. Given an increase in central venous pressure, predict how hepatic microcirculatory fluid exchange will be altered, including the development of ascites.

CV 123. Describe how the GI circulation is adapted for secretion and absorption. Explain the enterohepatic circulation.

CV 124. Contrast local and neural control of cutaneous blood flow.

CV 125. Discuss the unique characteristics of skin blood flow that are adaptive for body temperature regulation.

**Exercise** (also see Integration)

CV 126. Describe the cardiovascular consequences of exercise on peripheral resistance, cardiac output, A-V oxygen difference, and arterial pressure.

CV 127. Describe the redistribution of cardiac output during exercise to the CNS, coronary, splanchnic, cutaneous, and skeletal muscle vascular beds during sustained exercise (distance running). Explain the relative importance of neural and local control in each vascular bed.

CV 128. Discuss four adaptations to physical training on the cardiovascular system. Explain the mechanisms underlying each.

CV 129. Contrast the effects of static vs. dynamic exercise on blood pressure.

CV 130. Contrast the neural and local control of skeletal muscle blood flow at rest and during exercise.

CV 131. Contrast the effect of phasic and sustained skeletal muscle contraction on extravascular compression of blood vessels and on central venous pressure.

CV 132. Predict the changes in cardiac output and arterial pressure during the initial and the sustained phases of the Valsalva maneuver.

# Cell and General

(revised 2011)

## Biological Membranes, Solutes and Solutions

- CE 1. Understand the general concepts of homeostasis and the principles of positive and negative feedback in physiological systems.
- CE 2. Describe the polar structure of water, and explain how the formation of hydrogen bonds permits the dissociation of salts (such as NaCl), saccharides, and other polar molecules. Contrast the definitions of hydrophobic and hydrophilic related to water polarity.
- CE 3. Describe the composition of a cell membrane. Diagram its cross section, and explain how the distribution of phospholipids and proteins influences the membrane permeability of ions, hydrophilic and hydrophobic compounds.
- CE 4. Using a cell membrane as an example, define a reflection coefficient, and explain how the relative permeability of a cell to water and solutes will generate an osmotic pressure. Contrast the osmotic pressure generated across a cell membrane by a solution of particles that freely cross the membrane with that of a solution with the same osmolality, but particles that cannot cross the cell membrane.
- CE 5. Contrast the following units used to describe concentration: mM, mEq/l, mg/dl, mg%. List the typical value and normal range for plasma  $\text{Na}^+$ ,  $\text{K}^+$ ,  $\text{H}^+$  (pH),  $\text{HCO}_3^-$ ,  $\text{Cl}^-$ ,  $\text{Ca}^{2+}$ , and glucose, and the typical intracellular pH and concentrations of  $\text{Na}^+$ ,  $\text{K}^+$ ,  $\text{Cl}^-$ ,  $\text{Ca}^{2+}$ , and  $\text{HCO}_3^-$ .
- CE 6. Differentiate between the terms osmole, osmolarity, osmolality and tonicity. List the typical value and normal range for plasma osmolality.
- CE 7. Understand that the difference in free energy of a solute or solvent between two components can have chemical, electrical and/or hydrostatic pressure components. At equilibrium, for a given component, the free energy difference between the two compartments is zero.
- CE 8. Define the Donnan equilibrium and list the resulting characteristics.
- CE 9. Describe the linear relationship between forces and flows (e.g., Ohm's Law, Fick's Law of diffusion, and the law of hydrodynamic flow).

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CE 10. Write Fick's Law of diffusion, and explain how changes in the concentration gradient, surface area, time, and distance will influence the diffusional movement of a compound.

CE 11. Based on the principle of ionic attraction, explain how a potential difference across a membrane will influence the distribution of a cation and an anion.

CE 12. Define the term "steady state," and differentiate it from "equilibrium." Relate the pump-leak model of steady-state ion content to cell solute gradients and cell volume maintenance.

CE 13. Write the Nernst equation, and indicate how this equation accounts for both the chemical and electrical driving forces that act on an ion.

CE 14. Based on the Nernst equilibrium potential, predict the direction that an ion will take (follow) when the membrane potential a) is at its equilibrium potential, b) is higher than the equilibrium potential, or c) is less than the equilibrium potential. List values in a typical non-excitable cell for the membrane potential, for  $E_{Na}$ ,  $E_K$ ,  $E_{Cl}$ , and  $E_{Ca}$ .

CE 15. Define the concepts of electrochemical equilibrium and equilibrium potential, and give internal and external ion concentrations. Be able to calculate an equilibrium potential for that ion using the Nernst equation. Contrast the difference in  $E_K$  (the Nernst potential for  $K^+$ ) caused by a 5 mEq/l increase in extracellular  $K^+$  with the change in  $E_{Na}$  (the Nernst potential for  $Na^+$ ) caused by a 5 mEq/l increase in extracellular  $Na^+$ .

CE 16. Explain how the resting membrane potential is generated and calculate membrane potential by using either a) the Goldman-Hodgkin-Katz equation or b) the chord conductance equation. Given an increase or decrease in the permeability of  $K^+$ ,  $Na^+$ , or  $Cl^-$ , predict how the membrane potential would change.

CE 17. Differentiate the following terms based on the source of energy driving the process and the molecular pathway for: diffusion, facilitated diffusion, secondary active transport, and primary active transport.

CE 18. Describe how transport rates of certain molecules and ions are accelerated by specific membrane transport proteins ("transporter" and "channel" molecules).

CE 19. Describe how energy from ATP hydrolysis is used to transport ions such as  $Na^+$ ,  $K^+$ ,  $Ca^{2+}$ , and  $H^+$  against their electrochemical differences (e.g., via the  $Na^+$  pump, sarcoplasmic reticulum  $Ca^{2+}$  pump, and gastric  $H^+$  pump).

CE 20. Understand the role of ATP-binding cassette transporters in, for example, multi-drug resistance and its significance for cancer chemotherapy.

CE 21. Explain how energy from the  $\text{Na}^+$  and  $\text{K}^+$  electrochemical gradients across the plasma membrane can be used to drive the net “uphill” (against a gradient) movement of other solutes (e.g.,  $\text{Na}^+$ /glucose co-transport;  $\text{Na}^+$ / $\text{Ca}^{2+}$  exchange or counter-transport). Apply this principle to understand oral rehydration procedures.

CE 22. Describe the role of water channels (aquaporins) in facilitating the movement of water across biological membranes.

CE 23. Understand the mechanisms and role of selective transporters for amino acids, neurotransmitters, nutrients, etc.

### **Excitable Cells**

CE 24. Define the following properties of ion channels: gating, activation, and inactivation.

CE 25. State the cell properties that determine the rate of electronic conduction.

CE 26. Differentiate between the properties of electrotonic conduction, conduction of an action potential, and saltatory conduction. Identify regions of a neuron where each type of electrical activity may be found.

CE 27. Contrast the cell to cell spread of depolarization at a chemical synapse with that at a gap junction based on speed and fidelity (success rate). At the chemical synapse, contrast the terms temporal summation and spatial summation.

CE 28. Understand the principle of the voltage clamp and how it is used to identify the ionic selectivity of channels.

CE 29. Contrast the gating of ion-selective channels by extracellular ligands, intracellular ligands, stretch, and voltage.

CE 30. Know the properties of voltage-gated  $\text{Na}^+$ ,  $\text{K}^+$ , and  $\text{Ca}^{2+}$  channels, and understand that voltage influences their gating, activation, and inactivation.

CE 31. Understand how the activity of voltage-gated  $\text{Na}^+$ ,  $\text{K}^+$ , and  $\text{Ca}^{2+}$  channels generates an action potential and the roles of those channels in each phase (depolarization, overshoot, repolarization, hyperpolarization) of the action potential.

CE 32. Contrast the mechanisms by which an action potential is propagated along both nonmyelinated and myelinated axons. Predict the consequence on action potential propagation in the early and late stages of demyelinating diseases, such as multiple sclerosis.

## Cell Volume Regulation, Cytosolic pH, and Organelles

CE 33. Understand how regulation of the concentrations of  $K^+$ ,  $Cl^-$ , and other  $Na^+$  solutes influence cell volume.

CE 34. Understand how various transporters (e.g.  $Na^+/H^+$  exchange,  $Cl^-/HCO_3^-$  exchange,  $Na^+-HCO_3^-$  co-transport, etc.) contribute to the control of cytosolic pH.

CE 35. Describe  $Ca^{2+}$  accumulation in the sarcoplasmic and endoplasmic reticulum, mediated by  $Ca^{2+}$  ATPase.

CE 36. Understand the specifics of mechanisms that regulate the luminal composition of organelles (e.g., pH).

## Regulation of Cell Function

CE 37. Describe the concept of signaling pathways and their role in determination of cell state and function of proteins.

CE 38. Understand post-translational regulation of protein function in the cell (e.g., phosphorylation)

CE 39. Describe cell surface receptor structure and function (e.g., GPCRs, TRK, etc.)

CE 40. Diagram the intracellular signaling pathways for representative receptor families and the terms agonist and antagonist as related to membrane receptor ligands.

## Epithelia

CE 41. Draw an epithelium, labeling the tight junctions, the apical membrane, and the basolateral membrane. Trace the movement of a compound that travels across an epithelium by a transcellular pathway and a compound that travels via a paracellular pathway.

CE 42. Explain the role of the “tight” junctions in leaky and tight epithelia.

CE 43. Explain the functional significance of polarized distribution of various transport proteins to the apical or the basolateral cell membrane.

CE 44. Understand that movement of water is driven by solute movement.

## **Cell Motors**

CE 45. Understand the concept of molecular motors and their structural and functional properties.

CE 46. Explain how the mobilization of calcium initiates contractions in smooth, striated, and cardiac muscle. Explain the sliding filament model of muscle contraction and contrast the cellular and molecular basis of muscle contraction in smooth and striated muscle.

## **Transcapillary Transport**

CE 47. Differentiate the following terms: osmotic pressure, oncotic pressure, and hydrostatic pressure, as they pertain to movement across the endothelium of the capillaries.

CE 48. Predict the permeability of cardiovascular capillaries to small solutes and proteins (albumin) based on the capillary reflection coefficient.

CE 49. Based on the Starling hypothesis, explain how permeability, hydrostatic pressure and oncotic pressure influence transcapillary exchange of fluid.

# Endocrinology and Metabolism

## (revised 2011)

### General Principles

- EN 1. Explain the principle of negative feedback control of hormone secretion.
- EN 2. Explain the principles of positive feedback and feed forward control of hormone secretion.
- EN 3. Explain the bases of hormone measurements and assessment of biological activity.
- EN 4. Contrast the terms endocrine, paracrine, and autocrine based on the site of hormone release and the pathway to the target tissue. Provide an example of each, and describe major differences in mechanisms of action of peptides and steroids working through membrane receptors and steroids, vitamin D, and thyroid hormones working through nuclear receptors.
- EN 5. Contrast the location and signaling pathways of membrane bound and intracellular hormone receptors. For membrane bound hormone receptors, describe the process of activation, inactivation, up-regulation, down-regulation, sensitization, and desensitization.
- EN 6. Define and describe the interactions between hormones, target cells, and receptors.
- EN 7. Compare and contrast hormone actions that are exerted through changes in gene expression with those exerted through changes in protein activity, such as through phosphorylation.
- EN 8. Contrast the signal transduction pathways involved in G-protein coupled receptors, receptor enzymes (i.e., tyrosine kinase), and ligand-gated ion channels.
- EN 9. Understand the effects of plasma hormone binding proteins on access of thyroid hormones and steroid hormones to their sites of action and degradation and on the regulation of hormone secretion.
- EN 10. Explain the effects of secretion, excretion, degradation, and volume of distribution on the concentration of a hormone in blood plasma.
- EN 11. Explain the importance of patterns of hormone secretion, such as pulsatile, diurnal, and menstrual.

## **Pituitary Gland - Posterior**

- EN 12. Describe the posterior pituitary lobes with respect to cell types, vascular supply, development, and anatomical function relative to the hypothalamus.
- EN 13. List the target organs and functional effects of oxytocin.
- EN 14. Name the stimuli for oxytocin release in relation to its reproductive and lactation functions.
- EN 15. List the target cells for vasopressin and explain why vasopressin is also known as antidiuretic hormone.
- EN 16. Describe the stimuli and mechanisms that control vasopressin secretion.
- EN 17. Identify disease states caused by a) over-secretion, and b) under-secretion of vasopressin and list the principle symptoms of each.

## **Pituitary Gland – Anterior**

- EN 18. Describe the anterior pituitary lobe with respect to cell types, vascular supply, development, and anatomical function relative to the hypothalamus.
- EN 19. Describe the 3 major families of the anterior pituitary hormones and their biosynthetic and structural relationships.
- EN 20. Identify appropriate hypothalamic factors that control the secretion of each of the anterior pituitary hormones, and describe their route of transport from the hypothalamus to the anterior pituitary.
- EN 21. Understand negative feedback control of anterior pituitary hormone secretion at multiple levels.

## **Growth Hormone**

EN 22. Describe the relationship between growth hormone and the insulin-like growth factors and their binding proteins in the regulation of growth.

EN 23. Understand the regulation of growth hormone secretion. Identify the roles of hypothalamic factors, glucose and IGF-I.

EN 24. Identify the target organs or cell types for insulin-like growth factors that account for longitudinal growth.

EN 25. Describe the metabolic and growth promoting actions of growth hormone.

## **Thyroid Gland**

EN 26. Identify the steps in the biosynthesis, storage, and secretion of tri-iodothyronine ( $T_3$ ) and thyroxine ( $T_4$ ) and their regulation.

EN 27. Describe the absorption, uptake, distribution, and excretion of iodide.

EN 28. Explain the importance of thyroid hormone binding in blood on free and total thyroid hormone levels.

EN 29. Understand the significance of the conversion of  $T_4$  to  $T_3$  and reverse  $T_3$  ( $rT_3$ ) in extra-thyroidal tissues.

EN 30. Describe the physiologic effects and mechanisms of action of thyroid hormones.

EN 31. Understand the causes and consequences of a) over-secretion and b) under-secretion of thyroid hormones. Explain what conditions can cause an enlargement of the thyroid gland.

## **Hormonal Regulation of Calcium and Phosphate**

- EN 32. Identify the normal range of dietary calcium intake, calcium distribution in the body, and routes of calcium excretion.
- EN 33. Identify the normal range of dietary phosphate intake, phosphate distribution in the body, and routes of phosphate excretion.
- EN 34. Know the cells of origin for parathyroid hormone, its biosynthesis and degradation.
- EN 35. List the target organs and cell types for parathyroid hormone and describe its effects on each.
- EN 36. Describe the functions of the osteoblasts and the osteoclasts in bone remodeling and the factors that regulate their activities.
- EN 37. Describe the regulation of parathyroid hormone secretion and the role of the calcium-sensing receptor.
- EN 38. Understand the causes and consequences of a) over-secretion, and b) under-secretion of parathyroid hormone, as well as its therapeutic use.
- EN 39. Describe the normal function of parathyroid hormone related protein (PTHrP) and its role as a marker for some cancers.
- EN 40. Identify the sources of vitamin D and diagram the biosynthetic pathway and the organs involved in modifying it to the biologically active  $1,25(\text{OH})_2\text{D}_3$  (1-25 dihydroxy cholecalciferol).
- EN 41. Identify the target organs and cellular mechanisms of action for vitamin D.
- EN 42. Describe the negative feedback relationship between parathyroid hormone and the biologically active form of vitamin D [ $1,25(\text{OH})_2\text{D}_3$ ].
- EN 43. Describe the consequences of vitamin D deficiency and vitamin D excess.
- EN 44. Name the stimuli that can promote secretion of calcitonin, its actions, and identify which (if any) are physiologically important.

## **Adrenal Gland**

- EN 45. Identify the functional zones (one medullary and three cortical zones), innervation, and blood supply of the adrenal glands and the principal hormones secreted from each zone.
- EN 46. Describe the biosynthesis of the adrenal steroid hormones (glucocorticoids, mineralocorticoids, and androgens) and the key structural features that distinguish each class.
- EN 47. Understand the cellular mechanism of action of adrenal cortical hormones.
- EN 48. Identify the major physiological actions and therapeutic uses of glucocorticoids
- EN 59. Describe the components of the neuroendocrine axis that control glucocorticoid secretion.
- EN 50. Identify the causes and consequences of a) over-secretion and b) under-secretion of glucocorticoids and adrenal androgens.
- EN 51. List the major mineralocorticoids and identify their biological actions and target organs or tissues.
- EN 52. Understand the differential regulation of cortisol versus aldosterone release.
- EN 53. Describe the principal physiological stimuli that cause increased mineralocorticoid secretion. Relate these stimuli to regulation of sodium and potassium excretion.
- EN 54. Identify the causes and consequences of a) over-secretion and b) under-secretion of mineralocorticoids.
- EN 55. Identify the chemical nature of catecholamines, their biosynthesis, mechanism of transport within the blood, and how they are degraded and removed from the body.
- EN 56. Describe the biological consequences of activation of the adrenal medulla and identify the target organs or tissues for catecholamines along with the receptor subtype that mediates the response. Understand the mechanism by which epinephrine and norepinephrine can produce different effects in the same tissues.
- EN 57. Name the key stimuli causing catecholamine secretion. List the factors that can modulate a) the secretory response and b) the responses of target tissues.
- EN 58. Describe the interactions of adrenal medullary and cortical hormones in response to stress.
- EN 59. Identify disease states caused by an over-secretion of adrenal catecholamines.

## **Metabolism**

EN 60. Identify the normal range of plasma glucose concentrations, and list the chemical forms and anatomical sites of storage pools for glucose and other metabolic substrates.

EN 61. Identify the hormones that promote the influx and efflux of glucose, fat, and protein into and out of energy storage pools and their impact on the uptake of glucose by tissues. Establish specific roles for insulin, glucagon and catecholamines.

EN 62. Describe the changes in metabolic fuel utilization that occur in long- and short-term fasting and in acute and sustained exercise. Understand how increases or decreases in hormone secretion produce these changes.

EN 63. Describe the role of appetite and metabolic rate in the maintenance of long-term energy balance and fat storage. Identify the factors that regulate appetite and fuel oxidation.

## **Pancreas**

EN 64. Identify the major hormones secreted from the endocrine pancreas, their cells of origin, and their chemical nature.

EN 65. List the target organs or cell types for glucagon and describe its principal actions on each.

EN 66. List the major target organs or cell types for insulin, the major effects of insulin on each, and the consequent changes in concentration of blood constituents.

EN 67. Identify the time course for the onset and duration for the biological actions of insulin.

EN 68. Understand the relationship between blood glucose concentrations and insulin secretion.

EN 69. Describe the roles of neural input and gastrointestinal hormones on insulin secretion. List the factors that modulate the secretory response.

EN 70. Describe the control of glucagon secretion.

EN 71. Identify disease states caused by: a) over-secretion, b) under-secretion of insulin, or c) decreased sensitivity to insulin, and describe the principal symptoms of each.

## **Endocrine Integration of Energy and Electrolyte Balance**

- EN 72. Explain how thyroid, gonadal, and adrenal hormones modulate growth.
- EN 73. Understand the nature and actions of local growth factors: epidermal growth factor, nerve growth factor, platelet-derived growth factor, and angiogenic and antiangiogenic factors.
- EN 74. Identify the normal range of dietary sodium intake, sodium distribution in the body, and routes of sodium excretion. Explain the roles of antidiuretic hormone, aldosterone, angiotensin, and atrial natriuretic hormone in the regulation of sodium balance.
- EN 75. Identify the normal range of dietary potassium intake, potassium distribution in the body, and routes of potassium excretion. Explain how acute changes in aldosterone, insulin, and acid/base concentrations affect the plasma potassium concentration and the movement of potassium into and out of the intracellular compartment. Explain the chronic regulation of body potassium balance and plasma potassium levels by aldosterone through its actions on renal excretion, intestinal excretion, and dietary appetite/absorption.

## **Reproductive Physiology - Male**

- EN 77. Describe the physiological functions of the major components of the male reproductive tract.
- EN 78. Describe spermatogenesis and the role of Sertoli cells, Leydig cells and the basement membrane in this process.
- EN 79. Describe the endocrine regulation of testicular function: the role of the GnRH pulse generator, FSH, LH, testosterone, and inhibin.
- EN 80. Describe the, biosynthesis, mechanism of transport within the blood, metabolism and elimination of testosterone and related androgens.
- EN 81. List the major target organs and cell types for testosterone and other androgens.
- EN 82. Describe the actions and cellular mechanisms of testosterone and related androgens.
- EN 83. Describe the neural, vascular, and endocrine components of the erection and ejaculation response.

EN 84. Identify the causes and consequences of over-secretion and under-secretion of testosterone for a) prepubertal and b) postpubescent males.

EN 85 Understand aging- related changes in the hypothalamo-pituitary-goandal axis that lead to puberty, reproductive maturity, and reproductive senescence (andropause).

### **Reproductive Physiology - Female**

EN 86. Describe oogenesis and its relationship to changes in the ovarian follicle. Explain the roles of FSH, LH, estradiol, and inhibin in oogenesis and follicular maturation.

EN 87. Describe ovulation and the formation and decline of the corpus luteum and the roles of hormones in each of these processes.

EN 88. Describe the hormonal regulation of estrogen and progesterone biosynthesis and secretion by the ovary. Identify the cells responsible for their biosynthesis, the mechanism of their transport in the blood, and how they are degraded and removed from the body.

EN 89. List the major target organs and cell types for estrogen action and describe its effects on each.

EN 90. Describe the actions and cellular mechanisms of estrogen.

EN 91. List the principal physiological actions of progesterone, its major target organs and cell types, and describe its effects on each and the importance of “estrogen priming.”

EN 92. Describe the actions and cellular mechanisms of progesterone and other progestins.

EN 93. Graphically illustrate the timing of changes in blood levels of FSH, LH, estradiol, progesterone, and inhibin, and correlate these with structural changes in the endometrium and the ovary seen during the menstrual cycle.

EN 94 Describe how the changes in ovarian steroids produce the proliferative and secretory phases of the uterine endometrium and menstruation and the changes in basal body temperature during the menstrual cycle.

EN 95 Understand aging- related changes in the hypothalamo-pituitary-goandal axis that lead to puberty, reproductive maturity, and reproductive senescence (menopause).

## **Pregnancy and Birth**

EN 96. Describe the process of fertilization, including capacitation and the acrosome reaction, and the movement of the blastocyst to the uterus.

EN 97. Describe the process of implantation.

EN 98: Describe the development and the major physiological functions of the placenta.

EN 99. List the protein hormones secreted by the placenta and describe the role of human chorionic gonadotropin (hCG) in the rescue of the corpus luteum in maintaining pregnancy early post-implantation.

EN 100. Describe the interactions between the placenta and the fetus in the pathway for production of estrogens during pregnancy.

EN 101. Discuss the roles of sex steroids, oxytocin, relaxin, and prostaglandins in the initiation and maintenance of parturition.

EN 102. Explain the role of hormones in mammary gland development during puberty, pregnancy, and lactation.

EN 103. Explain the basis for the inhibition of milk secretion during pregnancy and the initiation of lactation after parturition.

EN 104. Describe the neuroendocrine regulation of milk secretion and milk ejection.

EN 105. Explain the physiological basis of steroid hormone contraception.

## **Sexual Differentiation**

EN 106. Compare and contrast the actions of testosterone, dihydrotestosterone, estradiol, and Müllerian inhibitory factor in the development of the male and female reproductive tracts.

EN 107. Describe developmental changes in the male and female reproductive systems, including the mechanisms responsible for these changes, during *in utero* development, and in childhood through puberty.

# Gastrointestinal

(revised 2011)

## Functions and Regulation of GI Tract

- GI 1. Identify the sources and typical amounts of fluid and nutrients entering and leaving the gastrointestinal tract daily.
- GI 2. For major classes of nutrients (carbohydrates, proteins, fats), differentiate the processes of ingestion, digestion, absorption, secretion, and excretion; include the location in the GI tract where each process occurs.
- GI 3. Describe the functions of splanchnic blood flow in sustaining intestinal viability and as a source/sink for material transported across the GI tract epithelium.
- GI 4. Describe how the single layer of epithelial cells that lines most of the GI tract is renewed, and describe the mechanisms whereby these cells are both a barrier and selective portal for secretion and absorption.
- GI 5. Understand the integrated regulation (neural, endocrine, luminal) that drives digestion and absorption of nutrients after a meal and the temporal sequence of regulatory events during digestion.
- GI 6. Understand how the physical and chemical compositions of luminal contents are sensed and the cellular and systemic responses to luminal stimuli.
- GI 7. Describe the major anatomical characteristics of the enteric nervous system and the major cellular divisions of enteric ganglia (sensory nerves, interneurons, and motor neurons). Given either a cross section or whole mount of the bowel wall, identify the anatomical positions and major characteristics of the myenteric and submucosal plexi.
- GI 8. Know how afferent and efferent extrinsic nerves (sympathetic and parasympathetic) interact with the enteric nervous system and regulate the functions of the GI tract.
- GI 9. Know the major excitatory and inhibitory motor neurotransmitters and major digestive hormones in the GI tract and how these biomediators affect function in GI tissues and cells.
- GI 10. Understand the neural circuitry driving major GI reflexes and the neural pathways and neurotransmitters that accomplish reflex control of GI functions.
- GI 11. Compare and contrast the regulation of gut function by nerves, hormones, and paracrine regulators.

GI 12. Understand how GI cells integrate regulatory inputs and explain how the ultimate behavior of GI tissues results from summation of inputs from multiple regulatory pathways.

GI 13. Identify the cell type and anatomical location of the endocrine cells secreting major GI hormones, such as gastrin, secretin, cholecystokinin (CCK), GLP-1, GLP-2, leptin, and motilin.

GI 14. Define the “incretin” concept, and as an example, describe the glucose-dependent release and action of an incretin from the gut.

### **Salivary Glands**

GI 15. Describe the volume and composition of salivary fluid coming from major salivary glands.

GI 16. Understand how acinar secretions are modified by duct cells to produce the final salivary fluid that enters the buccal cavity.

GI 17. Describe the physiological function of the components of saliva.

GI 18. Describe the stimuli and neural pathways involved in promoting salivary secretion.

GI 19. State the components of the saliva important in oral hygiene.

### **Esophagus**

GI 20. Know the normal range of resting luminal esophageal pressures, how esophageal pressure is measured in the clinic, and why luminal pressure varies with the respiratory cycle.

GI 21. Describe the afferent neuro-muscular pathways activated to initiate swallowing, the motor pathways and general targets for innervation that accomplish the swallowing reflex, and major nuclei of in the brain stem that integrate these afferent inputs.

GI 22. Understand the differences in the neural and muscular composition and function in the upper versus lower esophagus. Explicitly consider the upper and lower esophageal sphincters.

GI 23. Describe the dynamic pressure changes that occur in the regions of the esophagus after initiation of the swallowing reflex and how these pressure changes would propel a bolus of food from the mouth to the stomach.

GI 24. Describe how dysfunction in the spatial or temporal characteristics of the esophageal pressure wave and/or sphincter relaxation can lead to swallowing defects and disorders such as heart burn, achalasia and aspiration of food.

## **Stomach**

- GI 25. Describe the storage, digestion, and motility roles of the stomach.
- GI 26. Understand how the composition of gastric luminal fluid is affected by intake of a meal, as well as variable gastric secretions of acid, alkali, and attendant salts.
- GI 27. Identify the proteins secreted into the gastric lumen by chief cells, parietal cells, and mucous cells. Contrast the functions and regulation of these secretions.
- GI 28. Identify the gastric cell types secreting gastrin, somatostatin, histamine, and gastrin releasing peptide. Describe the stimuli that promote and inhibit release of these peptides, and their cellular targets.
- GI 29. Describe the role of HCl in the gastric digestion of carbohydrates and protein, and how pepsinogen is activated.
- GI 30. Describe the luminal pH of the stomach in the basal fasted state versus the time course of changes in luminal pH after a mixed meal.
- GI 31. Describe the role of stomach functions in preventing pernicious anemia and peptic ulcer disease.
- GI 32. Describe how parietal cells H-K-ATPase activity can be inhibited physiologically and pharmacologically.
- GI 33. Describe the ion transport mechanisms and cellular enzymes needed to allow parietal cell homeostasis during gastric acid secretion.
- GI 34. List the stomach cell types and secreted substances that contribute to regulation of gastric acid secretion via paracrine, hormonal, and neuroendocrine pathways. Understand the integrated feedback regulation of acid secretion via these pathways during a meal.
- GI 35. List the mechanisms contributing to gastric mucosal defense and how they can be compromised by drugs or pathogens.
- GI 36. Describe the role of duodenal contents in regulating gastric secretion.
- GI 37. Describe local and central reflex mechanisms involved in receptive relaxation of the proximal stomach. Understand how this reflex regulates gastric pressure and compliance.

GI 38. Describe origin and propagation of electrical activity and the progression of peristaltic waves across the body and antrum of the stomach. Describe their role in mixing and propulsion of gastric contents.

GI 39. Describe how the physical and chemical composition of a meal is sensed by the stomach and duodenum to affect the rate of gastric emptying.

GI 40. Describe the function and dysfunction of gastric peristalsis, the pyloric sphincter, and duodenal feedback in controlling gastric emptying rate.

GI 41. Describe the causes of peptic ulcer disease.

### **Exocrine Pancreas**

GI 42. List the major components secreted by the exocrine pancreas and the principal cell types involved in this secretion.

GI 43. Describe the process of digestive enzyme synthesis and packaging and how this process maintains the integrity of the pancreas.

GI 44. Describe the mechanisms by which chyme from the stomach is neutralized in the duodenum.

GI 45. Describe the mechanism by which pancreatic zymogens are activated in the small intestine.

GI 46. List the stimuli that release secretin and CCK and explain the route by which these regulatory peptides stimulate the pancreas.

GI 47. Describe the role of CFTR in pancreatic ductal secretion, and predict the consequences of cystic fibrosis on the GI system.

GI 48. Describe the mechanisms by which  $\text{HCO}_3^-$  is taken up by pancreatic ductal cells.

GI 49. State the effects of the autonomic nerves to the pancreas and vago-vagal reflexes on pancreatic secretion.

## **Hepatobiliary**

GI 50. Describe how liver blood flow and liver architecture impact liver function.

GI 51. List the water, ionic, bile salt, and bilirubin components of bile as secreted by the liver and after modification by the gallbladder.

GI 52. Describe the cellular mechanisms for the hepatic uptake, conjugation, and secretion of bile salts and bilirubin.

GI 53. Relate the clinical characteristics of end-stage acute and chronic liver disease to the normal functions of the liver, and describe how fibrosis affects liver function.

GI 54. Describe the basis for studying liver enzymes in the circulation as a measure of liver injury.

GI 55. Describe the mechanisms whereby the gall bladder concentrates bile, and the endocrine mechanism stimulating gall bladder contraction and the secretion of bile through the sphincter of Oddi into the small intestine.

GI 56. Describe the amphipathic structure of bile salts, and describe how this property assists the solubilization and digestion of fats.

GI 57. Describe the enterohepatic circulation, including any different handling among primary and secondary bile salts, and bile acids.

GI 58. Contrast the mechanism of reabsorption of bile acids/salts in the small intestine versus the colon.

GI 59. Predict the effects of an increase in hepatic portal vein bile acid concentration on the rate of bile secretion, bile acid synthesis, and diseases of the gallbladder.

GI 60. Describe the contribution of water and ion reabsorption in the gall bladder to gall stone formation. Identify the major types of gall stones and the potential consequence of gall stone formation.

## **Small Intestine**

GI 61. Describe how rates of absorption are affected by the macroscopic and microscopic architecture of the gut epithelium.

GI 62. Describe the sequential digestion of ingested starch by enzymes of the salivary glands, pancreas, and the intestinal apical membrane.

GI 63. Describe the sequential digestion of ingested proteins by gastric pepsin, pancreatic enzymes, and enzymes at the intestinal apical membrane. Make sure to include the role of duodenal enteropeptidase.

GI 64. Compare the membrane transport mechanisms responsible for uptake of sugars, amino acids and di-peptides by intestinal epithelial cells.

GI 65. Describe the mechanisms and molecules mediating the solubilization and digestion of lipids in the small intestine.

GI 66. Describe the mechanisms for the uptake, processing and release of lipids by the small intestinal epithelium and consequences of their malabsorption.

GI 67. Describe the composition and formation of chylomicrons, their movement across the enterocyte basolateral membrane, and the route of entry into the cardiovascular system.

GI 68. Describe common causes of steatorrhea, and predict effects of steatorrhea on absorption of fat-soluble vitamins.

GI 69 Compare the absorption of fat soluble and water soluble vitamins and give examples of diseases resulting from their malabsorption.

GI 70. Describe the location and the mechanisms that mediate the intestinal trans-epithelial movement of water, the major electrolytes, iron and calcium.

GI 71. List the diseases of enzyme and transport deficiencies leading to osmotic diarrhea.

## **Large Intestine**

- GI 72. Describe the mechanisms, localization and regulation of colonic sodium absorption.
- GI 73. Describe the mechanisms mediating colonic bicarbonate and potassium transport.
- GI 74. Describe the role of dietary fiber in promoting colonic motility.
- GI 75. Describe the factors contributing to intestinal and colonic gas composition and the consequences of an altered colonic microflora.
- GI 76. Describe the role of short chain fatty acids in colonic sodium absorption and in both colonic and body energy metabolism.
- GI 77. Describe the related roles of fluid malabsorption in the small intestine versus colon on the potential to cause diarrheal disease.
- GI 78. Describe the normal regeneration of the colonic epithelium from stem cells, and how this process is changed if a stem cell becomes cancerous or in the presence of inflammation.

## **Gastrointestinal Motility and Enteric Nervous System**

- GI 79. Describe the control of peristalsis by the enteric nervous system.
- GI 80. Describe the characteristics of the spontaneous and stimulated electrical activity of GI smooth muscles (electrical slow waves, action potentials, and contraction).
- GI 81. Describe the anatomical locations and role of interstitial cells of Cajal as slow wave pacemakers and mediators of inputs from the enteric nervous system.
- GI 82. Describe the functional importance of tonic inhibitory input from enteric motor neurons in the GI tract and how loss of this form of regulation might cause inappropriate GI motility.
- GI 83. Describe major motor patterns in the GI tract and their functions during fasting (migrating motor complex or MMC) and during digestion.
- GI 84. Describe how extrinsic nerves (sympathetic and parasympathetic) affect motor patterns.
- GI 85. Describe the role of colonic motility in facilitating the recovery of water and electrolytes.
- GI 86. Describe how distension of organs affects GI reflexes and alters responses to other regulatory inputs.

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GI 87. Understand how abnormal distension can cause GI pain and lead to abnormal motility.

GI 88. Describe how luminal pressure and stretch of the gut initiate reflexes in GI organs and how these inputs are integrated by intrinsic and extrinsic neural pathways (including enteric ganglia, prevertebral ganglia, spinal cord and brain) and determine whether stimuli are normal or noxious.

GI 89. Describe the function of colonic motility, in mediating formation of haustra and haustral shuttling, mass movements through the transverse and distal colon, and defecation.

GI 90. Describe the sequence of events in the colon and anal sphincters occurring during reflexive defecation, differentiating those movements under voluntary control and those under autonomic control.

GI 91. Describe the disorders of motility that can lead to gastroparesis, achalasia, diarrhea, constipation, megacolon and irritable bowel syndrome.

# Integration and Exercise

(revised 2011)

## Thermoregulation

INT 1. Diagram the thermal balance for the body, including heat production (metabolism, exercise, shivering) and heat loss (convection, conduction, radiation, and evaporation). Identify those mechanisms that shift from heat production to heat loss when environmental temperature exceeds body core temperature.

INT 2. Define the thermoregulatory set point. Diagram the negative feedback control of body core temperature, including the role of the hypothalamic set point.

INT 3. Contrast the stability of body core with that of skin temperature. Include the control and mechanisms of cutaneous blood flow and sweating on skin temperature.

INT 4. Identify the mechanisms for maintaining thermal balance in the following environments: desert (120°F), snow skiing (10°F), falling through ice into a lake (water temp 37°F), and snorkeling in 80°F water.

INT 5. Explain how the change in core temperature that accompanies exercise differs from the change in core temperature produced by influenza, which alters the thermoregulatory set point.

INT 6. List and describe the physiological changes that occur as a result of acclimatization to heat and cold.

## **Exercise**

INT 7. Contrast the normal distribution of cardiac output with the distribution of cardiac output during aerobic (sustained) exercise and anaerobic (brief maximal burst) exercise. Include local regulation of blood flow and the role of capillary reserve in altering skeletal muscle blood flow.

INT 8. Define  $VO_{2MAX}$  and identify situations in which it is limited by cardiac output, pulmonary gas exchange, and skeletal muscle blood flow and oxygen uptake.

INT 9. Explain the control mechanisms responsible for the increases in minute ventilation and heart rate that accompany exercise and how they can occur without any measurable change in arterial blood gas values.

INT 10. Define the effects of exercise training on the heart and coronary circulation and how these changes contribute to an increase in  $VO_{2MAX}$ .

INT 11. Explain how each of the following can alter exercise performance: muscle fatigue,  $VO_{2MAX}$ , anaerobic threshold, gender, and age.

INT 12. Describe how exercise training alters insulin action and glucose entry into cells.

INT 13. Describe the health benefits of exercise training on the cardiovascular, musculoskeletal, endocrine, immune and nervous systems.

INT 14. Explain mechanisms of central and peripheral fatigue.

INT 15. Explain metabolic substrate utilization at varying intensities and durations of exercise and the impact on weight control.

# Muscle

(revised 2011)

## General Principles for Skeletal, Cardiac, and Smooth Muscle

- MU 1. Explain the overall transmembrane signaling steps whereby increases in cytosolic calcium initiate crossbridge cycling.
- MU 2. Identify the multiple sources, localization, and roles of calcium in muscle contraction and relaxation.
- MU 3. Draw a myosin molecule and label the subunits (heavy chains, light chains) and describe the function of the subunits.
- MU 4. Diagram the structure of the thick and thin myofilaments and label the constituent proteins.
- MU 5. Diagram the chemical and mechanical steps in the cross-bridge cycle, and explain how the cross-bridge cycle results in shortening of the muscle.
- MU 6. Explain the relationship of preload, afterload and total load in the time course of an isotonic contraction.
- MU 7. Distinguish between an isometric and isotonic contraction.
- MU 8. Draw the length versus force diagram for muscle and label the three lines that represent passive (resting), active, and total force. Describe the molecular origin of these forces in the three muscle types.
- MU 9. Explain the interaction of the length:force and the force:velocity relationships and how they vary in the three muscle types.
- MU 10. List the energy sources of muscle contraction and rank the sources with respect to their relative speed and capacity to supply ATP for contraction and how they are different in the three muscle types.

## **Skeletal Muscle Structure and Mechanism of Contraction**

MU 11. Draw and label a skeletal muscle at all anatomical levels, from the whole muscle to the molecular components of the sarcomere. At the sarcomere level, include at least two different stages of myofilament overlap.

MU 12. Describe the relationship of the myosin-thick filament bare zone to the shape of the active length:force relationship.

## **Control of Skeletal Muscle Contraction: Excitation-Contraction Coupling and Neuromuscular Transmission**

MU 13. List the steps in excitation-contraction coupling in skeletal muscle, and describe the roles of the sarcolemma, transverse tubules, sarcoplasmic reticulum, thin filaments, and calcium ions.

MU 14. Describe the roles of ATP in skeletal muscle contraction and relaxation.

MU 15. Draw the structure of the neuromuscular junction.

MU 16. List in sequence the steps involved in neuromuscular transmission in skeletal muscle and point out the location of each step on a diagram of the neuromuscular junction.

MU 17. Distinguish between an endplate potential and an action potential in skeletal muscle.

MU 18. List the possible sites for blocking neuromuscular transmission in skeletal muscle and provide an example of an agent that could cause blockage at each site.

## **Mechanics and Energetics of Skeletal Muscle Contraction**

MU 19. Distinguish between a twitch and tetanus in skeletal muscle and explain why a twitch is smaller in amplitude than tetanus and the continuum of force development between a twitch and tetanus including the intracellular events.

MU 20. Draw force versus velocity relationships for two skeletal muscles of equal maximum force generating capacity but of different maximum velocities of shortening.

MU 21. Using a diagram, relate the power output of skeletal muscle to its force versus velocity relationship.

MU 22. Describe the influence of skeletal muscle tendons on contractile function.

MU 23. Define muscular fatigue. List some intracellular factors that can cause fatigue.

MU 24. Construct a table of structural, enzymatic, and functional features of the three major categories (fast-glycolytic, fast-oxidative-glycolytic, and slow-oxidative fiber types) of skeletal muscle fiber types and their relative plasticity.

MU 25. Describe the role of the myosin crossbridges acting in parallel to determine active force and the rate of crossbridge recycling to determine muscle speed of shortening and rate of ATP utilization during contraction.

MU 26. Describe how the origin and insertion of a skeletal muscle to the skeleton can influence mechanical performance of the muscle.

MU 27. Define a motor unit and describe the order of recruitment of motor units during skeletal muscle contraction of varying strengths.

### **Smooth Muscle**

MU 28. Describe the differences in actomyosin regulation of, respectively, smooth and skeletal muscle and indicate the structural similarities in their respective contractile units.

MU 29. Explain why smooth muscles can develop and maintain force with a much lower rate of ATP hydrolysis than skeletal muscle.

MU 30. Distinguish between muscle relaxation from the contracted state and the phenomenon of stress relaxation and give examples of each process.

MU 31. Diagram the intracellular pathways that control contraction and relaxation in smooth muscle. Distinguish between electromechanical coupling and pharmacomechanical coupling.

MU 32. Describe the distinguishing characteristics of multi-unit and unitary smooth muscles.

MU 33. Describe the mechanisms responsible for myofilament calcium sensitization and desensitization.

MU 34. Describe the plasticity of smooth muscle to chronic stimuli such as pregnancy and exercise.

## **Cardiac Muscle**

MU 35. Diagram the relationship between the timing of the action potential and a twitch in cardiac muscle and explain why this prevents tetanic contraction.

MU 36. Diagram the steps in the excitation-contraction coupling mechanism in cardiac muscle and compare with skeletal muscle including different mechanisms for sarcoplasmic reticulum calcium release.

MU 37. On the length versus force diagram show how an increase in contractility changes the relationship between afterload and amount of shortening.

MU 38. Describe the mechanisms through which inotropic interventions change cardiac contractility.

MU 39. Describe the physiological consequences of the low-resistance, gap junction pathways between cardiac muscle cells.

# Neurophysiology

(revised 2012)

## Cellular Neurophysiology, Blood Brain Barrier, Cerebrovascular Physiology

### A. Physiology of the Neuron

NEU 1. Define, and identify on a diagram of a motor neuron, the following regions: dendrites, axon, axon hillock, soma, and an axodendritic synapse.

NEU 2. Define, and identify on a diagram of a primary sensory neuron, the following regions: receptor membrane, peripheral axon process, central axon process, soma, sensory ganglia.

NEU 3. Write the Nernst equation, and explain the effects of altering the intracellular or extracellular  $\text{Na}^+$ ,  $\text{K}^+$ ,  $\text{Cl}^-$ , or  $\text{Ca}^{2+}$  concentration on the equilibrium potential for that ion.

NEU 4. Describe the normal distribution of  $\text{Na}^+$ ,  $\text{K}^+$ , and  $\text{Cl}^-$  across the cell membrane, and using the chord conductance (Goldman) equation, explain how the relative permeabilities of these ions create a resting membrane potential.

NEU 5. Describe ionic basis of an action potential.

NEU 6. Distinguish the effects of hyperkalemia, hypercalcemia, and hypoxia on the resting membrane and action potential.

NEU 7. Explain how the abnormal function of ion channels (channelopathies) can alter the resting membrane and action potential and cause paralysis, ataxia, or night blindness.

NEU 8. Describe the ionic basis of each of the following local graded potentials: excitatory post synaptic potential (EPSP), inhibitory post synaptic potential (IPSP), end plate potential (EPP) and a receptor (generator) potential.

NEU 9. Contrast the generation and conduction of graded potentials (EPSP and IPSP) with those of action potentials.

NEU 10. On a diagram of a motor neuron, indicate where you would most likely find IPSP, EPSP, action potential trigger point, and release of neurotransmitter.

NEU 11. On a diagram of a sensory neuron, indicate where you would most likely find receptor potential or generator potential, action potential trigger point, and release of neurotransmitter.

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NEU 12. Describe how focal depolarization (EPSP) or hyperpolarization (IPSP) of a neuron can initiate action potential initiation by the processes of temporal and spatial summation.

NEU 13. Describe the functional role of myelin in promoting saltatory conduction, contrasting the differences between the CNS and PNS.

NEU 14. Describe the basis for the calculation of the space constant and time constant of neuron process.

NEU 15. Define membrane capacitance and identify how membrane capacitance affects the spread of current in myelinated and unmyelinated neurons.

NEU 16. Describe the effects of demyelination on action potential propagation and nerve conduction and the outcomes for recovery in CNS vs. PNS.

NEU 17. Compare conduction velocities in a compound nerve, identifying how the diameter and myelination lead to differences in conduction velocity. Use these differences to classify sensory nerve fibers as group Ia, Ib, II, III, and IV fibers or as A<sub>alpha</sub>, A<sub>beta</sub>, A<sub>delta</sub>, B, and C fibers.

NEU 18. Describe how inhibitory and excitatory post-synaptic potentials can alter synaptic transmission.

NEU 19. Explain the role of astrocytes in maintaining neuronal milieu.

NEU 20. Describe the molecular mechanisms (initiation, specific receptors, enzymes, and locations in the CNS) underlying enhanced (long-term potentiation) or hindering (long-term depression) synaptic strength.

## **B. Neurochemistry**

NEU 21. Compare electrical and chemical synapses based on velocity of transmission, fidelity, and the possibility for neuromodulation (facilitation or inhibition).

NEU 22. Describe chemical neurotransmission, listing in correct temporal sequence events beginning with the arrival of a wave of depolarization at the pre-synaptic membrane and ending with a graded potential generated at the post-synaptic membrane.

NEU 23. Define the characteristics of a classical neurotransmitter.

NEU 24. Learn the synthetic pathways, inactivation mechanisms and neurochemical anatomy and mechanisms of receptor transduction for the following classical and non-classical neurotransmitters:

- Catecholamines: dopamine,  
    norepinephrine, epinephrine
- Acetylcholine
- Serotonin (5-hydroxytryptamine)
- Histamine
- GABA ( $\gamma$ -aminobutyric acid)
- Glutamate
- Endorphins
- Enkephalins
- Dynorphins
- Substance P
- Nitric Oxide
- Carbon Monoxide
- Endocannabinoid

NEU 25. List the major receptor classifications and representative receptor agonists and antagonists for the above transmitters.

NEU 26. Describe the relationship between neurotransmitter dysfunction and neuropathology.

NEU 27. Diagram the steps that lead to phosphorylation of a channel protein when a  $G_s$  protein is activated.

NEU 28. Diagram the steps that lead to an increase in intracellular  $Ca^{2+}$  and activation of protein kinase C following activation of a  $G_q$  protein.

NEU 29. Describe how changes in neuronal membrane chloride ion transporters can cause GABA to be an excitatory or an inhibitory transmitter.

### **C. Cerebrovascular System**

NEU 30. Describe the local factors affecting brain blood flow and contrast their effectiveness with that of autonomic regulation of cerebral blood flow. Understand the role of blood flow in relation to fMRI.

NEU 31. Describe cerebrovascular disorders (stroke, hemorrhage, aneurysm, migraine headache) as to primary cause and effect, including how excitotoxic mechanisms can lead to neuronal death following stroke or injury.

### **D. Cerebrospinal Fluid, Blood Brain Barriers**

NEU 32. Diagram the adult ventricular system and relate it to its embryological development.

NEU 33. Identify on a diagram the meninges and subarachnoid spaces; differentiate a subarachnoid from an epidural hemorrhage by location, symptoms, and CT scan.

NEU 34. Describe formation and reabsorption of cerebral spinal fluid (CSF), including the anatomy and function of the choroid plexus.

NEU 35. Contrast the barrier mechanisms between the blood brain barrier and the blood CSF barrier and the consequences of barrier break down.

NEU 36. Describe the impact of the blood brain barrier for the CNS distribution of intravenously administered hydrophilic and hydrophobic drugs.

NEU 37. Locate and describe the function of circumventricular organs.

NEU 38. Describe the normal pressure, flow, volume (ventricular vs. cisternal), and composition of the CSF.

NEU 39. Contrast the difference between a communicating and a non-communicating hydrocephalus.

NEU 40. Describe how CSF composition can vary in certain pathological conditions.

NEU 41. Describe the consequences of sampling CSF from the lumbar cistern when the CSF pressure is above normal.

## **Sensory Processes**

### **A. Somatosensory System**

NEU 42. Describe the cutaneous and proprioceptive mechanoreceptors and their function: Pacinian corpuscles, Meissner's corpuscles, Ruffini endings, Merkel cell, A-delta and C free nerve endings, Golgi tendon organ, muscle spindle.

NEU 43. Describe the submodalities of somatic sensibility subserved by the Dorsal Column-Medial Lemniscus system and by the spino-thalamic system, respectively.

NEU 44. Define the terms receptor sensitivity, receptor specificity, and receptive field. Correlate these definitions with the types of receptors transmitting information to the Dorsal Column-Medial Lemniscus system and to the spino-thalamic system, respectively.

NEU 45. Contrast the proprioceptive pathways to the cerebellum with those to the cerebral cortex.

NEU 46. List the receptors and afferent nerve fibers that subserve vibration, discriminative touch, joint position sense, thermoreception and nociception.

NEU 47. Define rapidly and slowly adapting sensory reception and correlate these with the types of sensory receptors serving the Dorsal Column-Medial Lemniscus system and the spino-thalamic system, respectively.

NEU 48. Describe the steps in sensory transduction and action potential generation at a mechanoreceptor and at a nociceptor.

NEU 49. Use the Weber-Fechner Law to determine the relationship between afferent neuronal firing frequency and perception of a stimulus.

NEU 50. Define the concept of a dermatome and explain the dermatomal organization of the head and body.

NEU 51. Trace the borders of the dermatomes.

NEU 52. Define the concept of a somatosensory receptive field and explain how dermatomes and receptive fields are related.

NEU 53. Explain how the peripheral innervation density is related to receptive field size.

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- NEU 54. Define two-point discrimination and tell how it is related to peripheral innervation density and receptive field size.
- NEU 55. Explain how peripheral innervation density distorts the dermatomal organization (topographical pattern) of the postcentralgyrus.
- NEU 56. Discuss what is meant by the Fine Touch System and be able to trace its connections to the cerebral cortex.
- NEU 57. Discuss what is meant by the Pain/Temperature/Coarse Touch System and be able to trace its connections to the cerebral cortex.
- NEU 58. List the neural components of the Dorsal Column-Medial Lemniscus system and its Trigeminal analogs.
- NEU 59. Describe the functional properties of the Dorsal Column-Medial Lemniscus system,
- NEU 60. Describe how afferent surround inhibition improves spatial two-point discrimination.
- NEU 61. Describe the topographic representation of the body at the level of the dorsal column nuclei, the ventrobasal thalamus, and the somatic sensory cortex.
- NEU 62. Describe the factors that contribute to the high somatic sensory acuity of the hands and face.
- NEU 63. Describe signs and symptoms of Dorsal Column-Medial Lemniscus system dysfunction.
- NEU 64. List the neural components of the spino-thalamic system and its trigeminal analogues.
- NEU 65. List functional properties of the spino-thalamic system.
- NEU 66. Differentiate between fast and slow pain and identify the peripheral nerve fibers and central connections that account for these different types of pain.
- NEU 67. Describe how endogenous opiates may modulate the pain experience.
- NEU 68. Describe the deficits caused by lesions in the spino-thalamic system.
- NEU 69. Describe the mechanism of referred pain of visceral origin.
- NEU 70. Describe the concept of dorsal horn mechanism of gating pain.

## **B. Visual System**

NEU 71. Describe the gross structure of the eye and basic physiological optics.

NEU 72. Describe the refraction of light as it passes through the eye to the retina, identifying the eye components that account for refraction of light at the center of the eye and away from the center.

NEU 73. Describe the process of accommodation, contrasting the refraction of light by the lens in near vision and in far vision.

NEU 74. Describe the refractive deficits that account for myopia, hyperopia, presbyopia, and astigmatism and their correction by eyeglasses and contact lenses.

NEU 75. List the structure and cell types of the human retina.

NEU 76. Describe the basic biochemistry of the photo-transduction process, the “dark current,” and the photoreceptor response to capturing a photon.

NEU 77. Explain the chromatic and luminance properties of the different photoreceptor types.

NEU 78. Understand the intrinsic circuitry of the retina and its functioning.

NEU 79. Understand the connectivity and synaptic interactions of photoreceptors, horizontal cells, and bipolar cells in the construction of center-surround antagonistic receptive fields.

NEU 80. Delineate the receptive field properties of photoreceptors, bipolar cells, and retinal ganglion cells and their neuronal responses to light.

NEU 81. Define antagonistic center-surround receptive fields.

NEU 82. Name the major retinal neurotransmitter for retinal throughput.

NEU 83. Describe how different post-synaptic receptors create depolarizing or hyperpolarizing responses and how they are organized to create different on-center and off-center responses and the antagonistic surrounds.

NEU 84. Describe the electrical responses produced by bipolar cells, horizontal cells, amacrine cells, and ganglion cells, and comment on the function of each.

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- NEU 85. Differentiate between scotopic and photopic vision.
- NEU 86. Explain the differing light sensitivities of the fovea and optic disk.
- NEU 87. Trace the projections of the visual hemifields onto the retina (nasal/temporal).
- NEU 88. Diagram the central visual pathways.
- NEU 89. Draw the retino-thalamo-cortical pathway.
- NEU 90. Explain how the crossing of optic nerve fibers accounts for visual field representations at each stage.
- NEU 91. Review the midbrain path of the accessory visual system for the pupillary light reflex.
- NEU 92. Describe the structural and functional specializations of the lateral geniculate nucleus (LGN).
- NEU 93. Recognize the receptive field properties of LGN neurons and primary visual cortex neurons.
- NEU 94. Explain the general functional organization of V1.
- NEU 95. Recognize how center-surround antagonistic receptive fields are combined to report complex parameters, such as orientation specificity and motion detection.
- NEU 96. Differentiate between the general organization and functional specializations of the dorsal and ventral extrastriate visual streams.
- NEU 97. Understand binocular disparity and its relationship to stereopsis.
- NEU 98. Describe the topographic representation of the visual field within the primary visual cortex, including the topics of retinotopic organization, orientation selectivity, and ocular dominance.
- NEU 99. Describe the processing of information in the visual cortex and the consequence of a lesion in the higher visual association areas.

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- NEU 100. Differentiate the retino-geniculo-cortical pathway from extrastriate visual projections systems.
- NEU 101. Describe the functioning of the pupillary light reflex and its diagnostic value.
- NEU 102. Sketch the major lesion deficits after key disruptions in the retino-geniculo-cortical pathway.
- NEU 103. Predict the visual field deficits resulting from the following lesions in the visual pathway: retinal lesion, optic nerve lesion, optic chiasm, optic tract, LGN, optic radiations, and primary visual cortex.
- NEU 104. Name the major lesion deficits and the most likely place of the lesion incident.
- NEU 105. Name the most common syndromes after central lesions of visual processing areas.
- NEU 106. Discuss and describe the syndrome of spatial hemineglect.
- NEU 107. Identify one or two cognitive visual deficits.
- NEU 108. Define the following terms: visual perimeter, visual acuity, optic disc, astigmatism, glaucoma, macular degeneration, myopia, hyperopia, achromatopsia, protanopia, deuteranopia, protanomaly, deuteranomaly, tritanopia, and tritanomaly.
- NEU 109. Contrast the following vision tests: Snellen chart, Sloan letters, Landolt C, Amsler grid, Ishihara test, astigmatism wheel, and perimetry testing. Describe the aspect of the visual system for which each tests and explains how each test works to reveal dysfunction or pathology.

## **C. Smell and Taste**

- NEU 110. Describe the location, structure, and afferent pathways of taste receptors.
- NEU 111. Describe the location, structure, and afferent pathways of smell receptors.
- NEU 112. Describe the structure and functions of the first central relay station for olfactory information, its afferent input, and efferent output.
- NEU 113. Describe the structure and function of the central taste centers.
- NEU 114. Explain the term molecular receptive range.
- NEU 115. Explain the terms topography, spatial topography, and functional topography.
- NEU 116. Describe the olfactory cilium and the family of olfactory receptor genes housed in its membrane.
- NEU 117. Name the basic taste sensations, i.e., identify the five distinct gustatory modalities.
- NEU 118. Describe the cells of a taste bud.
- NEU 119. Explain how taste receptors are activated and explain the mechanism of taste transduction for each taste quality.
- NEU 120. Explain how olfactory receptors are activated and explain the mechanism of olfactory transduction.
- NEU 121. Name and discuss disorders of the chemical senses.
- NEU 122. Identify the three cranial nerves that transmit taste information to the cerebral cortex.
- NEU 123. Describe the structure and function of the central olfactory centers beyond the olfactory bulb.

## **D. Auditory System**

NEU 124. Describe the function of the outer, middle, and inner ear structures in the mechano-electrical transduction process of sound energy into nerve impulses.

NEU 125. List the mechanical structures involved in sound detection.

NEU 126. Describe the nerves and muscles in and around the middle ear and pathologies involving them.

NEU 127. Draw the human audibility curve and explain the changes that occur with aging.

NEU 128. Explain the frequency analysis performed by the cochlea on the basis of its physical properties.

NEU 129. Identify the neuronal elements of the organ of Corti.

NEU 130. Explain how deformations of the basilar membrane are converted into action potentials in auditory nerve fibers.

NEU 131. Diagram the auditory pathways including all central connections.

NEU 132. Describe how pitch, loudness, and localization of sounds in space are coded by central auditory neurons.

NEU 133. Distinguish conductive, central, and sensorineural deafness, and list the tests used to assess them.

NEU 134. Describe the development of the inner ear and list the major embryonic malformations.

NEU 135. List the function of some hearing aids/prostheses.

NEU 136. Define the following terms: conduction deafness, neural deafness, tinnitus, and presbycusis.

NEU 137. Describe the following hearing tests and explain how they contribute to the diagnosis of hearing disorders: audiometry, Weber test, Rinne test, and auditory brainstem response testing.

## **E. Vestibular System**

- NEU 138. Describe the three-dimensional structure of the membranous labyrinth.
- NEU 139. Identify the components of the labyrinth innervated by the eighth cranial nerve.
- NEU 140. Differentiate semicircular canals and otoliths.
- NEU 141. List the mechanical structures involved in movement detection and relate their function to the components of the labyrinth.
- NEU 142. Explain the biophysics and receptor mechanism of the labyrinthine hair cells.
- NEU 143. List the neuronal pathways coming from the labyrinth and the systems they address.
- NEU 144. List the most important vestibular and associated reflexes.
- NEU 145. Outline the steps of the optokinetic reflex.
- NEU 146. Explain how optokinetic and vestibular nystagmus interact.
- NEU 147. Identify the causes of the major vestibular syndromes.
- NEU 148. Discuss the embryology of the labyrinth and some of the genes necessary for its development.
- NEU 149. Describe the structure, normal stimulus, transduction at the receptor level, and function of the otolith organs.
- NEU 150. Describe the structure, normal stimulus, transduction at the receptor level, and function of the semicircular canals.
- NEU 151. Describe the central connections of the vestibular nerve (the targets of the primary nerve fibers and the targets of the second-order neurons) and relate these to the three or four major functions of the vestibular apparatus.
- NEU 152. List and describe caloric and rotational tests of vestibular function.
- NEU 153. Describe the neural mechanisms of vestibular nystagmus, caloric testing, and the direction of nystagmus to the direction of rotation or which ear (left or right) was irrigated with cold or warm water and the effect of consciousness.

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NEU 154. Describe the following tests of the vestibular system and explain how they are used in diagnosis: posturography, electronystagmography, rotary chair test, Dix-Hallpike test, Halmagyi head jerk, Fukuda stepping test, and caloric reflex test.

NEU 155. List and describe clinical signs of vestibular system dysfunction.

NEU 156. Define the following terms: otolith, endolymph, vertigo, linear acceleration, angular acceleration, frontal gaze center, pontine horizontal gaze center, inter-nuclear ophthalmoplegia, benign paroxysmal positional vertigo (BPPV), Ménière's disease, and labyrinthitis.

NEU 157. List the extraocular muscles.

NEU 158. Describe the approximate orientations and kinematic actions of the extraocular muscles.

NEU 159. Explain the spatial coordination of eye movements.

NEU 160. List the major types of eye movements.

NEU 161. Differentiate the key oculomotor deficits based on their symptoms.

NEU 162. Identify the major supranuclear brain centers involved in oculomotor control.

NEU 163. Name and delineate the major pathways underlying eye movement control.

NEU 164. Describe the different kinds of gaze (voluntary eye movements and reflex eye movements).

NEU 165. Define the following terms: vergence, divergence, saccade, optical nystagmus, vestibular nystagmus, strabismus, oculomotor apraxia, and oculomotor nerve palsy.

NEU 166. Describe the following tests of oculomotor function and explain how each reveals specific deficits in the oculomotor system: saccade test, ocular following test, smooth pursuit test, vergence/divergence test, optokinetic tests, electronystagmography, and vestibulo-ocular reflex test.

## Effectors and Command Systems

### A. Autonomic Nervous System

- NEU 167. Define the sympathetic and parasympathetic systems.
- NEU 168. Differentiate the components of the sympathetic and parasympathetic systems.
- NEU 169. Contrast the functions of the sympathetic and parasympathetic systems.
- NEU 170. Compare and contrast terms and concepts related to the sympathetic and parasympathetic systems, including: the central location of cell body of origin, number of synapses between CNS and effector organs, degree of myelination, and general effects on target tissues.
- NEU 171. Define and contrast pre- and postganglionic autonomic neurons, and white and gray rami communicantes.
- NEU 172. List the cranial and sacral nerves that produce parasympathetic outflow.
- NEU 173. Describe the sensory input and roles for visceral afferent fibers of the ANS.
- NEU 174. Define the anatomical and functional relationships of the autonomic ganglia and plexus.
- NEU 175. Locate the main anatomical regions that make up the central ANS.
- NEU 176. Describe ways the ANS contributes to homeostasis.
- NEU 177. Describe the synaptic characteristics, receptors, and neurotransmitters for the parasympathetic and sympathetic division of the ANS.
- NEU 178. Describe the function of non-adrenergic, non-cholinergic fibers in the ANS.
- NEU 179. Explain the relatively diffuse action of the sympathetic division compared with the parasympathetic division.
- NEU 180. Describe the ANS signaling mechanism and the effects of sympathetic and parasympathetic stimulation of lungs, heart, arteries, and veins; gastrointestinal function; renal function; and sexual function.
- NEU 181. Describe signs and symptoms of ANS dysfunction that may accompany lesions that affect the ANS. Include Horner's Syndrome, medullary dysfunction, common visceral dysfunction, and multiple system atrophy (Shy-Drager syndrome).

## **B. Descending Control of Movements**

- NEU 182. Define motor unit and how it relates to myotomes of the body.
- NEU 183. Describe the metabolic and physiological characteristics of the three main types of motor units.
- NEU 184. Explain how motor units are normally recruited to increase muscular force and what the functional advantages are of this recruitment order.
- NEU 185. Discuss the underlying physiological mechanisms in which muscular force can be increased by increasing the rate at which action potentials are transmitted to the muscle from the CNS.
- NEU 186. Describe excitation-contraction coupling in skeletal muscle.
- NEU 187. Explain the molecular mechanisms for force generation in skeletal and smooth muscles.
- NEU 188. Discuss the functions of skeletal muscle that pertain during climbing up a hill versus descending a hill and how the molecular mechanisms of contraction mediate these functions.
- NEU 189. Discuss the influence of the elastic properties of tendons on motor performance.
- NEU 190. Discuss the relationship between motion of the lower limb and electromyographic activity of lower limb muscles during the step cycle. Explain how the inertial properties of the limb segments result in an apparent dissociation between movement and muscular activity.
- NEU 191. Describe the concept of central pattern generator and list the motor activities that are supported by these circuits.
- NEU 192. Describe the enteric nervous system, its anatomy and function. Discuss what patterns of activity are supported by the enteric nervous system.
- NEU 193. Describe the functional relationship between the enteric and immune systems.
- NEU 194. Explain the rhythmic patterns of activity that arise from circuits in the hypothalamus.
- NEU 195. Describe two hypothesized mechanisms for pattern generation in the CNS and internal organs.

NEU 196. Describe the somatotopic arrangement of motor neuron pools in the spinal cord.

NEU 197. Describe the functions of the medial and lateral motor pathways. Describe their origins and terminations within the spinal cord.

NEU 198. Describe the effects of lesions in the medial and lateral descending motor pathways.

## **Sensorimotor Integration and Internal Regulation**

### **A. Spinal Cord - Brainstem Physiology**

NEU 199. Understand the functional basis of lower motor neurons in the spinal cord and brainstem. Describe the locations of cell body, axon, and their neuromuscular junction.

NEU 200. Understand the functional basis of upper motor neurons in the cerebral cortex and their synaptic connections with interneurons and lower motor neurons in spinal cord and brainstem. Describe the locations of cell body, axon, and somatotopic organization.

NEU 201. Distinguish between postsynaptic inhibition and presynaptic inhibition between neurons and provide examples of each.

NEU 202. Describe the anatomical location, function, and afferent neurotransmission of muscle spindle and Golgi tendon organs.

NEU 203. Trace the neuronal activity initiated by striking the patellar tendon with a percussion hammer (patellar tendon reflex) that leads to contraction of a muscle. Contrast this reflex with the inverse myotactic reflex.

NEU 204. Describe the role of the gamma efferent system in the stretch reflex and explain the significance of alpha-gamma co-activation. Contrast the actions of static and dynamic gamma motor neurons.

NEU 205. Describe the properties of the flexor reflex initiated by touching a hot stove. Identify when pain is sensed, when flexor contraction occurs, and the neuronal connections and role of the crossed extensor reflex.

NEU 206. Describe the clinical tests and findings that allow a physician to distinguish between upper and lower motor neuron disorders, including the Babinski sign, clonus, and clasp knife response.

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NEU 207. Describe the anatomy and functions of the major ascending tracts (anterolateral and dorsal column-medial lemniscus systems) and descending spinal cord tract (cortico-spinal tract, CST), including crossing of midline.

NEU 208. Describe the use of dermatomes, sensory deficits, and motor deficits to identify spinal cord lesions, including spinal cord hemisection. Describe the immediate and long-term consequences of spinal cord versus spinal nerve transaction.

NEU 209. Describe the use of dermatomes, sensory deficits, and motor deficits to identify brainstem lesions, including lateral medullary infarction, base of pons infarction, and medial midbrain infarction. Describe the immediate and long-term consequences of cranial nerve (PNS) transaction versus brainstem (CNS) infarction.

NEU 210. Describe the function of the following brainstem reflexes: cardiovascular baroreceptor, respiratory stretch receptor, cough reflex, pupillary light reflex, gag reflex, and blink reflex.

NEU 211. For each brainstem reflex, list the stimulus and its receptor, the afferent pathway, the brainstem nuclei involved, the efferent pathway, and the resulting effect.

NEU 212. Describe the function and location of the brainstem reticular formation. Explain its role in pain perception and modulation, level of consciousness, integration of brainstem reflexes, and the location of noradrenergic, serotonergic, and dopaminergic nuclei.

## **B. Diencephalon Function**

NEU 213. Describe the hypothalamus in terms of body homeostasis and integration with the ANS.

NEU 214. Relate the functions of the supraoptic and paraventricular nuclei to water balance and thirst behavior and their response to circumventricular osmoreceptors.

NEU 215. Describe the control of body temperature, appetite, defecation, micturition, heart rate, arterial pressure, sexual reproductive activity, lactation, and growth.

NEU 216. Describe the impact of leptin on hypothalamic nuclei and its interaction with the sympathetic nervous system.

NEU 217. Locate the following hypothalamic nuclei and describe their main function(s): arcuate nucleus, posterior nuclei, anterior nuclei, pre-optic nucleus, paraventricular nucleus, supraoptic nucleus and suprachiasmatic nucleus, periventricular nuclei and lateral nuclei.

NEU 218. Describe the function of retinal melanopsin and destruction to the input to the supraoptic nucleus on sleep-wake cycle, drinking, and hormone secretion.

NEU 219. Identify the cortical areas that receive have reciprocal connections with the following thalamic nuclei: ventral lateral, dorsomedial, pulvinar, medial geniculate, lateral geniculate, ventral posterolateral, and posteromedial.

NEU 220. Describe the functions of the reticular and intralaminar thalamic nuclei on cortical arousal and consciousness.

NEU 221. Describe how the anterolateral system conducting afferent pain and temperature interacts with the thalamus.

NEU 222. Describe the appearance of coma and its progression to a vegetative state.

## **Brain and Behavior**

### **A. Cerebral Cortex**

NEU 223. Describe the major areas of the cerebral cortex and their roles in perception and motor coordination. Identify the Brodmann areas for visual, auditory, somatosensory, motor, and speech areas.

NEU 224. Explain the function of somatotopic maps, where are they found in the CNS, and what they represent. Contrast them with tonotopic and retinotopic maps.

NEU 225. Describe kinesthesia and how is it mediated by the cerebral cortex.

NEU 226. Describe the major differences in human cerebrum in terms of the representational and categorical functions.

NEU 227. Describe the location of short-term (working) memory and long-term memory and the requirement of a functional medial temporal lobe and medial diencephalic structures and tracts for declarative memory function.

NEU 228. Describe the characteristics of Alzheimer's disease and contrast it with senile dementia.

NEU 229. Outline the common functional changes seen in the CNS with normal aging and associate them with gross, histological, or biochemical changes.

NEU 230. Describe the concept of motor memory and contrast how it differs from declarative memory function.

NEU 231. Describe the origin, course, termination, and consequences of damage to the corticospinal tract. Contrast the effects of pyramidal tract lesions to lesions of motor cortex.

NEU 232. Compare and contrast the consequences of infarction of the anterior, middle, and posterior cerebral arteries.

NEU 233. Draw a flow diagram for the brain regions involved in planning, initiating, and executing skilled voluntary movements.

NEU 234. Describe the clinical presentation of apraxia and what might account for it.

NEU 235. Describe the cortical areas important for language and the connections between them.

NEU 236. Describe the cortical mechanisms involved during grasping a jar with one hand and unscrewing the cap with the other. Explain the kinds of control mechanisms important for each part of the task.

NEU 237. Compare and contrast the functions of the medial and dorsolateral prefrontal cortex.

NEU 238. Describe the classic lesions of the human cortex and the associated symptoms.

## **B. Cerebellum**

NEU 239. List the three functional divisions of the cerebellum, detailing the input and output connections of each. Describe how these areas are integrated with the lateral and medial motor pathways.

NEU 240. Draw and label the circuitry of the cerebellar cortex and deep nuclei. Assign the functional role to each neuron type and give its synaptic action (excitatory or inhibitory).

NEU 241. Describe what is known about the role of the cerebellum in the regulation of skilled movement and in motor learning.

NEU 242. Predict the neurological disturbances that can result from disease or damage in different regions of the cerebellum.

NEU 243. Contrast the spinal proprioceptive pathways to the cerebellum with those to the cortex.

### **C. Basal Ganglia**

NEU 244. List and describe the major interconnections between components within the basal ganglia and between the basal ganglia and the cerebral cortex. Identify the associated neurotransmitters.

NEU 245. Describe the overall function of the basal ganglia in the initiation and control of movement.

NEU 246. List the appropriate signs of rigidity, dyskinesia, akinesia, and tremor for Parkinson's disease, Huntington's chorea, hemiballismus, athetosis and dystonia. Assign a likely lesion site or chemical system defect for each clinical syndrome.

NEU 247. Describe the rationale for treatment of Parkinson's disease with L-DOPA, pallidectomy, and deep brain stimulation.

NEU 248. Describe the mesolimbic dopaminergic control in the reward behavior pathway and the consequences of addiction.

### **D. Limbic System**

NEU 249. Describe the main functions of the limbic system (LS) and associate them with one or more major anatomical structures of the LS.

NEU 250. Relate how the amygdala interacts with the cerebral cortex to produce cognitive emotional behaviors.

NEU 251. Describe the role of the olfactory system in LS.

NEU 252. Relate the interactive nature of the LS and the ANS and how changes in body homeostasis change with changes in emotion.

NEU 252. Predict how lesions of various components of the LS would cause specific symptoms in humans.

## **E. Sleep**

NEU 253. Describe the three states of human brain activity based on EEG, EOG and EMG records.

NEU 254. Distinguish characteristics and parasomnias common only to non-rapid eye movement sleep (NREM).

NEU 255. Distinguish characteristics and parasomnias common only to rapid eye movement sleep (REM).

NEU 256. Outline the current understanding of regulatory mechanisms in the brainstem and diencephalon regulating the appearance of NREM, REM and wake states. Include the neurotransmitters and the mechanism of the ultradian rhythm underlying the sleep-wake cycle.

NEU 256. Describe the symptoms of narcolepsy, sleep apnea, disorders of initiating and maintaining sleep, and REM sleep behavior disorder.

NEU 257. Describe how respiration, cardiovascular, renal, gastrointestinal, eye movement, muscle, and endocrine function change from wake to NREM and REM states.

## **F. Seizure Activity**

NEU 258. Describe possible underlying causes or damage to the brain that might cause disordered cortical neuronal electrical activity known as a seizure and distinguish a seizure from epilepsy.

NEU 259. Recognize the difference between a generalized onset and a local-focal onset seizure based on EEG.

NEU 260. Explain the possible role of the intralaminar and midline thalamic nuclei on the appearance of disordered electrical activity in both cerebral hemispheres almost simultaneously.

NEU 261. Distinguish the major characteristics of the major seizure disorders: Grand mal, Absence seizure (Petite mal), simple partial and complex partial seizures, and status epilepticus.

## **Physiological Assessment of the PNS and CNS**

### **A. Nerve Conduction/EMG Studies**

NEU 262. Describe the procedure use for measuring nerve conduction velocity.

NEU 263. Describe the repetitive nerve stimulation procedure for assessing the integrity of the neuromuscular junction.

NEU 264. Compare the different EMG findings in neuropathy and myopathy.

NEU 265. Describe the physiological deficit and the consequence for patients with myasthenia gravis.

### **B. Electroencephalogram**

NEU 266. Explain the electrophysiological basis and origin of the electroencephalogram (EEG).

NEU 267. Describe the common clinical EEG frequency bands and the behaviors associated with them.

NEU 268. Explain how the EEG is used to analyze and generate evoked potentials for clinical use.

NEU 269. Describe the physiological deficit and the consequence for patients with myasthenia gravis.

### **C. Electrooculogram**

NEU 270. Describe the procedure for measuring eye movement and velocity.

NEU 271. Describe the origin of the electrooculogram and its uses clinically

## **D. Brain Imaging Techniques**

NEU 272. Explain the difference between the brain/spinal cord computerized tomography (CT) and magnetic resonance image (MRI).

NEU 273. Contrast the use of CT versus MRI for identifying deep brain structures, acute brain hemorrhage, tumors, and edema.

NEU 274. Describe the manipulations of MRI to produce T1, T2, and FLAIR images and identify the approach best suited for comparing and identifying demyelination, edema near CSF, and gliosis.

NEU 275. Compare the use of FLAIR MRI with diffusion weighted imaging for detection of water diffusion within the brain.

NEU 276. Describe the use of magnetic resonance spectroscopy for measuring brain neurochemicals.

NEU 277. Understand the use of diffusion tensor imaging to identify major brain tract functionality (tractography).

## **E. Proteomics and Genomics**

NEU 278. Describe the prominent brain protein abnormality associated with progressive dementia, Alzheimer's disease, and Parkinsonism.

NEU 279. Describe how genetic mutations have advanced basic understanding of brain function.

## **F. Gait Analysis**

NEU 280. Define "kinematics" and describe the use of motion analysis to obtain kinematic measurements.

NEU 281. Explain what information can be obtained using a force plate. Discuss how this information can be combined with the results of motion analysis to understand the dynamics of locomotion.

# Renal

(Revised January 2005, edited December 2010)

## Body Fluids

R 1. Given the body weight and percent body fat, estimate the a) total body water, b) lean body mass, c) extracellular fluid volume, d) intracellular fluid volume, e) blood volume, and f) plasma volume. Identify normal extracellular fluid (plasma) osmolality and concentrations of  $\text{Na}^+$ ,  $\text{K}^+$ ,  $\text{Cl}^-$ ,  $\text{HCO}_3^-$ , proteins, creatinine, and urea, and contrast these values with those for intracellular fluids.

R 2. Using the volumes/compartments identified in objective R 1, contrast the movement between intracellular and extracellular compartments caused by increases or decreases in extracellular fluid osmolality.

R 3. Given the composition and osmolality of a fluid, identify it as hypertonic, isotonic, or hypotonic. Predict the change in transcellular fluid exchange that would be caused by placing a red blood cell in solutions with varying tonicities.

R 4. Identify major routes and normal ranges for water intake and loss, and predict how changes in intake and loss affect the distribution of total body water.

R 5. Demonstrate the ability to use the indicator dilution principle to measure plasma volume, blood volume, extracellular fluid volume, and total body water, and identify compounds used to measure each volume.

R 6. Predict the changes in extracellular volume, extracellular osmolality, intracellular volume, and intracellular osmolality caused by infusion of three liters of 0.9% NaCl, lactated Ringer's solution, 0.45% NaCl, and 7.5% NaCl.

R 7. Identify the site of erythropoietin production, the adequate stimulus for erythropoietin release, and the target tissue for erythropoietin action.

## **Structure of the Kidney and Nephrons**

- R 8. Given a cross section of a kidney, identify the renal cortex, renal medulla, renal calyces, medullary pyramids, renal pelvic space, renal artery, renal vein, and ureter.
- R 9. Describe in sequence the tubular segments through which ultrafiltrate flows after it is formed at Bowman's capsule to when it enters the renal pelvis. Identify each structure as being located in the renal cortex or renal medulla. Based on the glomerulus location and the length of the loop of Henle, distinguish between cortical and juxtamedullary nephrons.
- R 10. Describe in sequence the blood vessels through which blood flows when passing from the renal artery to the renal vein, including the glomerular blood vessels, peritubular capillaries, and the vasa recta.
- R 11. On an electron micrograph and a line drawing, identify the following structures of the glomerular tuft: the afferent and efferent arterioles, glomerular capillary network, mesangium, Bowman's capsule, and the juxtaglomerular apparatus (including the specialized juxtaglomerular arteriole cells and the macula densa). Describe the three layers comprising the glomerular filtration barrier, and identify podocytes, foot processes, slits, and the basement membrane.
- R 12. Explain the role of somatic, (pudendal) sympathetic, and parasympathetic nerves in the micturition reflex and in urination.

## **Renal Clearance**

- R 13. Explain the clearance principle. Use the clearance equation and an appropriate compound to estimate the glomerular filtration rate, renal plasma flow, and renal blood flow.
- R 14. Distinguish between the use of inulin and creatinine clearances as measures of the glomerular filtration rate.
- R 15. Given the plasma and urine concentrations and the urine flow rate, calculate the filtered load, tubular transport, excretion rate, and clearance of inulin, creatinine, para-amino hippuric acid (PAH), glucose, and penicillin. Predict how changes in filtration, reabsorption, and secretion will affect renal excretion of each compound.
- R 16. For each of the compounds listed in objective R 15, graph the urine excretion of a compound against the plasma concentration. Using this graph, identify the tubular load, tubular transport maximum ( $T_{max}$ ), and splay for each substance.

## Glomerular Filtration Rate and Renal Hemodynamics

- R 17. Identify the filtration barriers, if any, which impede the filtration of H<sub>2</sub>O, Na<sup>+</sup>, inulin, albumin, and red blood cells.
- R 18. Define renal blood flow, renal plasma flow, glomerular filtration rate, and filtration fraction and list typical values.
- R 19. Define the filtration coefficient at the glomerular capillary, describe the membrane properties that contribute to it, and explain its role in determining GFR.
- R 20. Given the capillary and Bowman's capsule hydrostatic and oncotic pressures, calculate the net filtration force at the glomerular capillaries. Predict the changes in glomerular filtration caused by increases or decreases in any of those pressures.
- R 21. Describe the relative resistances of the afferent and efferent arterioles and the effects on renal blood flow and GFR of selective changes in each.
- R 22. Describe the myogenic and tubuloglomerular feedback mechanisms that mediate the autoregulation of renal plasma flow and glomerular filtration rate.
- R 23. Predict the change in renal blood flow and glomerular filtration rate caused by an increase in renal sympathetic nerve activity.
- R 24. Predict the change in renal blood flow and glomerular filtration caused by: a) increased synthesis of angiotensin II, b) increased release of atrial natriuretic peptide, c) increased prostaglandin formation, and d) increased nitric oxide formation.
- R 25. Identify which components of the filtration barrier whose damage would result in hematuria and proteinuria.
- R 26. Using the pressures described in objective R 20, predict the changes in net filtration force that occur as blood travels along the glomerular capillary and hydrostatic pressure falls and colloid osmotic pressure increases.
- R 27. Predict the change in renal blood flow and GFR caused by urinary tract obstruction, hypoalbuminemia, and diabetic nephropathy.

R 28. Compare blood flow to, and oxygen consumption by, the kidneys with that of skeletal muscle and cardiac muscle.

R 29. Describe the effects of changes in peritubular capillary hydrostatic and colloid osmotic pressures on net proximal tubular fluid reabsorption.

### Transport Properties of Nephron Segments

R 30. Using glucose, para-amino hippuric acid (PAH), water, and  $\text{Cl}^-$ , contrast the transcellular and paracellular pathways for movement across proximal tubular epithelia.

R 31. Distinguish between active (primary and secondary) transport, facilitated diffusion, and passive diffusion based on energy source and carrier protein involvement.

R 32. Describe the contribution of the major nephron segments to the reabsorption of the filtered load of solute and water.

R 33. Describe the cellular mechanisms for the transport of  $\text{Na}^+$ ,  $\text{Cl}^-$ ,  $\text{K}^+$ ,  $\text{HCO}_3^-$ ,  $\text{Ca}^{2+}$ , phosphate, organic solutes (e.g., glucose, amino acids, and urea), and water by the major tubular segments.

R 34. Describe the function of the following renal transporters and their predominant localization along the tubules with regard to nephron segment and apical versus basolateral membranes

- Transport ATPases ( $\text{Na}^+/\text{K}^+$ -ATPase,  $\text{H}^+/\text{K}^+$ -ATPase,  $\text{H}^+$ -ATPase, and  $\text{Ca}^{2+}$ -ATPase)
- Ion and water channels ( $\text{K}^+$ , ENaC,  $\text{Cl}^-$ ,  $\text{Ca}^{2+}$ , aquaporins)
- Coupled transporters ( $\text{Na}^+$ -glucose,  $\text{Na}^+/\text{H}^+$ -antiporter,  $\text{Na}^+/\text{K}^+/\text{2Cl}^-$ -symporter,  $\text{Na}^+$ -phosphate symporter,  $\text{Na}^+/\text{Cl}^-$ -symporter,  $\text{Na}^+/\text{HCO}_3^-$ -symporter,  $\text{Cl}^-/\text{HCO}_3^-$ -antiporter)

R 35. Describe the nephron sites and molecular mechanisms of action of the following classes of diuretics (osmotic, carbonic anhydrase inhibitors, loop, thiazide,  $\text{K}^+$ -sparing).

R 36. Describe clinical syndromes related to defects in specific renal transporters (e.g., Bartter's, Gittelman's, Liddle's, etc.).

R 37. Describe the effects of reductions in GFR on plasma creatinine concentrations and plot the relationship

## Urine Concentration and Dilution

R 38. Using the intake and loss routes identified in objective R 4, predict the changes in body fluid volume and osmolality caused by a net water loss or gain in the body. Predict how each of these disturbances would alter the rate of urine production and the osmotic composition of the urine.

R 39. Using the intake and loss routes identified in objective R 4, predict the changes in body fluid volume and osmolality caused by a net NaCl loss or gain in the body. Predict how each of these disturbances would alter the rate of urine production and the osmotic composition of urine.

R 40. Identify the two most powerful stimuli that cause ADH release, and describe the negative feedback control mechanisms for each.

R 41. Describe the role of the ascending limb of the loop of Henle in producing a high renal interstitial fluid osmolality. Beginning with the loop of Henle, contrast the tubular fluid and interstitial fluid osmolality changes that allow either a dilute or a concentrated urine to be produced and excreted.

R 42. Predict the consequence on urine concentrating ability if the medullary osmotic gradient is disrupted. Following disruption, describe how the osmotic gradient would be re-established.

R 43. Identify the tubular section and cellular mechanism by which ADH increases permeability to water and urea. Describe the role of these changes on the ability of the kidney to produce either a dilute or a concentrated urine.

R 44. Given urine and plasma osmolarities and urine volume, calculate osmolar and free water clearance. Identify expected free water clearance for an individual producing either a dilute or a concentrated urine.

R 45. Describe the actions of diuretics listed on objective R 35 on the ability of the kidneys to maximally concentrate and dilute urine.

R 46. Distinguish between central and nephrogenic diabetes insipidus based on plasma ADH levels and the response to an injection of ADH.

## Na<sup>+</sup> Balance and Regulation of Extracellular Fluid Volume

R 47. Identify the normal range of dietary Na<sup>+</sup> intake and major routes of Na<sup>+</sup> loss from the body. Define the role of Na in maintaining extracellular fluid volume.

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R 48. Calculate the normal filtered load of  $\text{Na}^+$ . Identify the tubular sites of Na reabsorption, and the alterations in  $\text{Na}^+$  reabsorption in conditions of euolemia, volume depletion, and volume expansion.

R 49. Describe the receptors involved in the monitoring of ECF volume (e.g., high-pressure baroreceptors and low-pressure cardiopulmonary stretch receptors), and diagram the neural reflex regulation of renal  $\text{Na}^+$  and water excretion.

R 50. Diagram the formation and generation of angiotensin II, beginning with renin. Identify four factors that can promote renin release.

R 51. Describe the regulation of  $\text{Na}^+$  reabsorption along the nephron, including the effects of sympathetic nerves, angiotensin II, aldosterone, and atrial natriuretic peptide.

R 52. Describe the effects of diuretics listed in objective R 35 on  $\text{Na}^+$  handling by the kidneys and, thus, on ECF volume regulation.

R 53. Explain the contribution of the kidneys to progression of and/or the compensation for the altered fluid volume regulation characteristic of congestive heart failure and hepatic cirrhosis.

R 54. Describe the regulation of proximal tubule reabsorption that underlies the phenomenon of glomerulotubular balance.

R 55. Describe the role of the renin-angiotensin-aldosterone system in the regulation of systemic arterial blood pressure in volume-replete and volume-depleted states and in secondary forms of hypertension.

### **$\text{K}^+$ Balance**

R 56. Identify the normal range of dietary  $\text{K}^+$  intake and major routes of  $\text{K}^+$  loss from the body. Define the role of extracellular  $\text{K}^+$  in maintaining normal nerve and muscle function.

R 57. Describe  $\text{K}^+$  distribution within the body, extrarenal  $\text{K}^+$  homeostasis, and the role insulin, epinephrine, and aldosterone play in the movement of  $\text{K}^+$  between intracellular and extracellular pools. Describe the  $\text{K}^+$  shift caused by acidosis.

R 58. Calculate the normal filtered load of  $\text{K}^+$ . Identify the tubular sites of  $\text{K}^+$  reabsorption and secretion.

R 59. Describe the factors that regulate  $K^+$  secretion in the collecting duct (i.e., aldosterone, plasma  $K^+$ ) and distinguish these from factors that alter  $K^+$  secretion at this site (i.e., luminal fluid flow rate, acid-base disturbances, anion delivery).

R 60. Contrast the tubular sites of action of  $K^+$  wasting and  $K^+$  sparing diuretics.

### **$Ca^{2+}$ and Phosphate Balance**

R 61. Identify the normal range of dietary  $Ca^{2+}$  and phosphate intake, major storage pools of Ca and phosphate, and major routes of  $Ca^{2+}$  and phosphate loss from the body. Describe the regulation of plasma  $Ca^{2+}$  by calcitonin and phosphate by parathyroid hormone.

R 62. Calculate the normal filtered load of  $Ca^{2+}$ . Identify the tubular sites of  $Ca^{2+}$  reabsorption. Calculate the normal filtered load of phosphate. Identify the tubular sites of phosphate reabsorption.

R 63. Describe the renal regulation of  $Ca^{2+}$  and phosphate transport by PTH, calcitonin, and 1,25-dihydroxy vitamin D (calcitriol), and distinguish from other factors that alter their transport (ECF volume, acid-base disorders).

R 64. Describe the role of the kidney in the production of 1,25-dihydroxy vitamin D (calcitriol).

R 65. Describe the effects of diuretics on  $Ca^{2+}$  and phosphate excretion, especially noting the effect of thiazides to decrease  $Ca^{2+}$  excretion and loop diuretics to increase  $Ca^{2+}$  excretion.

### **Acid-Base Balance**

R 66. Identify the normal range of pH values, and the upper and lower limits compatible with life. Describe the role of buffers in maintaining pH, including the roles of the lungs and kidneys.

R 67. Describe the respiratory and renal regulation of the  $CO_2/HCO_3^-$  buffer system, which allows a buffer with a  $pK_a$  of 6.1 to be physiologically important in the maintenance of the normal plasma pH of 7.4.

R 68. Distinguish between  $CO_2$ -derived (volatile acid) and nonvolatile acid, the relative amounts produced each day through dietary intake and cellular metabolism, and the normal routes of loss from the body.

R 69. Calculate the filtered load of  $\text{HCO}_3^-$ , and identify the major sites of reabsorption (and secretion) along the nephron, emphasizing the importance of  $\text{H}^+$  secretory mechanisms in this process. Describe the cellular mechanisms responsible for net transepithelial movement of  $\text{HCO}_3^-$ .

R 70. Describe the adjustments in filtered load and  $\text{HCO}_3^-$  reabsorption ( $\text{H}^+$  secretion) by alterations in systemic acid-base balance and distinguish from factors that alter this process (i.e., ECF volume, aldosterone, and angiotensin II).

R 71. Describe net acid excretion by the kidneys, titratable acid, the importance of urinary buffers, and the production and excretion of ammonium. Distinguish between the reclamation of filtered bicarbonate and the formation of new bicarbonate.

R 72. Given a sudden increase or decrease in pH, identify the magnitude and the time course of the compensations that act to minimize change in pH of the body fluids, including a) buffers, b) respiratory adjustments, and c) renal adjustments.

R 73. From blood values, identify simple and mixed metabolic and respiratory acid-base disturbances. Distinguish between increased and normal anion gap metabolic acidosis, chloride-sensitive and -resistant metabolic alkalosis, and acute and chronic respiratory disturbances.

R 74. Describe processes that lead to acid-base disturbances and list common causes.

R 75. Describe the effects of carbonic anhydrase inhibitors and the other diuretics listed on objective R 35 on acid-base balance and the reabsorption of  $\text{HCO}_3^-$  by the nephron.

### **Integrative and Pathophysiological Aspects; Hypertension**

R 76. Describe the relationships between sodium balance and plasma volume as they contribute to cardiovascular hemodynamics and arterial pressure.

R 77. Describe the role of the renin-angiotensin-aldosterone systems in the regulation of sodium balance and arterial pressure with emphasis on the actions of angiotensin II on renal hemodynamics and tubular transport.

R 78. Describe pressure natriuresis and the mechanisms mediating and modulating this process.

R79. Describe how impairments in renal function and pressure natriuresis contribute to the long-term regulation of arterial pressure and the development and maintenance of hypertension.

# Respiration

(revised 2006)

## Pulmonary Mechanics

PUL 1. Diagram how pleural pressure, alveolar pressure, airflow, and lung volume change during a normal quiet breathing cycle. Identify on the figure the onset of inspiration, cessation of inspiration, and cessation of expiration. Describe how differences in pressure between the atmosphere and alveoli cause air to move in and out of the lungs.

PUL 2. Draw a normal pulmonary pressure-volume (compliance) curve (starting from residual volume to total lung capacity and back to residual volume), labeling the inflation and deflation limbs. Explain the cause and significance of the hysteresis in the curves.

PUL 3. Define compliance and identify two common clinical conditions in which lung compliance is higher or lower than normal.

PUL 4. Draw the pressure-volume (compliance) curves for the lungs, chest wall, and respiratory system on the same set of axes. Show and explain the significance of the resting positions for each of these three structures.

PUL 5. Identify the forces that generate the negative intrapleural pressure when the lung is at functional residual capacity, and predict the direction that the lung and chest wall will move if air is introduced into the pleural cavity (pneumothorax).

PUL 6. Draw a normal spirogram, labeling the four lung volumes and four capacities. List the volumes that comprise each of the four capacities. Identify which volume and capacities cannot be measured by spirometry.

PUL 7. Define the factors that determine total lung capacity, functional residual capacity, and residual volume. Describe the mechanisms responsible for the changes in those volumes that occur in patients with emphysema and pulmonary fibrosis.

PUL 8. Define surface tension and describe how it applies to lung mechanics, including the effects of alveolar size and the role of surfactants. Define atelectasis and the role of surfactants in preventing it.

PUL 9. Describe the principal components of pulmonary surfactant and explain the roles of each.

PUL 10. Describe the effects of airway diameter and turbulent flow on airway resistance.

PUL 11. Describe how airway resistance alters dynamic lung compliance.

PUL 12. Draw a spirogram resulting from a maximal expiratory effort. Label the forced vital capacity (FVC), timed forced expiratory volumes (FEVs), and the maximal expiratory flow rate between 25-75% of FVC (FEF25-75%).

PUL 13. Draw a normal maximal effort flow-volume curve, labeling the effort-dependent and -independent regions. Use the concept of dynamic compression of airways to explain why each point in the effort-independent region of the curve represents a maximal flow rate that is uniquely dependent on lung volume. Describe how and why the shape of the flow-volume curve is shifted in chronic obstructive lung disease (COPD).

PUL 14. Differentiate between the two broad categories of restrictive and obstructive lung disease, including the spirometric abnormalities associated with each category.

PUL 15. Describe the regional differences in alveolar ventilation in healthy and diseased lungs and explain the basis for these differences.

### **Alveolar Ventilation**

PUL 16. Define partial pressure and fractional concentration as they apply to gases in air. List the normal fractional concentrations and sea level partial pressures for O<sub>2</sub>, CO<sub>2</sub>, and N<sub>2</sub>.

PUL 17. List the normal airway, alveolar, arterial, and mixed venous PO<sub>2</sub> and PCO<sub>2</sub> values. List the normal arterial and mixed venous values for O<sub>2</sub> saturation, [HCO<sub>3</sub><sup>-</sup>], and pH.

PUL 18. Define and contrast the following terms: anatomic dead space, physiologic dead space, wasted (dead space) ventilation, total minute ventilation and alveolar minute ventilation.

PUL 19. Describe the concept by which physiological dead space can be measured.

PUL 20. Define and contrast the relationships between alveolar ventilation and the arterial PCO<sub>2</sub> and PO<sub>2</sub>.

PUL 21. Describe in quantitative terms the effect of ventilation on  $PCO_2$  according to the alveolar ventilation equation.

PUL 22. Be able to estimate the alveolar oxygen partial pressure ( $P_{AO_2}$ ) using the simplified form of the alveolar gas equation. Be able to use the equation to calculate the amount of supplemental  $O_2$  required to overcome a reduction in  $P_{AO_2}$  caused by hypoventilation or high altitude.

PUL 23. Define the following terms: hypoventilation, hyperventilation, hypercapnea, eupnea, hypopnea, and hyperpnea.

### **Pulmonary Circulation**

PUL 24. Contrast the systemic and pulmonary circulations with respect to pressures, resistance to blood flow, and response to hypoxia.

PUL 25. Describe the regional differences in pulmonary blood flow in an upright person. Define zones I, II, and III in the lung, with respect to pulmonary vascular pressure and alveolar pressure.

PUL 26. Describe how pulmonary vascular resistance changes with alterations in cardiac output or pulmonary arterial pressure. Explain in terms of distention and recruitment of pulmonary vessels. Identify the zones in which these two mechanisms apply.

PUL 27. Describe how pulmonary vascular resistance changes with lung volume. Explain in terms of alterations in alveolar and extra-alveolar blood vessels.

PUL 28. Describe the consequence of hypoxic pulmonary vasoconstriction on the distribution of pulmonary blood flow.

PUL 29. Describe the effects of inspired nitric oxide on pulmonary vascular resistance and hypoxic vasoconstriction.

PUL 30. Explain the development of pulmonary edema by a) increased hydrostatic pressure, b) increased permeability, c) impaired lymphatic outflow or increased central venous pressure, and d) hemodilution (e.g., with saline volume resuscitation).

PUL 31. Describe the major functions of the bronchial circulation.

## **Pulmonary Gas Exchange**

PUL 32. Name the factors that affect diffusive transport of a gas between alveolar gas and pulmonary capillary blood.

PUL 33. Describe the kinetics of oxygen transfer from alveolus to capillary and the concept of capillary reserve time (i.e., the portion of the erythrocyte transit time in which no further diffusion of oxygen occurs).

PUL 34. Define oxygen diffusing capacity, and describe the rationale and technique for the use of carbon monoxide to determine diffusing capacity.

PUL 35. Describe how the ventilation/perfusion (V/Q) ratio of an alveolar-capillary lung unit determines the PO<sub>2</sub> and PCO<sub>2</sub> of the blood emerging from that lung unit.

PUL 36. Identify the average V/Q ratio in a normal lung. Explain how V/Q is affected by the vertical distribution of ventilation and perfusion in the healthy lung.

PUL 37. Describe the normal relative differences from the apex to the base of the lung in alveolar and arterial PO<sub>2</sub>, PCO<sub>2</sub>, pH, and oxygen and carbon dioxide exchange.

PUL 38. Predict how the presence of abnormally low and high V/Q ratios in a person's lungs will affect arterial PO<sub>2</sub> and PCO<sub>2</sub>.

PUL 39. Describe two causes of abnormal V/Q distribution.

PUL 40. Define right-to-left shunts, anatomic and physiological shunts, and physiologic dead space (wasted ventilation). Describe the consequences of each for pulmonary gas exchange.

PUL 41. Describe the airway and vascular control mechanisms that help maintain a normal ventilation/perfusion ratio. Name two compensatory reflexes for V/Q inequality.

PUL 42. Be able to calculate the alveolar to arterial PO<sub>2</sub> difference, (A-a)DO<sub>2</sub>. Describe the normal value for (A-a) DO<sub>2</sub> and the significance of an elevated (A-a) DO<sub>2</sub>.

PUL 43. Name five causes of hypoxemia.

## Oxygen and Carbon Dioxide Transport

PUL 44. Define oxygen partial pressure (tension), oxygen content, and percent hemoglobin saturation as they pertain to blood.

PUL 45. Draw an oxyhemoglobin dissociation curve (hemoglobin oxygen equilibrium curve) showing the relationships between oxygen partial pressure, hemoglobin saturation, and blood oxygen content. On the same axes, draw the relationship between  $PO_2$  and dissolved plasma  $O_2$  content (Henry's Law). Compare the relative amounts of  $O_2$  carried bound to hemoglobin with that carried in the dissolved form.

PUL 46. Describe how the shape of the oxyhemoglobin dissociation curve influences the uptake and delivery of oxygen.

PUL 47. Define P50.

PUL 48. Show how the oxyhemoglobin dissociation curve is affected by changes in blood temperature, pH,  $PCO_2$ , and 2,3-DPG, and describe a situation where such changes have important physiological consequences.

PUL 49. Describe how anemia and carbon monoxide poisoning affect the shape of the oxyhemoglobin dissociation curve,  $PaO_2$ , and  $SaO_2$ .

PUL 50. List the forms in which carbon dioxide is carried in the blood. Identify the percentage of total  $CO_2$  transported as each form.

PUL 51. Describe the importance of the chloride shift in the transport of  $CO_2$  by the blood.

PUL 52. Identify the enzyme that is essential to normal carbon dioxide transport by the blood and its location.

PUL 53. Draw the carbon dioxide dissociation curves for oxy- and deoxyhemoglobin. Describe the interplay between  $CO_2$  and  $O_2$  binding on hemoglobin that causes the Haldane effect.

PUL 54. Explain why the total gas pressure of the venous blood is subatmospheric and why this situation is accentuated when breathing 100%  $O_2$ . Explain how breathing 100%  $O_2$  can result in further arterial  $O_2$  desaturation in hypoxemic patients who develop mucous plugging of their airways (absorption atelectasis).

PUL 55. Define respiratory acidosis and alkalosis and give clinical examples of each.

PUL 56. Describe the mechanism and function of respiratory acid base compensations.

## **Respiratory Control**

PUL 57. Identify the regions in the central nervous system that play important roles in the generation and control of cyclic breathing.

PUL 58. Give three examples of reflexes involving pulmonary receptors that influence breathing frequency and tidal volume. Describe the receptors and neural pathways involved.

PUL 59. List the anatomical locations of chemoreceptors sensitive to changes in arterial  $PO_2$ ,  $PCO_2$ , and pH that participate in the control of ventilation. Identify the relative importance of each in sensing alterations in blood gases.

PUL 60. Describe how changes in arterial  $PO_2$  and  $PCO_2$  alter alveolar ventilation, including the synergistic effects when  $PO_2$  and  $PCO_2$  both change.

PUL 61. Describe the respiratory drive in a COPD patient, and predict the change in respiratory drive when oxygen is given to a COPD patient.

PUL 62. Describe the mechanisms for the shift in alveolar ventilation that occur immediately upon ascent to high altitude, after remaining at altitude for two weeks, and immediately upon return to sea level.

PUL 63. Describe the physiological basis of shallow water blackout during a breath-hold dive.

PUL 64. Describe the significance of the feedforward control of ventilation (central command) during exercise, and the effects of exercise on arterial and mixed venous  $PCO_2$ ,  $PO_2$ , and pH.

## **Age Effects and Nonrespiratory Lung Functions**

PUL 65. Describe the effect of aging on lung volumes, lung and chest wall compliance, blood gases, and respiratory control.

PUL 66. Identify the mechanism by which particles are cleared from the airways.

PUL 67. Describe mechanisms for clearance of vasoactive substances from the blood during passage through the lung. Identify a substance that is almost completely cleared and one that is not cleared to any significant extent.