## Contents

Preface vi
Human Anatomy and Physiology Laboratory Safety Procedures viii
Trends in Instrumentation x

### Part One: Exercises

<table>
<thead>
<tr>
<th>Exercise</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>The Language of Anatomy</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>Organ Systems Overview</td>
<td>7</td>
</tr>
<tr>
<td>3</td>
<td>The Microscope</td>
<td>11</td>
</tr>
<tr>
<td>4</td>
<td>The Cell: Anatomy and Division</td>
<td>18</td>
</tr>
<tr>
<td>5A</td>
<td>The Cell: Transport Mechanisms and Permeability—Wet Lab</td>
<td>24</td>
</tr>
<tr>
<td>6A</td>
<td>Classification of Tissues</td>
<td>33</td>
</tr>
<tr>
<td>7</td>
<td>The Integumentary System</td>
<td>41</td>
</tr>
<tr>
<td>8</td>
<td>Classification of Covering and Lining Membranes</td>
<td>47</td>
</tr>
<tr>
<td>9</td>
<td>Overview of the Skeleton: Classification and Structure of Bones and Cartilages</td>
<td>51</td>
</tr>
<tr>
<td>10</td>
<td>The Axial Skeleton</td>
<td>57</td>
</tr>
<tr>
<td>11</td>
<td>The Appendicular Skeleton</td>
<td>65</td>
</tr>
<tr>
<td>12</td>
<td>The Fetal Skeleton</td>
<td>73</td>
</tr>
<tr>
<td>13</td>
<td>Articulations and Body Movements</td>
<td>76</td>
</tr>
<tr>
<td>14</td>
<td>Microscopic Anatomy and Organization of Skeletal Muscle</td>
<td>82</td>
</tr>
<tr>
<td>15</td>
<td>Gross Anatomy of the Muscular System</td>
<td>87</td>
</tr>
<tr>
<td>16A</td>
<td>Skeletal Muscle Physiology: Frogs and Human Subjects</td>
<td>96</td>
</tr>
<tr>
<td>17</td>
<td>Histology of Nervous Tissue</td>
<td>105</td>
</tr>
<tr>
<td>18A</td>
<td>Neurophysiology of Nerve Impulses: Wet Lab</td>
<td>111</td>
</tr>
<tr>
<td>19</td>
<td>Gross Anatomy of the Brain and Cranial Nerves</td>
<td>116</td>
</tr>
<tr>
<td>20</td>
<td>Electroencephalography</td>
<td>124</td>
</tr>
<tr>
<td>21</td>
<td>Spinal Cord, Spinal Nerves, and the Autonomic Nervous System</td>
<td>128</td>
</tr>
<tr>
<td>22</td>
<td>Human Reflex Physiology</td>
<td>135</td>
</tr>
<tr>
<td>23</td>
<td>General Sensation</td>
<td>142</td>
</tr>
<tr>
<td>24</td>
<td>Special Senses: Vision</td>
<td>146</td>
</tr>
<tr>
<td>25</td>
<td>Special Senses: Hearing and Equilibrium</td>
<td>155</td>
</tr>
<tr>
<td>26</td>
<td>Special Senses: Olfaction and Taste</td>
<td>162</td>
</tr>
<tr>
<td>27</td>
<td>Functional Anatomy of the Endocrine Glands</td>
<td>166</td>
</tr>
<tr>
<td>Exercise</td>
<td>Title</td>
<td>Page</td>
</tr>
<tr>
<td>---------------</td>
<td>----------------------------------------------------------------------</td>
<td>------</td>
</tr>
<tr>
<td>28A</td>
<td>Role of Thyroid Hormone, Pituitary Hormone, Insulin, and Epinephrine: Wet Lab</td>
<td>172</td>
</tr>
<tr>
<td>29A</td>
<td>Blood</td>
<td>179</td>
</tr>
<tr>
<td>30</td>
<td>Anatomy of the Heart</td>
<td>188</td>
</tr>
<tr>
<td>31</td>
<td>Conduction System of the Heart and Electrocardiography</td>
<td>194</td>
</tr>
<tr>
<td>32</td>
<td>Anatomy of Blood Vessels</td>
<td>198</td>
</tr>
<tr>
<td>33A</td>
<td>Human Cardiovascular Physiology: Blood Pressure and Pulse Determinations</td>
<td>205</td>
</tr>
<tr>
<td>34A</td>
<td>Frog Cardiovascular Physiology: Wet Lab</td>
<td>214</td>
</tr>
<tr>
<td>35A</td>
<td>The Lymphatic System and Immune Response</td>
<td>222</td>
</tr>
<tr>
<td>36</td>
<td>Anatomy of the Respiratory System</td>
<td>228</td>
</tr>
<tr>
<td>37A</td>
<td>Respiratory System Physiology</td>
<td>234</td>
</tr>
<tr>
<td>38</td>
<td>Anatomy of the Digestive System</td>
<td>243</td>
</tr>
<tr>
<td>39A</td>
<td>Chemical and Physical Processes of Digestion: Wet Lab</td>
<td>251</td>
</tr>
<tr>
<td>40</td>
<td>Anatomy of the Urinary System</td>
<td>258</td>
</tr>
<tr>
<td>41A</td>
<td>Urinalysis</td>
<td>264</td>
</tr>
<tr>
<td>42</td>
<td>Anatomy of the Reproductive System</td>
<td>269</td>
</tr>
<tr>
<td>43</td>
<td>Physiology of Reproduction: Gametogenesis and the Female Cycles</td>
<td>276</td>
</tr>
<tr>
<td>44</td>
<td>Survey of Embryonic Development</td>
<td>282</td>
</tr>
<tr>
<td>45</td>
<td>Principles of Heredity</td>
<td>288</td>
</tr>
<tr>
<td>46</td>
<td>Surface Anatomy Roundup</td>
<td>295</td>
</tr>
</tbody>
</table>

**Part Two: Cat Dissection Exercises**

<table>
<thead>
<tr>
<th>Dissection Exercise</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Dissection and Identification of Cat Muscles</td>
<td>298</td>
</tr>
<tr>
<td>2</td>
<td>Dissection of Cat Spinal Nerves</td>
<td>301</td>
</tr>
<tr>
<td>3</td>
<td>Identification of Selected Endocrine Organs of the Cat</td>
<td>302</td>
</tr>
<tr>
<td>4</td>
<td>Dissection of the Blood Vessels of the Cat</td>
<td>304</td>
</tr>
<tr>
<td>5</td>
<td>The Main Lymphatic Ducts of the Cat</td>
<td>306</td>
</tr>
<tr>
<td>6</td>
<td>Dissection of the Respiratory System of the Cat</td>
<td>307</td>
</tr>
<tr>
<td>7</td>
<td>Dissection of the Digestive System of the Cat</td>
<td>308</td>
</tr>
<tr>
<td>8</td>
<td>Dissection of the Urinary System of the Cat</td>
<td>310</td>
</tr>
<tr>
<td>9</td>
<td>Dissection of the Reproductive System of the Cat</td>
<td>312</td>
</tr>
</tbody>
</table>

**Part Three: Fetal Pig Dissection Exercises**

<table>
<thead>
<tr>
<th>Dissection Exercise</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Dissection and Identification of Fetal Pig Muscles</td>
<td>314</td>
</tr>
<tr>
<td>2</td>
<td>Dissection of the Spinal Cord and Spinal Nerves of the Fetal Pig</td>
<td>317</td>
</tr>
</tbody>
</table>
Organization of this Instructor Guide


Each exercise in this manual includes detailed directions for setting up the laboratory, comments on the exercise (including common problems encountered), some additional or alternative activities, and answers to the new pre-lab quizzes and activity questions that appear in the text of the lab manual. (Answers to questions regarding student observations and data have not been included.)

Answers to the lab manual Review Sheets have been integrated to follow each exercise. In some cases several acceptable answers have been provided. Answers to the dissection review questions are located in this guide with the dissection exercises.

Directions for use of the kymograph have been removed from the lab manual but appear in Exercise 16 in the Instructor Guide. Several complete exercises incorporating PowerLab®, iWorx®, and Intelitool® computer data acquisition and compilation systems, as well as instructions for the BIOPAC® software and 2-channel unit, can be downloaded from the Instructor Resource section of the new myA&P website for the Human Anatomy & Physiology Laboratory Manuals, and may be duplicated for student use.

The time allotment at the beginning of each exercise, indicated by the hourglass icon, is an estimate of the amount of in-lab time it will take to complete the exercise, unless noted otherwise. If you are using multimedia, add the running time to the time allotted for a given exercise.

Suggested multimedia resources, indicated by the computer icon, are listed for each exercise. Format options include VHS, CD-ROM, DVD, Website, and streaming webcast. Information includes title, format, running time, and distributor. The key to distributor abbreviations is in the Guide to Multimedia Resource Distributors, Appendix B. Street and Web addresses of the distributors are also listed in Appendix B.

Each exercise includes directions for preparing needed solutions, indicated by the test tube icon.

Trends in Instrumentation includes information about laboratory techniques and equipment, including information on PowerLab®, iWorx®, and Intelitool®. There are some suggestions about additional investigations using techniques and equipment not described in the laboratory manual.

The Laboratory Materials list in each exercise is intended as a convenience when ordering. Amounts listed assume a laboratory class of 24 students working in groups of four. Information about several supply houses appears in Appendix A. Note: The information provided is not an exhaustive list of suppliers.

Laboratory Safety

Always establish safety procedures for the laboratory. Students should be given a list of safety procedures at the beginning of each semester and should be asked to locate exits and safety equipment. Suggested procedures may be found on pp. viii–ix, along with a student acknowledgment form. These pages may be copied and given to the students. Signed student acknowledgment forms should be collected by the instructor once the safety procedures have been read and explained and the safety equipment has been located.

Special precautions must be taken for laboratories using body fluids. Students should use only their own fluids or those provided by the instructor. In many cases, suitable alternatives have been suggested. All reusable glassware and plasticware should be soaked in 10% bleach solution for 2 hours and then washed with laboratory detergent and autoclaved if possible. Disposable items should be placed in an autoclave bag for 15 minutes at 121°C and 15 pounds of pressure to ensure sterility. After autoclaving, items may be discarded in any disposal facility.
Disposal of dissection materials and preservatives should be arranged according to state regulations. Be advised that regulations vary from state to state. Contact your state Department of Health or Environmental Protection Agency or their counterparts for advice. Keep in mind that many dissection specimens can be ordered in formaldehyde-free preservatives; however, even formaldehyde-free specimens may not be accepted by local landfill organizations.

Acknowledgments

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Susan J. Mitchell
Human Anatomy and Physiology
Laboratory Safety Procedures

1. Upon entering the laboratory, locate exits, fire extinguisher, fire blanket, chemical shower, eye wash station, first aid kit, broken glass containers, and cleanup materials for spills.

2. Do not eat, drink, smoke, handle contact lenses, store food, or apply cosmetics or lip balm in the laboratory. Restrain long hair, loose clothing, and dangling jewelry.

3. Students who are pregnant, taking immunosuppressive drugs, or who have any other medical condition (e.g., diabetes, immunological defect) that might necessitate special precautions in the laboratory must inform the instructor immediately.

4. Wearing contact lenses in the laboratory is inadvisable because they do not provide eye protection and may trap material on the surface of the eye. If possible, wear regular eyeglasses instead.

5. Use safety glasses in all experiments involving liquids, aerosols, vapors, and gases.

6. Decontaminate work surfaces at the beginning and end of every laboratory period, using a commercially prepared disinfectant or 10% bleach solution. After labs involving dissection of preserved material, use hot soapy water or disinfectant.

7. Keep liquids away from the edge of the lab bench to help avoid spills. Clean up spills of viable materials using disinfectant or 10% bleach solution.

8. Properly label glassware and slides.

9. Use mechanical pipeting devices; mouth pipeting is prohibited.

10. Wear disposable gloves when handling blood and other body fluids, mucous membranes, or nonintact skin, and/or when touching items or surfaces soiled with blood or other body fluids. Change gloves between procedures. Wash hands immediately after removing gloves. (Note: Cover open cuts or scrapes with a sterile bandage before donning gloves.)

11. Place glassware and plasticware contaminated by blood and other body fluids in a disposable autoclave bag for decontamination by autoclaving or place them directly into a 10% bleach solution before reuse or disposal. Place disposable materials such as gloves, mouthpieces, swabs, and toothpicks that come into contact with body fluids into a disposable autoclave bag, and decontaminate before disposal.

12. To help prevent contamination by needle stick injuries, use only disposable needles and lancets. Do not bend needles and lancets. Needles and lancets should be placed promptly in a labeled puncture-resistant leakproof container and decontaminated, preferably by autoclaving.


14. Report all spills or accidents, no matter how minor, to the instructor.

15. Never work alone in the laboratory.

16. Remove protective clothing and wash hands before leaving the laboratory.
Laboratory Safety Acknowledgment Form

I hereby certify that I have read the safety recommendations provided for the laboratory and have located all
of the safety equipment listed in Safety Procedure Number 1 of these procedures.

Student’s Name ____________________________________________________________

Course ____________________________________________________________ Date __________

Instructor’s Name _________________________________________________________

Adapted from:

Centers for Disease Control. 1996. “Universal Precautions for Prevention of Transmission of HIV and Other Bloodborne

Pearson Benjamin Cummings.

Trends in Instrumentation

Robert Anthony and Alan Wade, Triton College
Peter Zao, North Idaho College
Susan J. Mitchell, Onondaga Community College

This section is designed for instructors interested in incorporating additional laboratory technologies and instrumentation into their anatomy and physiology courses. The following techniques will introduce students to some standard approaches and instrumentation currently used in clinical and research facilities. Although these techniques are used in various biology and chemistry laboratory courses, many students in basic anatomy and physiology are not routinely introduced to these skills. Rather than detailing specific laboratory procedures, this discussion will provide insight into some of the options for bringing technology into the introductory anatomy and physiology laboratory.

One of the standard methods available to medical technicians and researchers is computerized data acquisition. Currently available computer packages can measure and analyze various aspects of cardiac, reflex, muscle, and respiratory physiology. Other standard methods include chromatography, spectrophotometry, and electrophoresis. Applications of available computer data acquisition systems and clinical technologies for use in an anatomy and physiology laboratory are listed on the following pages. Included in each application are relevant exercises in the laboratory manual and a brief description of each possible application. A list of companies offering appropriate products is included in Appendix A.

Computerized Data Acquisition

Computerized equipment is commonly used to monitor patients in today’s allied health areas. We have found that students appreciate the brief exposure to computers in our labs and begin to realize that a computer is not an intimidating machine, but a tool that allows them to perform specific tasks. Incorporating computer-based exercises into the lab also generates increased interest because most students realize that they will be using computers in their chosen professions.

Analog-to-digital converters can be used to create customized physiological data collection systems. Easy to use computer data acquisition systems include BIOPAC®, PowerLab®, Intelitool®, iWorx®, and Vernier® systems. The packages are designed for use in college-level courses and require minimal computer experience. Directions for BIOPAC® are included in the lab manual. Exercises using PowerLab®, iWorx®, and Intelitool® can be downloaded from the Instructor Resource section of the myA&P companion website for the lab manuals at www.myaandp.com. The Vernier system can be easily adapted to sections of Exercises 31 and 31A.

General Tips for Computer Data Acquisition Systems

Use in the Laboratory

The following ideas are general guidelines designed as an introduction to the operation of computer acquisition systems. Each system contains the software, equipment, and basic instructions needed to conduct the experiments on a computer.

Starting the Laboratory

- Prepare the laboratory for a computer-assisted data acquisition exercise by connecting the transducers and cables to the computer.
- Run through each exercise yourself so that you have a good idea of how much time is required to complete the activities in the given lab time period.
• You may wish to start the program so that the main menu is visible as the students sit down to work. If computer novices are left to start and prepare the system by themselves, their initial frustration may waste valuable lab time and detract from the experience.
• Once the program menu is up, students should be able to follow the exercise procedures without difficulty.
• It may be helpful to have an introductory lab designed to introduce the students to the general operation of the system.

Exercises Based on the PowerLab® System

Laboratory Exercises with PowerLab® instructions are available for download from the Instructor Resource section of myA&P for the following lab exercises:

- Exercise 16A  Skeletal Muscle Physiology: Frogs and Human Subjects
- Exercise 22  Human Reflex Physiology
- Exercise 31  Conduction System of the Heart and Electrocardiography
- Exercise 33A  Human Cardiovascular Physiology: Blood Pressure and Pulse Determinations
- Exercise 34A  Frog Cardiovascular Physiology: Wet Lab
- Exercise 37A  Respiratory System Physiology

Comments and tips specific to each exercise are included in the instructions.

Exercises Based on iWorx®

Laboratory Exercises with iWorx® instructions are available for download from the Instructor Resource section of myA&P for the following lab exercises:

- Exercise 16A  Electromyography in a Human Subject Using iWorx®
- Exercise 20  Electroencephalography Using iWorx®
- Exercise 22  Measuring Reaction Time Using iWorx®
- Exercise 31  Electrocardiography Using iWorx®
- Exercise 33A  Measuring Pulse Using iWorx®
- Exercise 34A  Recording Baseline Frog Heart Activity
- Exercise 37A  Measuring Respiratory Variations

Exercises Based on Intelitool® Systems

Laboratory exercises with Intelitool® instructions are available for download from the Instructor Resource section of myA&P for the following lab exercises:

- Exercise 16A  Muscle Physiology
- Exercise 22  Human Reflex Physiology
- Exercise 31  Conduction System of the Heart and Electrocardiography
- Exercise 37A  Respiratory System Physiology

Comments and tips specific to each exercise are included on a separate Tips for Instructors page preceding each exercise.

Exercises in Cell Physiology and Clinical Chemistry

Modern cell physiology lab exercises frequently involve biochemical analysis of cellular components and products. A number of techniques can be used to detect and quantify the constituents of cells and body fluids.
Some of the more commonly used clinical and research techniques include chromatography, spectrophotometry, and electrophoresis.¹

**Chromatography**

**Exercise 4: The Cell: Anatomy and Division** Introduce molecular separation techniques when discussing the cell (or macromolecules).

**Exercise 29: Blood** Separate protein and lipid components during blood analysis.

**Application**

Chromatographic techniques have a number of applications in cell physiology and chemistry. Chromatography is used for separation and identification of components in mixtures containing amino acids, nucleic acids, sugars, vitamins, steroids, antibiotics, and other drugs.

The major forms of chromatography for the college physiology laboratory include thin-layer, paper, column, gas-liquid, and high-performance liquid chromatography. Descriptions of these procedures and their clinical applications can be found in a number of clinical method manuals.²

Gas and high-performance liquid chromatography offer the greatest sensitivity and quantitative ability, but the high initial investment usually makes these systems prohibitive unless they are already in place.

Thin-layer and paper chromatography are economical, and they can be performed with a minimum of equipment. Both methods can be used as qualitative or semiquantitative screening techniques to detect the presence of both endogenous and exogenous compounds.³

An example of a clinically significant screening test is the determination by thin-layer chromatography of abnormal levels of certain amino acids that are associated with genetic diseases affecting metabolism. The disorders phenylketonuria, alkaptonuria, and homocystinuria result in abnormal levels of phenylalanine, homogentisic acid, and methionine, respectively, in the urine and blood. The sample and standards are applied to a thin-layer plate coated with cellulose acetate, or a silica gel, or to a Whatman #4 chromatography paper, and run in a butanol/acetic acid/water solvent. For visualization and identification of amino acids, an indicator such as ninhydrin may be used. The color intensity for the appropriate amino acids can be compared to normal values.

**Spectrophotometry**

**Exercise 29A: Blood** Analyze protein or lipid composition, or enzyme hydrolysis.

**Exercise 41A: Urinalysis** Analyze various substances present in urine.

**Exercise 39A: Chemical and Physical Processes of Digestion** Quantitative spectrophotometric analysis of enzyme hydrolysis.

**Application**

Spectrophotometry is a common procedure used in clinical and research settings for determining concentrations of substances in solution, based on the amount of radiant energy transmitted through or absorbed by a substance in solution. Spectrophotometric measurements include total protein, total lipid, cholesterol, lipoprotein, and hemoglobin.

Spectrophotometry can also be used as a quantitative measure of enzymatic hydrolysis using commercially available colorogenic substrates. Most determinations in spectrophotometry utilize wavelengths in visible or ultraviolet ranges. For a more detailed description of the theory of spectrophotometry and use of the equipment, refer to a biochemistry or clinical methods manual.

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¹ Due to the hazards associated with the laboratory use of human body fluids, it may be advisable to avoid using student-drawn blood samples for analysis. There are a wide variety of commercially available blood components, both normal and abnormal, as well as blood component standards.


Diagnostic kits (for specific diseases) include:
1. Bilirubin (liver disease)
2. Total cholesterol and HDL cholesterol (atherosclerosis)
3. Creatine kinase (striated muscle damage)
4. Hemoglobin (anemia)
5. Creatinine (kidney disease)

Electrophoresis

Exercise 29A: Blood Analyze protein and lipid components of blood.

Exercise 45: Principles of Heredity DNA fingerprinting systems, comparison of adult and sickle-cell hemoglobin.

Application

Electrophoretic techniques, which demonstrate the migration and separation of charged solutes in an electrical field, have many important applications in cell and molecular biology. The most commonly used techniques involve zone electrophoresis, in which migration occurs within a semisolid support medium. In a majority of these procedures, agarose, polyacrylamide, or sodium dodecyl sulfate gels are used as the support medium. Sample migration can be horizontal or vertical, depending on the type of apparatus. Directions for agarose gel separation of hemoglobin can be found in Exercise 45 of the laboratory manual.

An increasing number of supply companies are recognizing the importance of studies in molecular biology and their impact on the study of cell physiology and human disease. The companies are becoming involved with biotechnology education by offering lab systems that are designed to introduce the methods of molecular biology and biotechnology to students at the pre-college and college levels. These systems are often in kit form and facilitate hands-on experience with a variety of important procedures. Some of the experimental systems available are:
1. Molecular weight determination (proteins)
2. Separation and identification of serum proteins
3. Cardiac risk assessment—analysis of lipoproteins
4. DNA fingerprinting—restriction fragmentation patterns

Sources of Equipment and Reagents

Supplies for the biochemical techniques described in the above section can be obtained from the supply houses listed in Appendix A. The list is by no means complete but includes companies that are familiar to most educators. The Intelitool® products are best obtained directly from the company rather than through another vendor, as delivery times are much quicker.
The Language of Anatomy

If time is a problem, most of this exercise can be done as an out-of-class assignment.

**Time Allotment:** 1/2 hour (in lab).

**Multimedia Resources:** See Appendix B for Guide to Multimedia Resource Distributors.

* A.D.A.M.® Interactive Anatomy 4.0 (AIA: CD-ROM, DVD)

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**Laboratory Materials**

*Ordering information is based on a lab size of 24 students, working in groups of 4. A list of supply house addresses appears in Appendix A.*

- 1–2 human torso models
- 2 human skeletons, one male and one female
- 3–4 preserved kidneys (sheep)
- Scalpels
- Gelatin-spaghetti molds

---

**Advance Preparation**

1. Set out human torso models and have articulated skeletons available.
2. Obtain three preserved kidneys (sheep kidneys work well). Cut one in transverse section, one in longitudinal section (usually a sagittal section), and leave one uncut. Label the kidneys and put them in a demonstration area. You may wish to add a fourth kidney to demonstrate a frontal section.
3. The day before the lab, prepare gelatin or Jell-O® using slightly less water than is called for and cook the spaghetti until it is al dente. Pour the gelatin into several small molds and drop several spaghetti strands into each mold. Refrigerate until lab time.
4. Set out gelatin-spaghetti molds and scalpel.

---

**Comments and Pitfalls**

1. Students will probably have the most trouble understanding proximal and distal, often confusing these terms with superior and inferior. They also find the terms anterior/ventral and posterior/dorsal confusing because these terms refer to the same directions in humans, but different directions in four-legged animals. Other than that there should be few problems.

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**Answers to Pre-Lab Quiz (p. 1)**

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<tr>
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<tbody>
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<td>1.</td>
<td>false</td>
</tr>
<tr>
<td>2.</td>
<td>axial</td>
</tr>
<tr>
<td>3.</td>
<td>b, toward or at the body surface</td>
</tr>
<tr>
<td>4.</td>
<td>b, sagittal</td>
</tr>
<tr>
<td>5.</td>
<td>cranial, vertebral</td>
</tr>
<tr>
<td>6.</td>
<td>Heart</td>
</tr>
</tbody>
</table>
Answers to Activity Questions

Activity 2: Practicing Using Correct Anatomical Terminology (p. 4)
The wrist is *proximal* to the hand.
The trachea (windpipe) is *anterior* or *ventral* to the spine.
The brain is *superior* or *cephalad* to the spinal cord.
The kidneys are *inferior* or *caudal* to the liver.
The nose is *medial* to the cheekbones.
The thumb is *lateral* to the ring finger.
The thorax is *superior* or *cephalad* to the abdomen.
The skin is *superficial* to the skeleton.

Activity 4: Identifying Organs in the Abdominopelvic Cavity (p. 9)
Name two organs found in the left upper quadrant: *stomach, spleen, large intestine*
Name two organs found in the right lower quadrant: *small intestine, large intestine, appendix*
What organ is divided into identical halves by the median plane line? *urinary bladder*
The Language of Anatomy

Surface Anatomy

1. Match each of the following descriptions with a key equivalent, and record the key letter or term in front of the description.

Key:
- a. buccal
- b. calcaneal
- c. cephalic
- d. digital
- e. patellar
- f. scapular

a; buccal 1. cheek  
d; digital 2. pertaining to the fingers  
f; scapular 3. shoulder blade region  
c; cephalic 4. anterior aspect of knee  
b; calcaneal 5. heel of foot  

2. Indicate the following body areas on the accompanying diagram by placing the correct key letter at the end of each line.

Key:
- a. abdominal
- b. antecubital
- c. brachial
- d. cervical
- e. crural
- f. femoral
- g. fibular
- h. gluteal
- i. lumbar
- j. occipital
- k. oral
- l. popliteal
- m. pubic
- n. sural
- o. thoracic
- p. umbilical

3. Classify each of the terms in the key of question 2 above into one of the large body regions indicated below. Insert the appropriate key letters on the answer blanks.

b, c, e, f, g, l, n 1. appendicular  
a, d, h, i, j, k, m, o, p 2. axial

Body Orientation, Direction, Planes, and Sections

4. Describe completely the standard human anatomical position.

Standing erect, feet together, head and toes pointed forward, arms hanging at sides with palms forward.
5. Define *section*. A cut along an imaginary plane through the body wall or organ.

6. Several incomplete statements are listed below. Correctly complete each statement by choosing the appropriate anatomical term from the key. Record the key letters and/or terms on the correspondingly numbered blanks below.

   **Key:** a. anterior  b. distal  c. frontal  d. inferior  e. lateral  f. medial  g. posterior  h. proximal  i. sagittal  j. superior  k. transverse

   In the anatomical position, the face and palms are on the _1_ body surface; the buttocks and shoulder blades are on the _2_ body surface; and the top of the head is the most _3_ part of the body. The ears are _4_ and _5_ to the shoulders and _6_ to the nose. The heart is _7_ to the vertebral column (spine) and _8_ to the lungs. The elbow is _9_ to the fingers but _10_ to the shoulder. The abdominopelvic cavity is _11_ to the thoracic cavity and _12_ to the spinal cavity. In humans, the dorsal surface can also be called the _13_ surface; however, in quadruped animals, the dorsal surface is the _14_ surface.

   If an incision cuts the heart into right and left parts, the section is a _15_ section; but if the heart is cut so that superior and inferior portions result, the section is a _16_ section. You are told to cut a dissection animal along two planes so that both kidneys are observable in each section. The two sections that will always meet this requirement are the _17_ and _18_ sections. A section that demonstrates the continuity between the spinal and cranial cavities is a _19_ section.

   1. a; anterior  8. f; medial  14. j; superior
   2. g; posterior  9. h; proximal  15. i; sagittal
   3. j; superior  10. b; distal  16. k; transverse
   4. f; medial  11. d; inferior  17. c; frontal
   5. j; superior  12. a; anterior  18. k; transverse
   6. e; lateral  13. g; posterior  19. i; sagittal
   7. a; anterior

7. Correctly identify each of the body planes by inserting the appropriate term for each on the answer line below the drawing.

   (a) median (mid-sagittal) plane  (b) frontal plane  (c) transverse plane
8. Draw a kidney as it appears when sectioned in each of the three different planes.

   [Images of kidney in frontal, sagittal, and transverse sections]

9. Correctly identify each of the nine areas of the abdominal surface by inserting the appropriate term for each of the letters indicated in the drawing.

   a. epigastric region
   b. right hypochondriac region
   c. left hypochondriac region
   d. umbilical region
   e. right lumbar region
   f. left lumbar region
   g. hypogastric (pubic) region
   h. right iliac region
   i. left iliac region

Body Cavities

10. Which body cavity would have to be opened for the following types of surgery or procedures? (Insert letter of key choice in same-numbered blank. More than one choice may apply.)

   Key:  a. abdominopelvic  b. cranial  c. dorsal  d. spinal  e. thoracic  f. ventral

   e, f  1. surgery to remove a cancerous lung lobe  a, f  4. appendectomy
   a, f  2. removal of the uterus, or womb  a, f  5. stomach ulcer operation
   b, c  3. removal of a brain tumor  d, c  6. delivery of pre-operative “saddle” anesthesia
11. Name the muscle that subdivides the ventral body cavity. 

Diaphragm

12. Which organ system would not be represented in any of the body cavities? Skeletal, muscular, integumentary

13. What are the bony landmarks of the abdominopelvic cavity? Dorsally, the vertebral column; laterally and anteriorly, the pelvis

14. Which body cavity affords the least protection to its internal structures? Abdominal

15. What is the function of the serous membranes of the body? The serous membranes produce a lubricating fluid (serous fluid) that reduces friction as organs slide across one another or against the cavity walls during their functioning.

16. Using the key choices, identify the small body cavities described below.

Key:

- a. middle ear cavity
- b. nasal cavity
- c. oral cavity
- d. orbital cavity
- e. synovial cavity

1. holds the eyes in an anterior-facing position
2. houses three tiny bones involved in hearing
3. contained within the nose
4. contains the tongue
5. lines a joint cavity

17. On the incomplete flowchart provided below:

- Fill in the cavity names as appropriate to boxes 3–8.
- Then, using either the name of the cavity or the box numbers, identify the descriptions in the list that follows.

Body cavities

1. Dorsal body cavity
2. Ventral body cavity

3. cranial cavity (superior)
4. vertebral/spinal cavity (inferior)
5. thoracic cavity (superior)
6. abdominopelvic cavity (inferior)
7. abdominal cavity (superior)
8. pelvic cavity (inferior)

1. contained within the skull and vertebral column
2. its name means belly
3. 1, 3, or 4
4. houses female reproductive organs
5. contains the heart
6. or 7
7. bounded by the ribs
8. 6 or 7

h. its walls are muscular
Organ Systems Overview

Time Allotment: 1 1/2 hours (rat dissection: 1 hour; if performing reproductive system dissection, 1/2 hour each for male and female; dissectible human torso model: 1/2 hour).


Homeostasis (FHS: 20 minutes, VHS, DVD, 3-year streaming webcast)
Homeostasis: The Body in Balance (HRM: 26 minutes, VHS, DVD)
Organ Systems Working Together (WNS: 14 minutes, VHS)
Practice Anatomy Lab™ 2.0 (PAL) (BC: CD-ROM, Website)

Solutions:
Bleach Solution, 10%
Measure out 100 milliliters of household bleach. Add water to a final volume of 1 liter.

Laboratory Materials

Ordering information is based on a lab size of 24 students, working in groups of 4. A list of supply house addresses appears in Appendix A.

| Dissectible human torso model or cadaver | 6–12 blunt probes | Disposable gloves, soap, and sponges |
| 6–12 forceps | 6–12 freshly killed or preserved rats | 6–12 dissecting trays |
| 6–12 scissors | Twine or large dissecting pins | Lab disinfectant or 10% bleach solution |

Advance Preparation

1. Make arrangements for appropriate storage and disposal of dissection materials. Check with the Department of Health or the Department of Environmental Protection, or their counterparts, for state regulations.
2. Designate a disposal container for organic debris, set up a dishwashing area with hot soapy water and sponges, and provide lab disinfectant such as Wavicide-01 (Carolina) or bleach solution for washing down the lab benches.
3. Set out safety glasses and disposable gloves for dissection of freshly killed animals (to protect students from parasites) and for dissection of preserved animals.
4. Decide on the number of students in each dissecting group (a maximum of four is suggested, two is probably best). Each dissecting group should have a dissecting pan, dissecting pins, scissors, blunt probe, forceps, twine, and a preserved or freshly killed rat.
5. Preserved rats are more convenient to use unless small mammal facilities are available. If live rats are used, they may be killed a half-hour or so prior to the lab by administering an overdose of ether or chloroform. To do this, remove each rat from its cage and hold it firmly by the skin at the back of its neck. Put the rat in a container with cotton soaked in ether or chloroform. Seal the jar tightly and wait until the rat ceases to breathe.
6. Set out dissectible human torso models and a dissected human cadaver if available.
Comments and Pitfalls

1. Students may be overly enthusiastic when using the scalpel and cut away organs they are supposed to locate and identify. Therefore, use scissors to open the body. Have blunt probes available as the major dissecting tool.

2. Be sure the lab is well ventilated, and encourage students to take fresh air breaks if the preservative fumes are strong. If the dissection animal will be used only once, it can be rinsed to remove most of the excess preservative.

3. Organic debris may end up in the sinks, clogging the drains. Remind the students to dispose of all dissection materials in the designated container.

4. Inferior vena cava and aorta may be difficult to distinguish in uninjected specimens.

Answers to Pre-Lab Quiz (p. 15)

1. The cell 4. respiratory
2. c, organ 5. urinary
3. nervous 6. diaphragm

Answers to Activity Questions

Activity 5: Examining the Human Torso Model (p. 24)

2. From top to bottom, the organs pointed out on the torso model are: brain, trachea, thyroid gland, lung, heart, diaphragm, liver, stomach, spleen, large intestine, greater omentum, small intestine

3. Dorsal body cavity: brain, spinal cord
   Thoracic cavity: aortic arch, bronchi, descending aorta (thoracic region), esophagus, heart, inferior vena cava, lungs, and trachea
   Abdominopelvic cavity: adrenal gland, descending aorta (abdominal region), greater omentum, inferior vena cava, kidneys, large intestine, liver, mesentery, pancreas, rectum, small intestine, spleen, stomach, ureters, urinary bladder
   Note: The diaphragm separates the thoracic cavity from the abdominopelvic cavity.
   Right Upper Quadrant: right adrenal gland, right kidney, large and small intestine, liver, mesentery, pancreas, stomach, right ureter
   Left Upper Quadrant: left adrenal gland, descending aorta, greater omentum, left kidney, large and small intestine, mesentery, pancreas, spleen, stomach, left ureter
   Right Lower Quadrant: large and small intestine, mesentery, rectum, right ureter, urinary bladder
   Left Lower Quadrant: descending aorta, greater omentum, large and small intestine, left ureter, urinary bladder

4. Digestive: esophagus, liver, stomach, pancreas, small intestine, large intestine (including rectum)
   Urinary: kidneys, ureters, urinary bladder
   Cardiovascular: aortic arch, heart, descending aorta, inferior vena cava
   Endocrine: pancreas, adrenal gland, thyroid gland
   Reproductive: none
   Respiratory: lungs, bronchi, trachea
   Lymphatic/Immunity: spleen
   Nervous: brain, spinal cord
1. Use the key below to indicate the body systems that perform the following functions for the body. Then, circle the organ systems (in the key) that are present in all subdivisions of the ventral body cavity.

Key:

- a. cardiovascular
- b. digestive
- c. endocrine
- d. integumentary
- e. lymphatic/immunity
- f. muscular
- g. nervous
- h. reproductive
- i. respiratory
- j. skeletal
- k. urinary

1. rids the body of nitrogen-containing wastes   a; cardiovascular
2. is affected by removal of the thyroid gland   g; nervous
3. provides support and levers on which the muscular system acts   j; skeletal
4. includes the heart   a; cardiovascular
5. causes the onset of the menstrual cycle   h; reproductive
6. protects underlying organs from drying out and from mechanical damage   e; lymphatic/immunity
7. protects the body; destroys bacteria and tumor cells   f; muscular
8. breaks down ingested food into its building blocks   b; digestive
9. removes carbon dioxide from the blood   i; respiratory
10. delivers oxygen and nutrients to the tissues   a; cardiovascular
11. moves the limbs; facilitates facial expression   k; urinary
12. conserves body water or eliminates excesses   c; endocrine
13. facilitate conception and childbearing   h; reproductive
14. controls the body by means of chemical molecules called hormones   c; endocrine
15. is damaged when you cut your finger or get a severe sunburn   d; integumentary

2. Using the above key, choose the organ system to which each of the following sets of organs or body structures belongs.

- e; lymphatic/immunity  thymus, spleen, lymphatic vessels
- h; reproductive  testis, ductus deferens, urethra
- j; skeletal  bones, cartilages, tendons
- b; digestive  esophagus, large intestine, rectum
- i; respiratory  trachea, bronchi, alveoli
- c; endocrine  pancreas, pituitary, adrenals
- f; muscular  muscles of the thigh, postural muscles
- d; integumentary  epidermis, dermis, and cutaneous sense organs

NAME ____________________________________ 
LAB TIME/DATE _______________________

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3. Using the key below, place the following organs in their proper body cavity.

   Key:
   a. abdominopelvic  b. cranial  c. spinal  d. thoracic

   a; abdominopelvic  1. stomach  a; abdominopelvic  4. liver  d; thoracic  7. heart
   d; thoracic  2. esophagus  c; spinal  5. spinal cord  d; thoracic  8. trachea
   a; abdominopelvic  3. large intestine  a; abdominopelvic  6. urinary bladder  a; abdominopelvic  9. rectum

4. Using the organs listed in question 3 above, record, by number, which would be found in the abdominal regions listed below.

   3, 6, 9  1. hypogastric region  1, 3, 4  4. epigastric region
   3  2. right lumbar region  3  5. left iliac region
   3  3. umbilical region  1, 3, 4  6. left hypochondriac region

5. The levels of organization of a living body are chemical, cell, tissue, organ, organ system, and organism.

6. Define organ. A body part (or structure) that is made up of two or more tissue types and performs a specific body function, e.g., the stomach, the kidney.

7. Using the terms provided, correctly identify all of the body organs provided with leader lines in the drawings shown below. Then name the organ systems by entering the name of each on the answer blank below each drawing.

   **Key:** blood vessels  heart  nerves  spinal cord  urethra
          brain  kidney  sensory receptor  ureter  urinary bladder

   ![Diagrams]

   a. nervous system  b. cardiovascular system  c. urinary system

8. Why is it helpful to study the external and internal structures of the rat? Many of the external and internal structures are similar to those in the human. Studying the rat can help you to understand your own structure.
The Microscope

If students have already had an introductory biology course where the microscope has been introduced and used, there might be a temptation to skip this exercise. I have found that most students need the review, so I recommend spending this time early in the course to make sure they are all comfortable with the microscope, as it is used extensively throughout the laboratory manual.

**Time Allotment:** 2 hours.

**Solutions:**
- **Bleach Solution, 10%**
  
  Measure out 100 milliliters of household bleach. Add water to a final volume of 1 liter.

- **Methylene Blue Solution (Loeffler’s)**
  
  Weigh out 0.5 gram methylene blue, 1 milliliter 1% potassium hydroxide solution, and 30 milliliters ethanol, absolute. Add to 100 milliliters distilled water. Warm the water to about 50 degrees C, stir in methylene blue and add other ingredients; filter.

- **Physiologic Saline (Mammalian, 0.9%)**
  
  Weigh out 9 grams of NaCl. Add distilled/deionized water to a final volume of 1 liter. Make fresh just prior to experiment.

**Laboratory Materials**

Ordering information is based on a lab size of 24 students, working in groups of 4. A list of supply house addresses appears in Appendix A.

- 24 compound microscopes, lens cleaning solution, lens paper, immersion oil
- 24 millimeter rulers
- 24 slides of the letter e
- 24 slides with millimeter grids
- 24 slides of crossed colored threads (threads should cross at a single junction)
- Filter paper or paper towels
- 1 box of microscope slides
- 1 box of coverslips
- 1 box of flat-tipped toothpicks
- 8–12 dropper bottles of physiologic saline
- 8–12 dropper bottles of methylene blue stain (dilute) or iodine
- 24 slides of cheek epithelial cells
- 10% bleach solution
- Autoclave bag, disposable

**Advance Preparation**

1. Provide each student with a compound microscope, millimeter ruler, bottle of immersion oil, lens paper, and millimeter grid slide. A supply of glass cleaner, such as Windex™, should be available for lens cleaning.

2. Have available slides of the letter e and slides of crossed colored threads. Some instructors prefer to have slides for an entire semester available in individual boxes, which can be handed out to students. Others prefer to keep the slides on trays to be distributed as needed.

3. Set up an area for wet mount supplies, including clean microscope slides and coverslips, flat-tipped toothpicks, physiologic saline, methylene blue stain or iodine, and filter paper, or set out prepared slides of cheek epithelial cells.
4. Set up a disposal area containing a 1L beaker of 10% bleach solution and an autoclave bag. Note: Detailed instructions for treatment and disposal of materials used in labs involving human tissue and excretions are found in the preface of this Instructor Guide.

5. If the microscopes are binocular rather than monocular, give additional instructions on focusing.
   a. After the parts of the microscope have been identified, turn on the light and adjust the interpupillary distance so that a single circle of light is visible through the eyepieces. This is difficult for some students, usually because they are moving back and forth and changing their eye position. Have each student record his/her own interpupillary distance for later use.
   b. For a microscope with an adjustable left eyepiece, focus the microscope as directed, using the right eye only.
   c. Focus using the left eyepiece with the right eye closed. Both eyepieces should now be focused on the specimen. (Reverse the directions if the right eyepiece is adjustable.)

6. The directions for perceiving depth (p. 33) are for microscopes with objective lenses that advance and retract during focusing. If the stage moves during focusing, the superior thread will come into focus first if these directions are followed. Alter instructions if necessary.

Comments and Pitfalls

1. Be sure to have the students check the orientation of the letter e on the slide before putting the slide on the microscope. If they forget to check, they will miss the point of the exercise.

2. Beware of common focusing problems: dirty lenses, inverted slide, objective lens not securely in place, and wrong lens in position (oil immersion instead of high-power).

3. It is difficult to use a millimeter ruler to measure the working distance of the high-power and oil immersion lenses on some microscopes. A best estimate is usually sufficient.

4. Many students have difficulty with the section on determining the size of the microscope field. The direct measurement is usually no problem, although some students measure area rather than diameter, and some students will have both the letter e slide and the grid on the stage at the same time. Emphasize that direct measurement should be done using only one lens. Otherwise, measuring discrepancies cause confusion. The problem is often with the math involved. It is probably worthwhile to stop the class and work through the use of the formula (p. 32) when you see that most students are at this point in the exercise.

5. Clarify what is meant by “detail observed” in the chart on p. 31.

6. Students may forget safety precautions when preparing the wet mount. Emphasize the importance of following directions for safe disposal of toothpicks and proper cleanup of glassware.

7. Many students forget to adjust the iris diaphragm and may end up using the light at its highest intensity, which is hard on the bulb. Remind students that the iris diaphragm should be adjusted so that the field is just filled with light when observed with the ocular lens removed. In practice, it may be necessary to adjust the iris diaphragm for best contrast, although some resolution may be lost.

Answers to Pre-Lab Quiz (p. 27)

1. d, stage
2. b, the slide should be in focus at higher magnifications once it is properly focused at lower magnifications.
3. $350 \times$
4. c, with special lens paper and cleaner
5. false
6. true
Answers to Activity Questions

Activity 2: Viewing Objects Through the Microscope (pp. 30–31)

5. Answers will vary depending on the lenses used. Working distance decreases as lens power increases. The  
   e appears upside down and backwards.
6. The image moves toward you. The image moves to the right.
7. and 8. Grains begin to appear and are very visible with the high-power lens.
   The image is much larger.
   The entire e is visible with the low-power lens, but less than 1/4 of the letter is probably visible with the  
   high-power lens.
   The field is smaller.
   The object must be centered so that it falls into the field of the higher power lens.
   The light to the field is reduced as the iris diaphragm is closed.
   The light intensity often must be increased when changing to a higher magnification, as the lens has a  
   smaller diameter and therefore lets in less light. In practice, if the microscope does not have a variable  
   light intensity adjustment, the iris diaphragm should be adjusted to obtain the best contrast.
9. Yes. Grains are very visible.
   The working distance is less than that of the high-power lens.
   It is desirable to begin focusing with a low-power lens because the field is larger, making it easier to find  
   the specimen on the slide, and the working distance is larger, reducing the chance of hitting the slide with  
   the lens.

Activity 3: Estimating the Diameter of the Microscope Field (pp. 32–33)

3. Answers depend on the field diameter of lenses used. For lenses with field diameters of 1.8 millimeters,  
   0.45 millimeter, and 0.18 millimeter, respectively, the estimated lengths are about 1.2 millimeters, 0.14  
   millimeter, and 0.18 millimeter.
4. No. The entire length of the object cannot be seen in one field. The estimate should be made with a lower-  
   power objective lens.

Activity 4: Perceiving Depth (p. 33)

2. When the stage descends, the first clearly focused thread is the bottom thread; the last clearly focused  
   thread is the top one.
   Answers depend on the order of the threads on the particular slides used.

Activity 5: Preparing and Observing a Wet Mount (pp. 33–34)

8. Most of the cells are separated from each other rather than in a continuous sheet.
10. A cheek epithelial cell is about 80–100 micrometers (µ) (0.08–0.1 millimeter) in diameter.
    They are more similar to those in Figure 3.5 and easier to measure because they are in a continuous sheet.
The Microscope

Care and Structure of the Compound Microscope

1. Label all indicated parts of the microscope.

2. Explain the proper technique for transporting the microscope.

*Carry with two hands—one supporting the base, the other holding the arm.*
3. The following statements are true or false. If true, write T on the answer blank. If false, correct the statement by writing on the blank the proper word or phrase to replace the one that is underlined.

   *with grit-free lens paper*
   1. The microscope lens may be cleaned with any soft tissue.

   *low-power or scanning*
   2. The microscope should be stored with the **oil immersion** lens in position over the stage.

   *T*
   3. When beginning to focus, the **lowest power** lens should be used.

   *away from*
   4. When focusing, always focus **toward** the specimen.

   *T*
   5. A coverslip should always be used with wet mounts and the **high-power** and **oil lenses**.

4. Match the microscope structures given in column B with the statements in column A that identify or describe them.

   **Column A**
   1. platform on which the slide rests for viewing
   2. used to increase the amount of light passing through the specimen
   3. secure(s) the slide to the stage
   4. delivers a concentrated beam of light to the specimen
   5. used for precise focusing once initial focusing has been done
   6. carries the objective lenses; rotates so that the different objective lenses can be brought into position over the specimen

   **Column B**
   a. coarse adjustment knob
   b. condenser
   c. fine adjustment knob
   d. iris diaphragm
   e. mechanical stage or spring clips
   f. movable nosepiece
   g. objective lenses
   h. ocular
   i. stage

5. Define the following terms.

   **virtual image**: An image that is erect and appears to be where it is not.

   **resolution**: Ability to discriminate two closely situated objects as separate.
Viewing Objects Through the Microscope

6. Complete, or respond to, the following statements:

1. The distance from the bottom of the objective lens in use to the specimen is called the _____.

2. Assume there is an object on the left side of the field that you want to bring to the center (that is, toward the apparent right). In what direction would you move your slide?

3. The area of the specimen seen when looking through the microscope is the _____.

4. If a microscope has a 10× ocular and the total magnification at a particular time is 950×, the objective lens in use at that time is _____.

5. Why should the light be dimmed when looking at living (nearly transparent) cells?

6. If, after focusing in low power, only the fine adjustment need be used to focus the specimen at the higher powers, the microscope is said to be ______.

7. If, when using a 10× ocular and a 15× objective, the field size is 1.5 mm, the approximate field size with a 30× objective is ______ mm.

8. If the size of the high-power field is 1.2 mm, an object that occupies approximately a third of that field has an estimated diameter of ______ mm.

7. You have been asked to prepare a slide with the letter k on it (as shown below). In the circle below, draw the k as seen in the low-power field.

8. Figure out the magnification of fields 1 and 3, and the field size of 2. (Hint: Use your ruler.) Note that the numbers for the field sizes below are too large to represent the typical compound microscope lens system, but the relationships depicted are accurate.

9. Say you are observing an object in the low-power field. When you switch to high power, it is no longer in your field of view. Why might this occur? The field decreases proportionately as magnification increases. Therefore, unless the object is centered at low power, it might be outside the higher-power field.

What should be done initially to prevent this from happening? Center the object that you wish to view.

10. Do the following factors increase or decrease as one moves to higher magnifications with the microscope?

resolution: increases (to a point) 
amount of light needed: increases 
working distance: decreases 
depth of field: decreases
11. A student has the high-dry lens in position and appears to be intently observing the specimen. The instructor, noting a working distance of about 1 cm, knows the student isn’t actually seeing the specimen.

How so? The working distance for the h.p. lens is closer to 1 mm.

12. Describe the proper procedure for preparing a wet mount.

Place the specimen on the slide with a medicine dropper or place a drop of water or saline on the slide. Mix specimen into drop using a toothpick. If staining, add a drop of stain and mix with a toothpick. Hold a coverslip with forceps so that the coverslip touches one side of the specimen drop, and then slowly and carefully lower the angled coverslip onto the specimen.

13. Indicate the probable cause of the following situations arising during use of a microscope.

a. Only half of the field is illuminated: The lens is not correctly rotated into place.

b. Field does not change as mechanical stage is moved: The slide is not correctly positioned in the clamp on the mechanical stage and does not move when the mechanical stage moves.
The Cell: Anatomy and Division

The Anatomy of the Composite Cell section can be given as an out-of-class assignment to save time. This might be necessary if audiovisual material is used.

**Time Allotment**: 2 hours.


- *Inside the Cell* (WNS: CD-ROM)
- *Inside the Living Cell* (WNS: VHS, set of 5)
- *An Introduction to the Living Cell* (CBS: 30 minutes, VHS, DVD)
- *A Journey Through the Cell* (FHS: VHS, DVD)
  - **Part One: Cells: An Introduction** (25 minutes)
  - **Part Two: Cell Functions: A Closer Look** (25 minutes)
- *Mitosis* (WNS: CD-ROM)
- *Mitosis and Meiosis* (DE: 23 minutes, VHS, DVD)
- *Practice Anatomy Lab™ 2.0* (PAL) (BC: CD-ROM, Website)

**Laboratory Materials**

*Ordering information is based on a lab size of 24 students, working in groups of 4. A list of supply house addresses appears in Appendix A.*

- 3-D model of composite cell or chart of cell anatomy
- 24 slides of simple squamous epithelium
- 24 slides of teased smooth muscle
- 24 slides of human blood cell smear
- 24 slides of sperm
- 24 slides of whitefish blastulae
- 24 compound microscopes, lens paper, lens cleaning solution, immersion oil
- 3-D models of mitotic stages
- Video or animation of mitosis

**Advance Preparation**

1. Set out slides (one per student) of simple squamous epithelium, teased smooth muscle, human blood cell smear, sperm, and whitefish blastulae. Students will also need lens paper, lens cleaning solution, immersion oil, and compound microscopes.

2. Set out a model or a lab chart of a composite cell, and models of mitotic stages.

**Comments and Pitfalls**

1. Observing differences and similarities in cell structure often gives students trouble, as many of them have never seen any cells other than epithelial cells. Slides or pictures of these cell types might help.
Answers to Pre-Lab Quiz (p. 39)

1. The structural and functional unit of all living things.
2. a, chromatin
3. d, selective permeability
4. Ribosomes
5. c, mitochondria
6. interphase
7. false
8. Four
9. b, interphase
10. false

Answers to Activity Questions

Activity 5: Observing Various Cell Structures (pp. 43–45)

4. Simple squamous epithelial cells are relatively large and irregularly (“fried-egg”) shaped. Smooth muscle cells are also relatively large, but are long and spindle shaped. Red blood cells and sperm are both examples of small cells. Red blood cells appear round, while sperm cells are streamlined with long flagella. Cell shape is often directly related to function. Epithelial cells fit tightly together and cover large areas. Elongated muscle cells are capable of shortening during contraction. The red blood cells are small enough to fit through capillaries, and are actually biconcave in shape, which makes them flexible and increases surface area (not obvious to the students at this point). Sperm cells’ streamlined shape and flagella are directly related to efficient locomotion.

The sperm cells have visible projections (flagella), which are necessary for sperm motility.

The function of sperm is to travel through the female reproductive system to reach the ovum in the uterine tubes. This requires motility, provided by the flagella.

None of the cells lacks a plasma membrane.

Mature red blood cells have no nucleus.

Nucleoli will probably be clearly visible in the epithelial cells, and possibly visible in the other nuclei.

No. Identifiable organelles are not visible in most of these cells. Filaments may be visible in the smooth muscle preparations. The details of organelle structure are usually below the limit of resolution of the light microscope. Unless special stains are used, there is no way to see or distinguish the organelles at this level.
The Cell: Anatomy and Division

Anatomy of the Composite Cell

1. Define the following terms:

   organelle: Highly organized intracellular structure that performs a specific (metabolic) function(s) for the cell.

   cell: The basic structural and functional unit of living organisms.

2. Although cells have differences that reflect their specific functions in the body, what functions do they have in common?

   Ability to metabolize, to reproduce, to grow (increase in mass), to respond to a stimulus, and to move.

3. Identify the following cell parts:

   plasma membrane 1. external boundary of cell; regulates flow of materials into and out of the cell; site of cell signaling

   lysosome 2. contains digestive enzymes of many varieties; “suicide sac” of the cell

   mitochondria 3. scattered throughout the cell; major site of ATP synthesis

   microvilli 4. slender extensions of the plasma membrane that increase its surface area

   inclusions 5. stored glycogen granules, crystals, pigments, and so on

   Golgi apparatus 6. membranous system consisting of flattened sacs and vesicles; packages proteins for export

   nucleus 7. control center of the cell; necessary for cell division and cell life

   centrioles 8. two rod-shaped bodies near the nucleus; direct formation of the mitotic spindle

   nucleolus 9. dense, darkly staining nuclear body; packaging site for ribosomes

   microfilaments 10. contractile elements of the cytoskeleton

   rough ER or endoplasmic reticulum 11. membranous system; involved in intracellular transport of proteins and synthesis of membrane lipids

   ribosomes 12. attached to membrane systems or scattered in the cytoplasm; synthesize proteins

   chromatin or chromatin threads 13. threadlike structures in the nucleus; contain genetic material (DNA)

   peroxisome 14. site of free radical detoxification
4. In the following diagram, label all parts provided with a leader line.

Differences and Similarities in Cell Structure

5. For each of the following cell types, list (a) one important structural characteristic observed in the laboratory, and (b) the function that the structure complements or ensures.

- **Squamous epithelium**
  a. cells fit closely together like floor tiles
  b. often a lining or covering tissue

- **Sperm**
  a. has a tail or flagellum
  b. allows sperm to propel itself to an egg

- **Smooth muscle**
  a. cells have an elongated shape
  b. a long axis allows a greater degree of shortening
6. What is the significance of the red blood cell being anucleate (without a nucleus)? Limited life span. Does not reproduce. The nucleus is gone; therefore, the cell cannot manufacture new proteins, etc. Did it ever have a nucleus? Yes If so, when? Before its release into the bloodstream.

7. Of the four cells observed microscopically (squamous epithelial cells, red blood cells, smooth muscle cells, and sperm) which has the smallest diameter? sperm Which is longest? smooth muscle or sperm (variable)

Cell Division: Mitosis and Cytokinesis

8. Identify the three phases of mitosis in the following photomicrographs.

   a. metaphase       b. anaphase       c. prophase

9. What is the importance of mitotic cell division? Provides cells for body growth and for repair of damaged tissue or provides additional cells with the same genetic makeup.

10. Draw the phases of mitosis for a cell that contains four chromosomes as its diploid or 2n number. (Refer to Figure 4.4.)
11. Complete or respond to the following statements:

   Division of the _1_ is referred to as mitosis. Cytokinesis is division of the _2_. The major structural difference between chromatin and chromosomes is that the latter are _3_. Chromosomes attach to the spindle fibers by undivided structures called _4_. If a cell undergoes mitosis but not cytokinesis, the product is _5_. The structure that acts as a scaffolding for chromosomal attachment and movement is called the _6_. _7_ is the period of cell life when the cell is not involved in division. Two cell populations in the body that do not routinely undergo cell division are _8_ and _9_.

12. Using the key, categorize each of the events described below according to the phase in which it occurs.

   Key: a. anaphase  b. interphase  c. metaphase  d. prophase  e. telophase

   __________  d  1. Chromatin coils and condenses, forming chromosomes.

   __________  a  2. The chromosomes are V-shaped.

   __________  e  3. The nuclear envelope re-forms.

   __________  e  4. Chromosomes stop moving toward the poles.

   __________  c  5. Chromosomes line up in the center of the cell.

   __________  d  6. The nuclear envelope fragments.

   __________  d  7. The mitotic spindle forms.

   __________  b  8. DNA synthesis occurs.

   __________  b  9. Centrioles replicate.

   __________  d  10. Chromosomes first appear to be duplex structures.

   __________  d (or a, c, and d)  11. Chromosomal centromeres are attached to the kinetochore fibers.

   __________  e  12. Cleavage furrow forms.

   __________  d (or a, c, and possibly d)  13. The nuclear envelope(s) is absent.

13. What is the physical advantage of the chromatin coiling and condensing to form short chromosomes at the onset of mitosis?

   Short, compact bodies are mechanically much easier to manipulate during mitosis than are long, thin chromatin threads.
This exercise has many parts to it. If students have had an introductory cell biology course, much of it should be review.

Time Allotment:
Observing Diffusion of Dye Through Agar Gel—set up: 5 minutes; observation: 60 minutes
Observing Diffusion of Dye Through Water—observations at end of lab session: 10 minutes
Observing Diffusion and Osmosis Through Nonliving Membranes—set up: 15 minutes; diffusion: 60 minutes; observation: 20 minutes
Investigating Diffusion and Osmosis Through Living Membranes: 25 minutes
Experiment 1—set up: 10 minutes; observation: 60 minutes
Experiment 2—15 minutes
Observing the Process of Filtration—15 minutes
Observations for diffusion and osmosis through living membranes, osmometer, and filtration can be done while waiting for the results of the other experiments.


An Introduction to the Living Cell (CBS: 30 minutes, VHS)
Mitosis and Meiosis (DE: VHS, DVD, 23 minutes)
The Outer Envelope (WNS: 15 minutes, VHS)
The Plasma Membrane and Cellular Transport (CVB: CD-ROM)

Solutions:

Agar Gel, 1.5%
Weigh out 15 grams of dried agar. Slowly add 1 liter of distilled water while heating. Bring slowly to a boil, stirring constantly until the agar dissolves. For immediate use, allow the agar to cool to about 45°C. Pour into petri dishes to solidify. Refrigerate in an inverted position. If the plates are to be kept for a longer time (more than one day), autoclave the agar solution in the flask, pour into sterile petri plates, allow the agar to solidify, invert the plates, and store in a refrigerator.

Benedict’s Solution
- 173.0 grams sodium citrate
- 100.0 grams sodium carbonate, anhydrous
- 17.3 grams cupric sulfate (pure crystalline)
Add the citrate and carbonate salts to 700–800 milliliters distilled water and heat to dissolve. Add the cupric sulfate to 100 milliliters distilled water and heat to dissolve. Cool the solutions and then combine. Add distilled water to make 1 liter of solution. Benedict’s solution is available for purchase from biology supply companies such as Carolina, WARD’S, or Fisher.

Bleach Solution, 10%
Measure out 100 milliliters of bleach and add water to a final volume of 1 liter.
Glucose, 40%
For each 100 milliliters of solution, weigh out 40 grams of glucose and bring to 100 milliliters with distilled water. It may be necessary to heat the mixture to get the glucose into solution. Refrigerate when not in use.

Methylene Blue Solution, 0.1M
Weigh out 3.2 grams of methylene blue powder and bring to 100 milliliters with distilled water.

Physiologic Saline (Mammalian, 0.9%)
Weigh out 9 grams of NaCl. Add distilled water to a final volume of 1 liter. Make fresh immediately prior to experiment.

Potassium Permanganate solution, 0.1M (1.6%)
Weigh out 1.6 grams of potassium permanganate crystals and bring to 100 milliliters with distilled water.

Silver Nitrate (2.9 or 3%)
Weigh out 2.9 grams (for 2.9%) or 3 grams (for 3%) of silver nitrate. Use caution, this is an oxidizing substance. Add distilled water to make 100 milliliters of solution. Store in light-resistant bottles. Make fresh for each use.

Sodium Chloride (NaCl), 5%
Weigh out 5 grams NaCl. Add distilled water to a final volume of 100 milliliters.

Sodium Chloride (NaCl), 10%
For each 100 milliliters of solution, weigh out 10 grams of NaCl and bring to 100 milliliters with distilled water. It may be necessary to heat the mixture to get the NaCl into solution.

Sucrose, 30%
For each 100 milliliters of solution, weigh out 30 grams of sucrose and bring to 100 milliliters with distilled water. It may be necessary to heat the mixture to get the sucrose into solution. Refrigerate when not in use.

Sucrose, 40% (with Congo Red Dye)
For each 100 milliliters of solution, weigh out 40 grams of sucrose and bring to 100 milliliters with distilled water. Add Congo red dye as necessary to color the solution red. It may be necessary to heat the solution to get the sucrose into solution. Refrigerate when not in use.

Uncooked Starch Solution
Add 20 grams of corn starch to 100 milliliters of distilled water and gently stir to form a milky solution. After 15 minutes, stir again. Stir before making filtration solution. Refrigerate when not in use.

Laboratory Materials

Ordering information is based on a lab size of 24 students, working in groups of 4. A list of supply house addresses appears in Appendix A.

24 compound microscopes, lens paper, lens cleaning solution, immersion oil
1 box of slides
1 box of coverslips
6 hot plates
6 forceps
6 petri plates with 1.5% agar gel
6 dropper bottles of 3.5% methylene blue solution
6 dropper bottles of 1.6% potassium permanganate solution

1000-milliliter graduated cylinder
6 15-milliliter graduated cylinders
Large beaker
Thistle tube osmometer
Molasses
6 millimeter rulers
25 dialysis sacs (or small Hefty® sandwich bags)
12 small funnels
6 dropper bottles of silver nitrate
6 dropper bottles of Benedict’s solution
6 dropper bottles of 40% glucose solution
6 dropper bottles of 10% NaCl solution
6 rolls of fine twine or 48 dialysis tubing clamps

24 test tubes
6 test tube holders
6 test tube racks
18 wax markers
6 25-milliliter graduated cylinders
24 250-milliliter beakers
6 dropper bottles of 60% glucose solution
6 rolls of fine twine or 48 dialysis tubing clamps
### Advance Preparation

*Note: This lab has many components. Either clearly designate supply areas for each part of the lab, or provide each lab group with its own set of supplies at the outset. The supplies for each part of the exercise are listed separately in case sections of the exercise are omitted. Some equipment is common to several parts of the lab.*

1. Set out slides and coverslips. Have compound microscopes available.
2. **Observing Diffusion of Dye Through Agar Gel.** Set out 0.1M or 3.5% methylene blue solution (Carolina) and 0.1M or 1.6% potassium permanganate solution (Carolina), 1.5% agar plates (12 milliliters of 1.5% agar per plate, one per group), medicine droppers, and millimeter rulers.
3. **Observing Diffusion of Dye Through Water (Demonstration).** On the morning of the laboratory session, place some crystals of potassium permanganate in the bottom of a 1000-milliliter graduated cylinder. Slowly and carefully fill the cylinder to the 1000-milliliter mark with water. Record the time at which the demonstration is set up. Set out millimeter rulers.
4. **Observing Diffusion and Osmosis Through Nonliving Membranes.** For each group, set out four dialysis sacs (WARD’S) or 10-centimeter lengths of dialysis tubing (Carolina), five 250-milliliter beakers, a wax marking pencil, 750 milliliters of distilled water, 20 milliliters of 10% NaCl solution, 20 milliliters of 40% sucrose-Congo red dye solution, 150 milliliters of 40% glucose solution, dropper bottles of Benedict’s solution (Carolina, or see above), silver nitrate, four test tubes, a test tube rack, test tube holder, small graduated cylinder, a small funnel, hot plate, and balance. Dialysis sacs can be prepared from cut sections of dialysis tubing. Soak dialysis tubing in a beaker of water for about 15 minutes. Once dialysis tubing has been soaked, open it by rubbing it between the thumb and forefinger until the tubing material separates. Tie the ends with fine twine or close with dialysis tubing closures (Carolina). Small Hefty® sandwich bags can also be used to make dialysis bags.
5. **Observing Osmometer Results (Demonstration).** At the beginning of the laboratory session, set up an osmometer, using a thistle tube and molasses. Fill the expanded end of the thistle tube with molasses and cover it securely with a differentially permeable membrane. Clamp the thistle tube to a stand and put the broad end into a beaker of distilled water. Mark the level of the molasses in the tube and record the time that the osmometer is set up. Set out millimeter rulers.
6. **Investigating Diffusion and Osmosis Through Living Membranes**
   - **Experiment 1:** Deshell eggs 48 to 72 hours before the day of the lab. To deshell eggs: immerse eggs in vinegar. After 24 hours, gently rub eggs under running water to remove shell. If there is any shell remaining, immerse in fresh vinegar. Repeat rubbing under water and immersion in fresh vinegar until all shell has been removed. Give each group 2 deshelled eggs, two 400-ml beakers, 200 ml distilled water, 200 ml 30% sucrose solution, wax markers, paper towels, weight boat, and laboratory balance.
   - **Experiment 2:** Give each group 6 microscope slides and coverslips, dropper bottles of distilled water, filter paper, plastic gloves, physiologic saline, 5% NaCl, a vial of animal blood, and medicine droppers (one per student). Set out a basin of 10% bleach, a wash bottle of 10% bleach, and a disposable autoclave bag.
7. **Observing the Process of Filtration.** Give each group a ring stand with ring clamp and ring attached, a funnel, a piece of filter paper, a beaker, a 10-ml graduated cylinder, 100 ml filtration solution, and a dropper bottle of Lugol’s iodine. Prepare the filtration solution by mixing 100 ml uncooked starch solution, 10 grams copper sulfate, and 10 grams powdered charcoal.

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**Comments and Pitfalls**

1. Caution students to keep careful track of time during the diffusion experiments. Lab timers might help. Suggestions for variables include different concentrations of solutions.
2. Dialysis sacs may leak. Check to see that they are tightly sealed.
3. You may substitute Clinitest™ tablets for Benedict’s solution.
4. Silver nitrate will stain and possibly damage clothing. Warn students to be careful.
5. Note that the **40% glucose solution** used in sac 1 of the osmosis experiment is not isoosmotic to the **10% NaCl solution** in sac 3, so caution students about the types of conclusions they may draw from this experiment. Also, sometimes no glucose will be present in the beaker at the end of the hour. You may need to extend the time for this part of the experiment.
6. Emphasize the importance of labeling test tubes and slides.
7. Red blood cells in physiologic saline may begin to crenate as the slide begins to dry out. Encourage students to make their observations quickly. If there is still trouble with crenation, use a slightly hypotonic saline solution.
8. Caution students to be careful when pouring starch solution into filter paper so that the solution does not overflow or cause the filter paper to collapse.

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**Answers to Pre-Lab Quiz (p. 53)**

1. diffusion
2. b, it contains more nonpenetrating solute particles than the interior of the cell.
3. d, vesicular transport
4. phagocytosis
5. active

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**Answers to Activity Questions**

**Activity 1: Observing Diffusion of Dye Through Agar Gel (pp. 55–56)**

6. Potassium permanganate (MW 158) diffused more rapidly than methylene blue (MW 320). The smaller the molecular weight, the faster the rate of diffusion. The dye molecules moved because they possess kinetic energy.

**Activity 2: Observing Diffusion of Dye Through Water (p. 56)**

4. Potassium permanganate diffuses more rapidly through the water. Although the agar gel is largely water, it does contain more solid particles, which hinder free diffusion.

**Activity 3: Observing Diffusion and Osmosis Through Nonliving Membranes (pp. 56–58)**

5. After 1 hour, sac 1 (originally containing 40% glucose) should have gained weight.

Water is moving into the sac by osmosis.

Glucose is still present in the sac, and a small amount of glucose may also be present in the beaker.

If the Benedict’s test is positive, glucose was able to pass through the dialysis membrane.

6. There should be no net weight change in sac 2.

Since the concentrations of glucose and water are the same on both sides of the membrane, there is no net movement of water or glucose.
7. Sac 3 will increase in weight, perhaps only by a small amount.
   There has been a net movement of water into the sac and the weight of the water was not completely off-
   set by the movement of the NaCl out of the sac.
   The solution in beaker 3 reacts with silver nitrate, indicating the presence of chloride in the beaker.
   Net dialysis of NaCl occurred.
8. There should be an increase in weight in sac 4.
   The water color did not turn pink; the dye was not able to diffuse out of the sac.
   The Benedict’s test for sugar was negative. Sucrose did not diffuse from the sac to the beaker.
   The dye and sucrose are too large to diffuse through the pores in the membrane or their rate of diffusion is
   too slow given the allowed time.
   Net simple diffusion occurred in situations 1, 3, and 4.
   Water molecules are very small, and move quickly down a concentration gradient. Na+ and Cl– in solution
   behave like slightly larger molecules, but are smaller than glucose molecules, which move slowly, if at all,
   through the dialysis tubing. (See item 5 in Comments and Pitfalls.) Note: Students may only be able to
   conclude that Na+ and Cl– in solution and water molecules are small, and glucose, sucrose, and Congo red
   dye molecules are larger, or that Na+ and Cl– in solution and water and glucose molecules are smaller than
   sucrose molecules.
   The dialysis sac is often compared to the plasma membrane of the cell.

Activity 4: Observing Osmometer Results (p. 58)
Net osmosis, movement of water into the molasses, occurred as shown by the increased distance that the col-
umn of water moved.

Activity 5: Investigating Diffusion and Osmosis Through Living Membranes—
Experiment 1 (pp. 58–59)
Conclusions: The egg placed in the distilled water gained weight because the egg is hypertonic to the distilled
water. The egg placed in 30% sucrose solution lost weight because the egg (14% solution) is hypotonic to the
30% sucrose solution. Water moves from the area of higher water concentration into an area of lower water
concentration.

Activity 5: Investigating Diffusion and Osmosis Through Living Membranes—
Experiment 2 (pp. 59–60)
3. The cells begin to shrink and develop a multipointed star shape.
4. When distilled water is added, the cells should begin to revert to their normal shape. Eventually they
   begin to look very bloated, and finally begin to disappear as their membranes burst open.

Activity 6: Observing the Process of Filtration (p. 60)
3. Passed: starch, copper sulfate, water
   Retained: powdered charcoal
   The filter paper represents a cell membrane.
   The filtration rate was greatest during the first 10-second counting period because the hydrostatic pressure
   was greater during that period.

The characteristic of the three solutes that determines whether or not they passed through the filter paper is
their size in relation to the size of the pores in the filter paper.
The Cell: Transport Mechanisms and Permeability—Wet Lab

Choose all answers that apply to questions 1 and 2, and place their letters on the response blanks to the right.

1. Molecular motion
   a. reflects the kinetic energy of molecules
   b. reflects the potential energy of molecules
   c. is ordered and predictable
   d. is random and erratic

2. Velocity of molecular movement
   a. is higher in larger molecules
   b. is lower in larger molecules
   c. increases with increasing temperature
   d. decreases with increasing temperature
   e. reflects kinetic energy

3. Summarize the results of Activity 3, diffusion and osmosis through nonliving membranes, below. List and explain your observations relative to tests used to identify diffusing substances, and changes in sac weight observed.

Sac 1 containing 40% glucose suspended in distilled water:

Glucose diffused from the sac into the water; using the Benedict’s test indicated the presence of the glucose that passed through the membrane. Water moved into the sac by osmosis; sac gained weight.

Sac 2 containing 40% glucose suspended in 40% glucose:

There was no net diffusion of glucose or osmosis because the water concentration on both sides of the membrane was the same. Net movement occurs only when there is a concentration gradient.

Sac 3 containing 10% NaCl suspended in distilled water:

NaCl diffused from the sac into the water; silver nitrate added to the water showed the presence of Cl\(^{-}\). Osmosis caused water to enter the sac because the solution in the sac was hypertonic to the distilled water in the beaker.

Sac 4 containing 40% sucrose and Congo red dye suspended in distilled water:

The Congo red dye did not diffuse from the sac into the water; the water in the beaker did not turn red. The sucrose did not diffuse from the sac; upon boiling, some of the sucrose bonds are hydrolyzed, releasing glucose and fructose. Using Benedict’s test then indicates the presence of glucose if sucrose passed through the membrane; the Benedict’s test was negative. Water moved into the sac by osmosis; the sac gained weight.
4. What single characteristic of the differentially permeable membranes used in the laboratory determines the substances that can pass through them? _______________________________________________________________________________

In addition to this characteristic, what other factors influence the passage of substances through living membranes?

Solubility in the lipid portion of the membrane and/or presence of membrane “carriers” for the substance(s).

___________________________________________________________________________________________________
___________________________________________________________________________________________________

5. A semipermeable sac containing 4% NaCl, 9% glucose, and 10% albumin is suspended in a solution with the following composition: 10% NaCl, 10% glucose, and 40% albumin. Assume that the sac is permeable to all substances except albumin. State whether each of the following will (a) move into the sac, (b) move out of the sac, or (c) not move.

glucose: a; moves into sac
albumin: c; does not move
water: b; moves out of sac
NaCl: a; moves into sac

6. Summarize the results of Activity 5, Experiment 1 (diffusion and osmosis through living membranes—the egg), below. List and explain your observations.

Egg 1 in distilled water: The egg gained weight because the concentration of the egg, 14%, is hypertonic to the water.

Water moves by osmosis from an area of higher water concentration into an area of lower water concentration.

Egg 2 in 30% sucrose: The egg lost weight because the concentration of the egg, 14%, is hypotonic to the 30% sucrose solution. Water moves by osmosis from an area of higher water concentration into an area of lower water concentration.

7. The diagrams below represent three microscope fields containing red blood cells. Arrows show the direction of net osmosis.

Which field contains a hypertonic solution? c The cells in this field are said to be crenated. Which field contains an isotonic bathing solution? b Which field contains a hypotonic solution? a What is happening to the cells in this field? Hemolysis; they are bursting as excessive water entry occurs.
8. Assume you are conducting the experiment illustrated in the next figure. Both hydrochloric acid (HCl) with a molecular weight of about 36.5 and ammonium hydroxide (NH₄OH) with a molecular weight of 35 are volatile and easily enter the gaseous state. When they meet, the following reaction will occur:

\[ \text{HCl} + \text{NH}_4\text{OH} \rightarrow \text{H}_2\text{O} + \text{NH}_4\text{Cl} \]

Ammonium chloride (NH₄Cl) will be deposited on the glass tubing as a smoky precipitate where the two gases meet. Predict which gas will diffuse more quickly and indicate to which end of the tube the smoky precipitate will be closer.

a. The faster-diffusing gas is \( \text{NH}_4\text{OH} \).

b. The precipitate forms closer to the \( \text{HCl} \) end.

9. What determines whether a transport process is active or passive? Whether or not the cell must provide ATP for the process; if so, the process is active.

10. Characterize membrane transport as fully as possible by choosing all the phrases that apply and inserting their letters on the answer blanks.

Passive processes: a, c, e, f (sometimes) Active processes: b, d, f (sometimes)

a. account for the movement of fats and respiratory gases through the plasma membrane

b. explain solute pumping, phagocytosis, and pinocytosis

c. include osmosis, simple diffusion, and filtration

d. may occur against concentration and/or electrical gradients

e. use hydrostatic pressure or molecular energy as the driving force

f. move ions, amino acids, and some sugars across the plasma membrane

11. For the osmometer demonstration (Activity 4), explain why the level of the water column rose during the laboratory session.

The thistle tube was immersed in a dialysis sac which, in turn, was immersed in water. Because water will move down its concentration gradient if it is able, water diffused from the beaker into the sac, where its concentration was much lower. As a result, the fluid column (molasses and entering water) rose in the thistle tube.
12. Define the following terms.

**diffusion:** Movement of molecules from a region of their higher concentration to an area where they are in lower concentration.

**osmosis:** Flow of water through a semipermeable or differentially permeable membrane. Water moves from an area of higher water concentration to an area of lower water concentration, from hypotonic (an area of low concentration of nonpenetrating solutes) to hypertonic (an area of higher concentration of nonpenetrating solutes) solution.

**simple diffusion:** Movement of molecules from a region of their higher concentration to a region of their lower concentration. Its driving force is kinetic energy of the molecules themselves.

**filtration:** Passage of substances across a membrane from an area of higher hydrostatic pressure to an area of lower hydrostatic pressure.

**active transport:** A transport system that requires that the cell provide ATP. One such system moves substances across the cell membrane attached to a carrier molecule called a solute pump.

**phagocytosis:** Engulfment of extracellular particles by pseudopod formation. "Cell eating."

**fluid-phase endocytosis:** Intake of extracellular fluids by vesicle formation. "Cell drinking."
Classification of Tissues

Time Allotment: 2 hours.


Laboratory Materials
Ordering information is based on a lab size of 24 students, working in groups of 4. A list of supply house addresses appears in Appendix A.

- 24 compound microscopes, lens paper, lens cleaning solution, immersion oil
- 24 slides of simple squamous, simple cuboidal, simple columnar, stratified squamous (nonkeratinized), pseudostratified ciliated columnar, stratified cuboidal, stratified columnar, and transitional epithelium
- 24 slides of mesenchyme; adipose, areolar, and dense connective tissue, regular (tendon) and irregular (dermis); hyaline cartilage, elastic cartilage, fibrocartilage; bone (cross section); and blood smear
- 24 slides of skeletal, cardiac, and smooth muscle (longitudinal sections)
- 24 slides of nervous tissue (spinal cord smear)

Advance Preparation
1. Set out prepared slides of simple squamous, simple cuboidal, simple columnar, stratified squamous (nonkeratinized), pseudostratified ciliated columnar, stratified cuboidal, stratified columnar, and transitional epithelium.
2. Set out prepared slides of mesenchyme; adipose tissue, areolar connective tissue, reticular connective tissue, dense connective tissue regular (tendon), and irregular (dermis) varieties; hyaline cartilage, elastic cartilage, and fibrocartilage; bone (cross section); and blood (smear).
3. Set out prepared slides of skeletal, cardiac, and smooth muscle (longitudinal sections) and teased smooth muscle.
4. Set out lens paper and lens cleaning solution. Have compound microscopes available.

Comments and Pitfalls
1. Slides of the lung are suggested for simple squamous epithelium and slides of the kidney are suggested for simple cuboidal epithelium. An analogy using a quarter or pavement stone will help students visualize the 3-dimensional shape of a squamous cell.
2. The dense fibrous regular connective tissue slide is sometimes labeled white fibrous tissue.

3. Students may have trouble locating the appropriate tissue on slides with multiple tissue types. Encourage them to consult lab manual Figures 6A.3–6A.7, available histology texts, and each other for help.

4. A television camera with a microscope adapter and monitor is very useful in this lab. By watching the monitor, students can observe the instructor locating the correct area of tissue on the slide (see item 3 in Comments and Pitfalls). It also makes it easier to answer student questions and share particularly good slides with the class.

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**Answers to Pre-Lab Quiz (p. 67)**

1. d, tissues
2. 4
3. true
4. c, squamous
5. b, single columnar
6. c, mesenchyme
7. c, neurons
8. true
9. neurons
10. 3
11. c, smooth

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**Answers to Activity Questions**

**Activity 2: Examining Connective Tissue Under the Microscope (pp. 75, 81)**

All connective tissues consist of cells located within a matrix. Blood is no exception, but its cells float freely in a liquid matrix. The matrix ground substance is the straw-colored fluid called plasma. Its proteins are soluble, rather than fibrous, and include albumin, globulins, and fibrinogen.
Classification of Tissues

Tissue Structure and Function—General Review

1. Define tissue. A group of cells similar to one another in structure that perform a common or related function.

2. Use the key choices to identify the major tissue types described below.

   Key: a. connective tissue  b. epithelium  c. muscle  d. nervous tissue

   - b; epithelium  1. lines body cavities and covers the body’s external surface
   - c; muscle  2. pumps blood, flushes urine out of the body, allows one to swing a bat
   - d; nervous  c; muscle  3. transmits electrochemical impulses
   - a; connective  4. anchors, packages, and supports body organs
   - b; epithelium  5. cells may absorb, secrete, and filter
   - d; nervous  6. most involved in regulating and controlling body functions
   - c; muscle  7. major function is to contract
   - b; epithelium  8. synthesizes hormones
   - a; connective  9. the most durable tissue type
   - a; connective  10. abundant nonliving extracellular matrix
   - a; connective  11. most widespread tissue in the body
   - d; nervous  12. forms nerves and the brain

Epithelial Tissue

3. Describe five general characteristics of epithelial tissue. The cells fit closely together, forming sheetlike membranes. Little intercellular material between the cells. Avascular. Membrane has a free edge. Generally has a high regenerative capacity.

4. On what basis are epithelial tissues classified? Number of layers and cell shape.
5. List five major functions of epithelium in the body, and give examples of each.

Function 1: protection  Example: skin
Function 2: absorption  Example: cells lining digestive tract
Function 3: filtration and secretion  Example: kidney tubule cells
Function 4: secretion  Example: glandular cells or kidney cells
Function 5: sensory reception  Example: free endings of sensory neurons

6. How does the function of stratified epithelia differ from the function of simple epithelia? Stratified epithelia have more layers for protection. Simple epithelia allow materials to move across them and are less protective.

7. Where is ciliated epithelium found? Lining of the respiratory tract and of the male and female reproductive tracts (ductus deferens and uterine tubes, respectively).
What role does it play? In the respiratory tract, it acts to sweep mucus superiorly away from the lungs. In the reproductive tract, it acts to propel sperm or ova (male and female tracts, respectively) along the tract.

8. Transitional epithelium is actually stratified squamous epithelium with special characteristics.
How does it differ structurally from other stratified squamous epithelia? When stretched, its top layers are squamous, but when not stretched, its top layers are pillow shaped.
How does the structural difference support its function? The surface cells have the ability to slide over one another, increasing the internal volume of the organ (e.g., bladder) as it fills and maintaining an intact lining whether stretched or contracted.

9. How do the endocrine and exocrine glands differ in structure and function? Endocrine glands are ductless glands. They produce hormones, which are liberated into the extracellular fluid to enter to the blood. Exocrine glands maintain their ducts and manufacture secretions of various types (perspiration, oil, digestive enzymes, etc.), which are ducted to the body (or membrane) surface.

10. Respond to the following with the key choices.
Key: a. simple squamous b. simple cuboidal c. simple columnar d. pseudostratified ciliated columnar e. stratified squamous f. transitional

e: stratified squamous  1. lining of the esophagus
c: simple columnar  2. lining of the stomach
a; simple squamous  3. alveolar sacs of lungs
b; simple cuboidal  4. tubules of the kidney
e; stratified squamous  5. epidermis of the skin
f; transitional  6. lining of bladder; peculiar cells that have the ability to slide over each other
a; simple squamous  7. forms the thin serous membranes; a single layer of flattened cells

Connective Tissue

11. What are three general characteristics of connective tissues? Common origin of connective tissue from mesenchyme, varied degrees of vascularity, and a large amount of extracellular matrix that varies with tissue type all characterize connective tissue.

12. What functions are performed by connective tissue? Protection, support, and the binding together of other body tissues. Transportation of substances within the body.

13. How are the functions of connective tissue reflected in its structure? There is a wide variety in the structures of connective tissue. This is reflected in the wide variety of functions they perform. Also, the large amount of nonliving matrix seen provides the strength needed to protect the body and carry out the normal functions of the body.

14. Using the key, choose the best response to identify the connective tissues described below.

   1. attaches bones to bones and muscles to bones  Key: a. adipose connective tissue
   b. areolar connective tissue
   c. dense fibrous connective tissue
   d. elastic cartilage
   e. elastic
   f. fibrocartilage
   g. hematopoietic tissue
   h. hyaline cartilage
   i. osseous tissue

   a; adipose  2. acts as a storage depot for fat
   c; dense  3. the dermis of the skin
   f; fibrocartilage  4. makes up the intervertebral discs
   i; osseous  5. forms the hip bone
   b; areolar  6. composes basement membranes; a soft packaging tissue with a jellylike matrix
   h; hyaline cartilage  7. forms the larynx, the costal cartilages of the ribs, and the embryonic skeleton
   d; elastic cartilage  8. provides a flexible framework for the external ear
   h; hyaline cartilage  9. firm, structurally amorphous matrix heavily invaded with fibers; appears glassy and smooth
   i; osseous  10. matrix hard owing to calcium salts; provides levers for muscles to act on
   a; adipose  11. insulates against heat loss
   e; elastic  12. walls of large arteries

15. Why do adipose cells remind people of a ring with a single jewel? They contain a large fat-filled vacuole occupying most of the cell volume. The nucleus is pushed to the periphery, giving the cell a “signet ring” appearance.
Nervous Tissue

16. What two physiological characteristics are highly developed in neurons (nerve cells)?  
Irritability and conductivity.

17. In what ways are neurons similar to other cells?  
They contain a nucleus and the usual organelles.

How are they different?  
Their cytoplasm is drawn out into long processes.

18. Describe how the unique structure of a neuron relates to its function in the body.  
Neurons conduct impulses over relatively long distances in the body. This is facilitated by their long cytoplasmic extensions.

Muscle Tissue

19. The three types of muscle tissue exhibit similarities as well as differences. Check the appropriate space in the chart to indicate which muscle types exhibit each characteristic.

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Skeletal</th>
<th>Cardiac</th>
<th>Smooth</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voluntarily controlled</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Involuntarily controlled</td>
<td></td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Striated</td>
<td>✓</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Has a single nucleus in each cell</td>
<td></td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Has several nuclei per cell</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Found attached to bones</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Allows you to direct your eyeballs</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Found in the walls of the stomach, uterus, and arteries</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Contains spindle-shaped cells</td>
<td></td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>Contains branching cylindrical cells</td>
<td></td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>Contains long, nonbranching cylindrical cells</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Has intercalated discs</td>
<td></td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>Concerned with locomotion of the body as a whole</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Changes the internal volume of an organ as it contracts</td>
<td></td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Tissue of the heart</td>
<td></td>
<td></td>
<td>✓</td>
</tr>
</tbody>
</table>
For Review

20. Label the tissue types illustrated here and on the next page, and identify all structures provided with leaders.

(a) Simple columnar epithelial

(b) Pseudostratified ciliated columnar epithelial

(c) Stratified squamous epithelial

(d) Transitional epithelial

(e) Areolar connective tissue

(f) Dense fibrous connective tissue, or dense regular connective tissue
(g) Bone (osseous tissue)

(h) Hyaline cartilage

(i) Adipose tissue

(j) Smooth muscle tissue

(k) Skeletal muscle tissue

(l) Cardiac muscle tissue
**The Integumentary System**

**Time Allotment:** 1 1/2 hours.

**Multimedia Resources:** See Appendix B for Guide to Multimedia Resource Distributors.

*How the Body Works: Skin, Bones, and Muscles* (AS: 19 minutes, DVD)
*Practice Anatomy Lab™ 2.0 (PAL)* (BC: CD-ROM, Website)
*The Senses: Skin Deep* (FHS: 26 minutes, VHS, DVD, 3-year streaming webcast)
*Skin* (FHS: 20 minutes, VHS, DVD, 3-year streaming webcast)
*The Skin* (NIMCO: 18 minutes, VHS)

**Solutions:**

*Lugol’s Iodine (IKI)*
- 20 grams potassium iodide
- 4 grams iodine crystals

Dissolve potassium iodide in 1 liter distilled water. Add the iodine crystals and stir to dissolve. Store in dark bottles.

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**Laboratory Materials**

*Ordering information is based on a lab size of 24 students, working in groups of 4. A list of supply house addresses appears in Appendix A.*

- 24 compound microscopes, lens paper, lens cleaning solution
- Adhesive tape
- 24 pairs of scissors
- 24 Betadine® swabs or 24 cotton swabs and 6 dropper bottles of Lugol’s iodine
- 24 slides and coverslips
- Data collection sheets
- Disposable gloves
- Porelon fingerprint pad or portable inking foils
- Ink cleaning towlettes
- Index cards (4 × 6)
- 24 magnifying glasses

**Advance Preparation**

1. Set out models of the skin, prepared slides of human scalp with hair follicles and skin of palm or sole, lens paper, and lens cleaning solution. Have compound microscopes available.
2. Terminology for layers of the epidermis differs from text to text. Decide on the terminology to be used, and inform the students at the onset of the laboratory session if there is a discrepancy between the laboratory manual and the text.
3. Set out 20# bond paper ruled in 1-centimeter squares, scissors, Betadine swabs, or *Lugol’s iodine* (Carolina, or see above), cotton swabs, and adhesive tape.
4. Prepare a data collection sheet for “palm” and “forearm” sweat gland data.
5. Set out 4 × 6 index cards, Porelon fingerprint pad or portable inking foils, ink cleaner towlettes, and magnifying glasses (all available from Sirchie® Finger Print Laboratories, Inc., 1-800-356-7311 or www.sirchie.com, and CSI Forensic Supply, 1-800-227-6020 or www.csiforensic.com).
Comments and Pitfalls

1. Students may have difficulty finding the arrector pili muscles and sweat glands. Some students will confuse the fibers of the dermis (dense fibrous irregular connective tissue) with smooth muscle.

Answers to Pre-Lab Quiz (p. 91)

1. d, site of vitamin A synthesis
2. epidermis, dermis
3. c, melanocytes
4. true
5. d, shaft
6. sebaceous
7. Apocrine

Answers to Activity Questions

Activity 3: Comparison of Hairy and Relatively Hair-Free Skin Microscopically (p. 97)

1. The stratified squamous epithelium of the skin is comprised of several recognizable layers, the outermost of which are keratinized or dead. Hair follicles are also present.

Both types of epithelia are protective, but the skin epithelium also protects against water loss to the external environment, UV damage, and chemical damage in addition to protecting against mechanical damage and bacterial invasion.

2. The thickness of the skin can be attributed to the presence of a fifth epithelial layer, the stratum lucidum, and a thicker stratum corneum and dermis. Thick skin lacks hair follicles, arrector pili muscles, and sebaceous glands that are present on thin skin of the scalp.

Activity 4: Differentiating Sebaceous and Sweat Glands Microscopically (p. 98)

Eccrine sweat glands have long, straight, or undulating ducts with twisted coils at their base. In contrast, sebaceous glands have short ducts leading from a fan-shaped base. Sebaceous glands are usually associated with hair follicles.

Activity 5: Plotting the Distribution of Sweat Glands (pp. 98–99)

6. In most students, the palm has a greater density of sweat glands when compared to the forearm. However, some students show a greater sweat gland density in the forearm when compared to their palm.

Activity 6: Taking and Identifying Inked Fingerprints (pp. 99–100)

7. Sometimes it was easy to classify the prints; at other times it was difficult.

This has to do with the clarity of the prints taken and the fact that more information on fingerprints is necessary to make accurate identifications.

The same individual would probably affect the fingerprinting process in the same way each time.
Basic Structure of the Skin

1. Complete the following statements by writing the appropriate word or phrase on the correspondingly numbered blank:

   The two basic tissues of which the skin is composed are dense irregular connective tissue, which makes up the dermis, and __1__, which forms the epidermis. The tough water-repellent protein found in the epidermal cells is called __2__. The pigments melanin and __3__ contribute to skin color. A localized concentration of melanin is referred to as a __4__.

   1. _____________________________
   2. _____________________________
   3. _____________________________
   4. _____________________________

2. Four protective functions of the skin are

   a. Prevents desiccation.  c. Protects against thermal damage.

3. Using the key choices, choose all responses that apply to the following descriptions.

   Key:  a. stratum basale  d. stratum lucidum  g. reticular layer
   b. stratum corneum  e. stratum spinosum  h. epidermis as a whole
   c. stratum granulosum  f. papillary layer  i. dermis as a whole

   d; stratum lucidum  1. translucent cells in thick skin containing keratin fibrils
   b & d; stratum corneum and lucidum  2. dead cells
   f; papillary layer  3. dermal layer responsible for fingerprints
   i; dermis (or f, g)  4. vascular region
   h; epidermis  5. major skin area that produces derivatives (nails and hair)
   a; stratum basale  6. epidermal region exhibiting the most rapid cell division
   b; stratum corneum  7. scalelike dead cells, full of keratin, that constantly slough off
   e; stratum spinosum  8. mitotic cells filled with intermediate filaments
   i; dermis (or g)  9. has abundant elastic and collagenic fibers
   a; stratum basale  10. location of melanocytes and tactile (Merkel) cells
   e; stratum spinosum  11. area where weblike pre-keratin filaments first appear
   f; papillary layer  12. region of areolar connective tissue
4. Label the skin structures and areas indicated in the accompanying diagram of thin skin. Then, complete the statements that follow.

![Image of skin diagram]

- a. **Laminated (or lamellated)** granules extruded from the keratinocytes prevent water loss by diffusion through the epidermis.
- b. Fibers in the dermis are produced by **fibroblasts**.
- c. Glands that respond to rising androgen levels are the **sebaceous (and apocrine sweat)** glands.
- d. Phagocytic cells that occupy the epidermis are called **epidermal dendritic or Langerhans cells**.
- e. A unique touch receptor formed from a stratum basale cell and a nerve fiber is a **tactile or Merkel disc**.
- f. What layer is present in thick skin but not in thin skin? **Stratum lucidum**
- g. What cell-to-cell structures hold the cells of the stratum spinosum tightly together? **Desmosomes**
5. What substance is manufactured in the skin that plays a role in calcium absorption elsewhere in the body? Vitamin D

6. List the sensory receptors found in the dermis of the skin. Free nerve endings (for pain, temperature), Meissner’s corpuscles (for touch in hairless skin), Pacinian corpuscles (pressure).


8. What is a bedsore (decubitus ulcer)? Localized area of tissue necrosis and death. Why does it occur? Pressure areas (points of increased pressure over bony areas) restrict the blood supply to the area.

Accessory Organs of the Skin

9. Match the key choices with the appropriate descriptions.

Key: a. arrector pili d. hair follicle g. sweat gland—apocrine
     b. cutaneous receptors e. nail h. sweat gland—eccrine
     c. hair f. sebaceous glands

f; sebaceous glands  1. produces an accumulation of oily material that is known as a blackhead
a; arrector pili  2. tiny muscles, attached to hair follicles, that pull the hair upright during fright or cold
h; sweat gland—eccrine  3. perspiration glands with a role in temperature control
d; hair follicle  4. sheath formed of both epithelial and connective tissues
g; sweat gland—apocrine  5. less numerous type of perspiration-producing gland; found mainly in the pubic and axillary regions
f; sebaceous glands  6. found everywhere on the body except the palms of hands and soles of feet
c, e; hair, nail  7. primarily dead/keratinized cells
b; cutaneous receptors  8. specialized nerve endings that respond to temperature, touch, etc.
f; sebaceous glands  9. secretes a lubricant for hair and skin
e; nail  10. sports a lunule and a cuticle
10. Describe two integumentary system mechanisms that help in regulating body temperature. (1) **When capillary blood flow to the skin is enhanced (by nervous system controls), heat radiates from the skin surface; restriction of blood flow conserves body heat.** (2) **Activity of sweat glands, i.e., when perspiration evaporates from the skin surface, heat is lost.**

11. Several structures or skin regions are listed below. Identify each by matching its letter with the appropriate area on the figure.

   a. adipose cells
   b. dermis
   c. epidermis
   d. hair follicle
   e. hair shaft
   f. sloughing stratum corneum cells

   ![image of skin structures]

   c
   f
   e
   b
   d
   a

**Plotting the Distribution of Sweat Glands**

12. With what substance in the bond paper does the iodine painted on the skin react? **The starch**

13. Based on class data, which skin area—the forearm or palm of hand—has more sweat glands? **Palm**

   Was this an expected result? **Yes**

   **Explain.** **For most people, hands sweat more than the forearm.**

   **Which other body areas would, if tested, prove to have a high density of sweat glands?** **Face, axillae**

14. What organ system controls the activity of the eccrine sweat glands? **Nervous system (sympathetic division)**

**Dermography: Fingerprinting**

15. Why can fingerprints be used to identify individuals?

   **Everyone's fingerprints are genetically distinct.**

16. Name the three common fingerprint patterns.

   **Loops**, **arches**, and **whorls**
Classification of Covering and Lining Membranes

Time Allotment: 1/2 hour.


A.D.A.M.® Interactive Anatomy 4.0 (AIA: CD-ROM, DVD)
Practice Anatomy Lab™ 2.0 (PAL) (BC: CD-ROM, Website)

Laboratory Materials

Ordering information is based on a lab size of 24 students, working in groups of 4. A list of supply house addresses appears in Appendix A.

- 24 compound microscopes, lens paper, lens cleaning solution
- 24 slides of the trachea (x.s.), esophagus (x.s.), and small intestine (x.s.)
- 24 slides of serous membrane, for example, mesentery artery and vein (x.s.) or small intestine (x.s.)
- Longitudinally cut fresh beef joint (if available)
- Disposable gloves

Advance Preparation

1. Set out slides of trachea (cross section), esophagus, small intestine (cross section), and a serous membrane such as a mesentery artery (WARD’S). If a slide of a mesentery artery is unavailable, use the visceral serosa on a slide of a cross section of the ileum, or substitute a slide of an artery (cross section) and study the endothelium. Have compound microscopes, lens paper, and lens cleaning solution available.
2. Arrange with a butcher or meat packer for a longitudinally cut fresh beef joint. Set out the beef joint and provide disposable gloves at the demonstration area.

Comments and Pitfalls

1. The students have not been introduced to the respiratory or digestive systems yet, and they may have difficulty locating the appropriate tissues. Remind them to look for free surfaces to find epithelium. The intestine slide may be confusing due to the presence of villi in longitudinal and cross sections. A simple diagram on the board may help, or refer students to Figure 8.2c or appropriate exercises later in the lab manual.
2. Start looking early for a butcher who will saw through a beef joint.
Answers to Pre-Lab Quiz (p. 105)
1. b, epithelial and synovial 4. true
2. a, cutaneous 5. parietal, visceral
3. b, lamina propria 6. c, synovial

Answers to Activity Questions

Activity 1: Examining the Microscopic Structure of Mucous Membranes (p. 107)
Goblet cells are found in both the tracheal and the intestinal epithelia.
The mucous membranes of the trachea and esophagus are mainly protective, while that of the small intestine is specialized for absorption. These membranes protect underlying tissues and the tracheal and intestinal epithelia secrete mucus.

Activity 2: Examining the Microscopic Structure of a Serous Membrane (p. 108)
The serous membranes of the heart and pericardial cavity are the visceral and parietal pericardia.
The membranes of the abdominal viscera and visceral cavity are the visceral peritoneum and parietal peritoneum.
### Classification of Covering and Lining Membranes

1. Complete the following chart.

<table>
<thead>
<tr>
<th>Membrane</th>
<th>Tissue types: membrane composition (epithelial/(connective))</th>
<th>Common locations</th>
<th>General functions</th>
</tr>
</thead>
<tbody>
<tr>
<td>cutaneous</td>
<td>epithelial, connective</td>
<td>The skin</td>
<td>Secretion (oil, sweat) Waterproofing (keratin) Bacteriostatic (acid mantle and sebum) Protection against chemical and mechanical damage (keratinization and continuity)</td>
</tr>
<tr>
<td>mucous</td>
<td>epithelial, connective (lamina propria)</td>
<td>Lining of the digestive, respiratory, and urogenital tracts</td>
<td>Secretion (mucus) Absorption Ciliated for movement of substances</td>
</tr>
<tr>
<td>serous</td>
<td>epithelial, connective</td>
<td>Lining of closed ventral body cavities</td>
<td>Secretion (serous fluid); decreases friction</td>
</tr>
<tr>
<td>synovial</td>
<td>connective tissue</td>
<td>Lining of joint cavities of freely movable joints</td>
<td>Secretion (synovial fluid); decreases friction</td>
</tr>
</tbody>
</table>

2. Respond to the following statements by choosing an answer from the key.

Key: a. cutaneous  b. mucous  c. serous  d. synovial

- **1.** membrane type in joints, bursae, and tendon sheaths
  - d

- **2.** epithelium of this membrane is always simple squamous epithelium
  - c

- **3.** membrane types not found in the ventral body cavity
  - a, d

- **4.** the only membrane type in which goblet cells are found
  - b

- **5.** the dry membrane with keratinizing epithelium
  - a

- **6.** “wet” membranes
  - b, c, d

- **7.** adapted for absorption and secretion
  - b

- **8.** has parietal and visceral layers
  - c
3. Using terms from the key above the figure, identify the different types of body membranes (cutaneous, mucous, and serous) by writing in the terms at the end of the appropriate leader lines.

**Key:**

- a. cutaneous membrane (skin)
- b. esophageal mucosa
- c. gastric mucosa
- d. mucosa of lung bronchi
- e. nasal mucosa
- f. oral mucosa
- g. parietal pericardium
- h. parietal pleura
- i. tracheal mucosa
- j. visceral pericardium
- k. visceral pleura

4. Knowing that -itis is a suffix meaning “inflammation of,” what do peritonitis, pleurisy, and pericarditis (pathological conditions) have in common?

   All are inflammations of serous membranes.

5. Why are these conditions accompanied by a great deal of pain? When serous membranes become inflamed, insufficient serous fluid may be produced. As a result, friction increases and adhesions may form.
Overview of the Skeleton: Classification and Structure of Bones and Cartilages

Time Allotment: 45 minutes.


How the Body Works: Skin, Bones, and Muscles (AS: 19 minutes, DVD)
Practice Anatomy Lab™ 2.0 (PAL) (BC: CD-ROM, Website)
Skeletal System (WNS: 15 minutes, VHS)
Skeletal System: The Infrastructure (FHS: 25 minutes, VHS, DVD, 3-year streaming webcast)

Solutions:
Hydrochloric Acid (HCl), 10%
Add 36 milliliters of 36% HCl to 200 milliliters of distilled water. Add water to a final volume of 360 milliliters.

Laboratory Materials
Ordering information is based on a lab size of 24 students, working in groups of 4. A list of supply house addresses appears in Appendix A.

Articulated skeleton
Numbered disarticulated bones showing four types
24 compound microscopes, lens paper, lens cleaning solution
Long bone sawed longitudinally
Long bone soaked in 10% HCl or vinegar
Long bone baked at 250°F
24 slides of ground bone (x.s.)
Disposable gloves
3-D models of microscopic structure of compact bone
24 slides of developing long bone undergoing endochondral ossification

Advance Preparation
1. If you have a local source, arrange to have a long bone sawed longitudinally. Keep refrigerated or frozen until used. Preserved, sawed long bones can be used instead. Provide disposable gloves at the demonstration area.
2. Bake some long bones (chicken or turkey bones work well) at 250°F for 2 hours or until they are brittle and snap or crumble easily. Prepare these the day before lab observations are to take place.
3. Soak some long bones in 10% hydrochloric acid or vinegar until flexible. Overnight soaking is usually sufficient for the hydrochloric acid; vinegar will take longer. Prepare well in advance.
4. Prepare numbered samples of long, short, flat, and irregular bones. These can be set out at a station in the lab where students can work on identification.
5. Put out prepared slides of ground bone (cross section) and developing long bone undergoing endochondral ossification. Also set out lens paper and lens cleaning solution, and have compound microscopes available.
6. Set out models of the microscopic structure of bone.
Comments and Pitfalls

1. Students may initially have some trouble classifying bones by shape; other than that, this lab should cause no problems.

2. Emphasize that all long bones have a long axis, but some long bones are much shorter than others! Long bones include most of the bones of the upper and lower limbs (humerus, radius, ulna, femur, tibia, fibula, metacarpals, metatarsals, phalanges). Short bones include the carpals and the tarsals. Flat bones are thin and include the bones of the roof of the cranial cavity, sternum, scapula, and ribs. Irregular bones include some skull bones, the vertebrae, and possibly bones of the pelvic girdle. Bones included in each of these categories vary from author to author.

Answers to Pre-Lab Quiz (p. 111)

1. b, production of melanin  
2. axial  
3. b, fibrocartilage  
4. Compact  
5. a, flat  
6. c, long  
7. diaphysis  
8. a, an osteon  
9. false

Answers to Activity Questions

Activity 2: Examining the Effects of Heat and Hydrochloric Acid on Bones (pp. 115–116)

The treated bones still have the same general shape as the untreated bones, although the acid-soaked bone may appear more fibrous.

The heated bone is very brittle and responds to gentle pressure by breaking.

The acid-treated bone is very flexible.

The acid appears to remove the calcium salts from the bone.

Heating dries out the organic matrix.

The acid-treated bone most closely resembles the bones of a child with rickets.
Overview of the Skeleton: Classification and Structure of Bones and Cartilages

Bone Markings

1. Match the terms in column B with the appropriate description in column A.

<table>
<thead>
<tr>
<th>Column A</th>
<th>Column B</th>
</tr>
</thead>
<tbody>
<tr>
<td>m; spine</td>
<td>a. condyle</td>
</tr>
<tr>
<td>o; tubercle</td>
<td>b. crest</td>
</tr>
<tr>
<td>h; crest</td>
<td>c. epicondyle</td>
</tr>
<tr>
<td>p; tuberosity</td>
<td>d. facet</td>
</tr>
<tr>
<td>h; head</td>
<td>e. fissure</td>
</tr>
<tr>
<td>k; ramus</td>
<td>f. foramen</td>
</tr>
<tr>
<td>a; condyle</td>
<td>g. fossa</td>
</tr>
<tr>
<td>e; fissure</td>
<td>h. head</td>
</tr>
<tr>
<td>i; meatus</td>
<td>i. meatus</td>
</tr>
<tr>
<td>f; foramen</td>
<td>j. process</td>
</tr>
<tr>
<td>g; fossa</td>
<td>k. ramus</td>
</tr>
<tr>
<td>l; sinus</td>
<td>l. sinus</td>
</tr>
<tr>
<td>n; trochanter</td>
<td>m. spine</td>
</tr>
<tr>
<td>c; epicondyle</td>
<td>n. trochanter</td>
</tr>
<tr>
<td>j; process</td>
<td>o. tubercle</td>
</tr>
<tr>
<td>d; facet</td>
<td>p. tuberosity</td>
</tr>
</tbody>
</table>

*a site of muscle and ligament attachment  
†takes part in joint formation  
‡a passageway for nerves or blood vessels

Classification of Bones

2. The four major anatomical classifications of bones are long, short, flat, and irregular. Which category has the least amount of spongy bone relative to its total volume? Long
3. Place the name of each labeled bone in Figure 9.1, page 112, into the appropriate column of the chart here.

<table>
<thead>
<tr>
<th>Long</th>
<th>Short</th>
<th>Flat</th>
<th>Irregular</th>
</tr>
</thead>
<tbody>
<tr>
<td>humerus, radius, ulna,</td>
<td>carpals, tarsals,</td>
<td>skull or cranium,</td>
<td>vertebra, ilium, ischium, pubis,</td>
</tr>
<tr>
<td>phalanges, metacarpals,</td>
<td>patella, calcaneus</td>
<td>sternum, scapula, ribs,</td>
<td>bones of pelvic girdle</td>
</tr>
<tr>
<td>femur, tibia, metatarsals,</td>
<td></td>
<td>clavicle</td>
<td></td>
</tr>
<tr>
<td>fibula</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Gross Anatomy of the Typical Long Bone

4. Use the terms below to identify the structures marked by leader lines and braces in the diagrams (some terms are used more than once).

Key:  
- a. articular cartilage  
- b. compact bone  
- c. diaphysis  
- d. endosteum  
- e. epiphyseal line  
- f. epiphysis  
- g. medullary cavity  
- h. nutrient artery  
- i. periosteum  
- j. red marrow cavity  
- k. trabeculae of spongy bone  
- l. yellow marrow
5. Match the terms in question 4 with the information below.

- **f** 1. contains spongy bone in adults
- **c** 2. made of compact bone
- **j** 3. site of blood cell formation
- **d, i** 4. major submembranous site of osteoclasts
- **g (l)** 5. scientific term for bone shaft
- **e** 6. contains fat in adult bones
- **7.** growth plate remnant
- **8.** major submembranous site of osteoblasts

6. What differences between compact and spongy bone can be seen with the naked eye?

*Compact bone appears homogenous; spongy bone has obvious spaces.*

7. What is the function of the periosteum?

*Protects the bone and is the structure from which blood vessels and nerves enter bone. It provides an attachment site for tendons and ligaments and supplies osteoblasts for new bone.*

**Microscopic Structure of Compact Bone**

8. Trace the route taken by nutrients through a bone, starting with the periosteum and ending with an osteocyte in a lacuna.

Periosteum → **perforating canal** → **central (Haversian) canal** → **canaliculus** → osteocyte

9. Several descriptions of bone structure are given below. Identify the structure involved by choosing the appropriate term from the key and placing its letter in the blank. Then, on the photomicrograph of bone on the right (208×), identify all structures named in the key and bracket an osteon.

*Key:* a. canaliculi  b. central canal  c. concentric lamellae  d. lacunae  e. matrix

- **c** 1. layers of bony matrix around a central canal
- **d** 2. site of osteocytes
- **b** 3. longitudinal canal carrying blood vessels, lymphatics, and nerves
- **a** 4. minute canals connecting osteocytes of an osteon
- **e** 5. inorganic salts deposited in organic ground substance
Chemical Composition of Bone

10. What is the function of the organic matrix in bone? To provide flexibility (and strength).

11. Name the important organic bone components. Cells, collagen fibers, and ground substance (proteoglycans and glycoproteins).

12. Calcium salts form the bulk of the inorganic material in bone. What is the function of the calcium salts? To provide hardness and strength and resist compression.


Ossification: Bone Formation and Growth in Length

14. Compare and contrast events occurring on the epiphyseal and diaphyseal faces of the epiphyseal plate.

Epiphyseal face: Cartilage cells are resting and relatively inactive. Right below this, the cartilage cells are rapidly reproducing.

Diaphyseal face: Chondrocytes are dying, the matrix is calcifying, and the cartilage is being replaced by bone.

Cartilages of the Skeleton

15. Using the key choices, identify each type of cartilage described (in terms of its body location or function) below.

Key: a. elastic b. fibrocartilage c. hyaline

1. supports the external ear b: fibrocartilage

2. between the vertebrae c: hyaline

3. forms the walls of the voice box (larynx) b: fibrocartilage

4. the epiglottis a: elastic

5. articular cartilages c: hyaline

6. meniscus in a knee joint

7. connects the ribs to the sternum

8. most effective at resisting compression

9. most springy and flexible

10. most abundant
EXERCISE 10

The Axial Skeleton

Time Allotment: 2 1/2 hours.


A.D.A.M.® Interactive Anatomy 4.0 (AIA: CD-ROM, DVD)
Practice Anatomy Lab™ 2.0 (PAL) (BC: CD-ROM, Website)

Laboratory Materials

Ordering information is based on a lab size of 24 students, working in groups of 4. A list of supply house addresses appears in Appendix A.

| Articulated vertebral column | X rays of individuals with kyphosis, scoliosis, and lordosis (if available) | Removable intervertebral discs |
| Beuchene skull              | X-ray viewing box                                                          | Isolated cervical, thoracic, and lumbar vertebrae, sacrum, and coccyx |
| 6–12 intact skulls          |                                                                           | 6–12 disarticulated skeletons |
| 2 articulated skeletons (one male, one female) |                                                                           |                                |

Advance Preparation

1. Set out one intact skull per group. A group of 3–4 students is ideal.
2. Set out labeled samples of disarticulated vertebrae, an articulated spinal column, a disarticulated skull, and a Beuchene skull.
3. Have articulated skeletons available. There should be a minimum of two, one male and one female.
4. Display X rays of individuals with scoliosis, kyphosis, and lordosis, if available. Students are often willing to bring in X rays for the class to use if none are available.
5. Set out blunt probes, pipe cleaners, or unsharpened pencils with erasers for the students to use while studying the bones. Caution them against marking the bones with pencils or markers.

Comments and Pitfalls

1. Point out sutures; remind students to look for sutures surrounding each bone.
2. Suggest that students identify all bones of the skull before identifying bone features.
3. Students may have some trouble with the numerous foramina of the skull. You may wish to have them locate all of the foramina at this time, but hold them responsible for identifying a smaller number.
4. The ethmoid bone may cause some problems, especially if the skulls are old and the conchae have begun to crumble. The disarticulated and Beuchene skulls will come in handy here.
5. “Saddle block” anesthesia is similar to epidural anesthesia.
6. There is the occasional student who asks whether males have one less rib than females. A trip to the articulated skeletons provides the answer: no.

Answers to Pre-Lab Quiz (p. 123)

1. a, bony thorax  
2. a, cranium  
3. 14  
4. mandible  
5. body  
6. a, cervical  
7. d, thoracic  
8. c, sternum  
9. false

Answers to Activity Questions

Activity 3: Examining Spinal Curvatures (p. 133)

2. When the fibrous disc is properly positioned, the spinal cord and peripheral nerves are not impaired in any way. If the disc is removed, the intervertebral foramina are reduced in size, and might pinch the nerves exiting at that level. *Slipped discs* often put pressure on spinal nerves, causing pain and/or loss of feeling.
The Skull

1. First, match the bone names in column B with the descriptions in column A (the items in column B may be used more than once). Then, circle the bones in column B that are cranial bones.

<table>
<thead>
<tr>
<th>Column A</th>
<th>Column B</th>
</tr>
</thead>
<tbody>
<tr>
<td>b: frontal</td>
<td>a. ethmoid</td>
</tr>
<tr>
<td>n: zygomatic</td>
<td>b. frontal</td>
</tr>
<tr>
<td>e: mandible</td>
<td>c. hyoid</td>
</tr>
<tr>
<td>g: nasal</td>
<td>d. lacrimal</td>
</tr>
<tr>
<td>i: palatine</td>
<td>e. mandible</td>
</tr>
<tr>
<td>j: parietal</td>
<td>f. maxilla</td>
</tr>
<tr>
<td>h: occipital</td>
<td>g. nasal</td>
</tr>
<tr>
<td>k: sphenoid</td>
<td>h. occipital</td>
</tr>
<tr>
<td>d: lacrimal</td>
<td>i. palatine</td>
</tr>
<tr>
<td>f: maxilla</td>
<td>j. parietal</td>
</tr>
<tr>
<td>a: ethmoid</td>
<td>k. sphenoid</td>
</tr>
<tr>
<td>l: temporal</td>
<td>l. temporal</td>
</tr>
<tr>
<td>m: vomer</td>
<td>m. vomer</td>
</tr>
</tbody>
</table>

b: frontal, f: maxilla, and e: mandible

1. forehead bone
2. cheekbone
3. lower jaw
4. bridge of nose
5. posterior bones of the hard palate
6. much of the lateral and superior cranium
7. most posterior part of cranium
8. single, irregular, bat-shaped bone forming part of the cranial floor
9. tiny bones bearing tear ducts
10. anterior part of hard palate
11. superior and middle nasal conchae formed from its projections
12. site of mastoid process
13. site of sella turcica
14. site of cribriform plate
15. site of mental foramen
16. site of styloid processes
17. four bones containing paranasal sinuses
18. condyles here articulate with the atlas
19. foramen magnum contained here
20. small U-shaped bone in neck, where many tongue muscles attach
21. middle ear found here
22. nasal septum
23. bears an upward protrusion, the “cock’s comb,” or crista galli
24. contain alveoli bearing teeth
2. Using choices from the numbered key to the right, identify all bones (line with ball on end), sutures (line with arrowhead on end), and bone markings provided with leader lines in the two diagrams below.

Key:
1. carotid canal
2. coronal suture
3. ethmoid bone
4. external occipital protuberance
5. foramen lacerum
6. foramen magnum
7. foramen ovale
8. frontal bone
9. glabella
10. incisive
11. inferior nasal concha
12. inferior orbital fissure
13. infraorbital foramen
14. jugular foramen
15. lacrimal bone
16. mandible
17. mandibular
18. mandibular symphysis
19. mastoid process
20. maxilla
21. mental foramen
22. middle nasal concha of ethmoid
23. nasal bone
24. occipital bone
25. occipital condyle
26. palatine bone
27. palatine process of maxilla
28. parietal bone
29. sagittal suture
30. sphenoid bone
31. styloid process
32. stylomastoid foramen
33. superior orbital fissure
34. supraorbital foramen
35. temporal bone
36. vomer
37. zygomatic bone
38. zygomatic process of temporal bone
3. Define *suture*. *Fibrous joint between skull bones.*

4. With one exception, the skull bones are joined by sutures. Name the exception. *Joint(s) between the mandible and temporal bones.*

5. What bones are connected by the lambdoid suture?
   *Occipital and parietal*

   What bones are connected by the squamous suture?
   *Temporal and parietal*

6. Name the eight bones of the cranium.

<table>
<thead>
<tr>
<th>Frontal</th>
<th>Occipital</th>
<th>Right parietal</th>
<th>Left parietal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sphenoid</td>
<td>Ethmoid</td>
<td>Right temporal</td>
<td>Left temporal</td>
</tr>
</tbody>
</table>

7. Give two possible functions of the sinuses. *(1) Lighten the skull, (2) resonance chambers for speech.*

8. What is the orbit? *Bony socket for the eye.*

   What bones contribute to the formation of the orbit? *Ethmoid, lacrimal, frontal, sphenoid, zygomatic, maxillary, palatine*

9. Why can the sphenoid bone be called the keystone of the cranial floor? *It articulates with all of the other cranial bones.*

**The Vertebral Column**

10. The distinguishing characteristics of the vertebrae composing the vertebral column are noted below. Correctly identify each described structure by choosing a response from the key.

   **Key:**
   a. *atlas*  
   b. *axis*  
   c. *cervical vertebra—typical*  
   d. *coccyx*  
   e. *lumbar vertebra*  
   f. *sacrum*  
   g. *thoracic vertebra*

   1. *Vertebral type containing foramina in the transverse processes, through which the vertebral arteries ascend to reach the brain*

   2. *Dens here provides a pivot for rotation of the first cervical vertebra (C₁)*

   3. *Transverse processes faceted for articulation with ribs; spinous process pointing sharply downward*

   4. *Composite bone; articulates with the hip bone laterally*

   5. *Massive vertebrae; weight-sustaining*

   6. *“Tail bone”; vestigial fused vertebrae*

   7. *Supports the head; allows a rocking motion in conjunction with the occipital condyles*
11. Using the key, correctly identify the vertebral parts/areas described below. (More than one choice may apply in some cases.) Also use the key letters to correctly identify the vertebral areas in the diagram.

| Key: a. body | d. pedicle | g. transverse process |
| b. intervertebral foramina | e. spinous process | h. vertebral arch |
| c. lamina | f. superior articular facet | i. vertebral foramen |

| i | 1. cavity enclosing the nerve cord |
| a | 2. weight-bearing portion of the vertebra |
| e, g | 3. provide levers against which muscles pull |
| a, g | 4. provide an articulation point for the ribs |
| b | 5. openings providing for exit of spinal nerves |
| a, h | 6. structures that form an enclosure for the spinal cord |

12. Describe how a spinal nerve exits from the vertebral column.

_Via the intervertebral foramina found between the pedicles of adjacent vertebrae._

13. Name two factors/structures that permit flexibility of the vertebral column.

_**Intervertebral discs** and **curvatures**_

14. What kind of tissue composes the intervertebral discs? _**Fibrocartilage**_

15. What is a herniated disc? _**A ruptured disc in which a portion of the disc protrudes outward.**_

What problems might it cause? _**It might compress a nerve, leading to pain and possibly paralysis.**_

16. Which two spinal curvatures are obvious at birth? _**Thoracic** and **sacral**_

Under what conditions do the secondary curvatures develop? _**The cervical curvature develops when the baby begins to raise its head independently. The lumbar curvature forms when the baby begins to walk (assumes upright posture).**_
17. On this illustration of an articulated vertebral column, identify each curvature indicated and label it as a primary or a secondary curvature. Also identify the structures provided with leader lines, using the letters of the terms listed in the key below.

**Key:**

a. atlas  
b. axis  
c. intervertebral disc  
d. sacrum  
e. two thoracic vertebrae  
f. two lumbar vertebrae  
g. vertebra prominens
The Thoracic Cage

18. The major bony components of the thorax (excluding the vertebral column) are the ribs and the sternum.

19. Differentiate between a true rib and a false rib. A true rib has its own costal cartilage attachment to the sternum; a false rib attaches to the sternum indirectly or not at all.

Is a floating rib a true or a false rib? False

20. What is the general shape of the thoracic cage? Inverted cone shape

21. Using the terms in the key, identify the regions and landmarks of the bony thorax.

Key: a. body
     b. clavicular notch
     c. costal cartilage
     d. false ribs
     e. floating ribs
     f. jugular notch
     g. manubrium
     h. sternal angle
     i. sternum
     j. true ribs
     k. xiphisternal joint
     l. xiphoid process
The Appendicular Skeleton

**Time Allotment:** 2 hours.

**Multimedia Resources:** See Appendix B for Guide to Multimedia Resource Distributors.

- *A.D.A.M.® Interactive Anatomy 4.0* (AIA: CD-ROM, DVD)
- *Anatomy of a Runner (Structure and Function of the Lower Limb)* (DE: 38 minutes, DVD)
- *Anatomy of the Hand* (FHS: 14 minutes, VHS, DVD, 3-year streaming webcast)
- *Anatomy of the Shoulder* (FHS: 18 minutes, VHS, DVD, 3-year streaming webcast)
- *Bones and Joints* (FHS: 20 minutes, VHS, DVD, 3-year streaming webcast)
- *Interactive Foot and Ankle* (LP: CD-ROM)
- *Interactive Shoulder* (LP: CD-ROM)
- *Practice Anatomy Lab™ 2.0* (PAL) (BC: CD-ROM, Website)

**Laboratory Materials**

*Ordering information is based on a lab size of 24 students, working in groups of 4. A list of supply house addresses appears in Appendix A.*

<table>
<thead>
<tr>
<th>Item</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>6–12 disarticulated skeletons</td>
<td></td>
</tr>
<tr>
<td>2 articulated skeletons (one male, one female)</td>
<td></td>
</tr>
<tr>
<td>1 articulated male pelvis</td>
<td></td>
</tr>
<tr>
<td>1 articulated female pelvis</td>
<td></td>
</tr>
<tr>
<td>X rays of bones of the appendicular skeleton</td>
<td></td>
</tr>
</tbody>
</table>

**Advance Preparation**

1. Have articulated skeletons (male and female) available.
2. Set out disarticulated skeletons. One per group of 3–4 students is ideal.
3. Set out male and female articulated pelves in a demonstration area.
4. Set out blunt probes, pipe cleaners, or unsharpened pencils with erasers for use during bone identification.
5. Set out X rays of bones of the appendicular skeleton.

**Comments and Pitfalls**

1. Students may have trouble distinguishing between right and left samples of bones. Remind them to review the bone markings before checking the disarticulated skeleton.
2. Stress the importance of bony landmarks for muscle location and identification.

**Answers to Pre-Lab Quiz (p. 145)**

1. appendicular
2. pectoral
3. scapulae
4. b, humerus
5. metacarpals
6. Female
7. a, femur
8. patella
9. true
The Appendicular Skeleton

Bones of the Pectoral Girdle and Upper Extremity

1. Match the bone names or markings in column B with the descriptions in column A.

<table>
<thead>
<tr>
<th>Column A</th>
<th>Column B</th>
</tr>
</thead>
<tbody>
<tr>
<td>g: deltoid tuberosity</td>
<td>a. acromion</td>
</tr>
<tr>
<td>i: humerus</td>
<td>b. capitulum</td>
</tr>
<tr>
<td>d: clavicle</td>
<td>c. carpals</td>
</tr>
<tr>
<td>o: radius</td>
<td>d. clavicle</td>
</tr>
<tr>
<td>a: acromion</td>
<td>e. coracoid process</td>
</tr>
<tr>
<td>p: scapula</td>
<td>f. coronoid fossa</td>
</tr>
<tr>
<td>d: clavicle</td>
<td>g. deltoid tuberosity</td>
</tr>
<tr>
<td>h: glenoid cavity</td>
<td>h. glenoid cavity</td>
</tr>
<tr>
<td>e: coracoid process</td>
<td>i. humerus</td>
</tr>
<tr>
<td>d: clavicle</td>
<td>j. metacarpals</td>
</tr>
<tr>
<td>s: trochlea</td>
<td>k. olecranon fossa</td>
</tr>
<tr>
<td>t: ulna</td>
<td>l. olecranon process</td>
</tr>
<tr>
<td>b: capitulum</td>
<td>m. phalanges</td>
</tr>
<tr>
<td>f: coronoid fossa</td>
<td>n. radial tuberosity</td>
</tr>
<tr>
<td>t: ulna</td>
<td>o. radius</td>
</tr>
<tr>
<td>m: phalanges</td>
<td>p. scapula</td>
</tr>
<tr>
<td>f: metacarpals</td>
<td>q. sternum</td>
</tr>
<tr>
<td>p: scapula</td>
<td>r. styloid process</td>
</tr>
<tr>
<td>q: sternum</td>
<td>s. trochlea</td>
</tr>
<tr>
<td>m: phalanges</td>
<td>t. ulna</td>
</tr>
</tbody>
</table>

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2. How is the arm held clear of the widest dimension of the thoracic cage?

The clavicle acts as a strut to hold the glenoid cavity of the scapula (therefore the arm) laterally away from the narrowest dimension of the rib cage.

3. What is the total number of phalanges in the hand? 14

4. What is the total number of carpals in the wrist? 8

Name the carpals (medial to lateral) in the proximal row, pisiform, triquetral, lunate, scaphoid

In the distal row, they are (medial to lateral) hamate, capitate, trapezoid, trapezium

5. Using items from the list at the right, identify the anatomical landmarks and regions of the scapula.

Key:

a. acromion
b. coracoid process
c. glenoid cavity
d. inferior angle
e. infraspinous fossa
f. lateral border
g. medial border
h. spine
i. superior angle
j. superior border
k. suprascapular notch
l. supraspinous fossa
6. Match the terms in the key with the appropriate leader lines on the drawings of the humerus and the radius and ulna. Also decide whether the bones shown are right or left bones and whether the view shown is an anterior or a posterior view.

Key:
- a. anatomical neck
- b. coronoid process
- c. distal radioulnar joint
- d. greater tubercle
- e. head of humerus
- f. head of radius
- g. head of ulna
- h. lateral epicondyle
- i. medial epicondyle
- j. olecranon fossa
- k. olecranon process
- l. proximal radioulnar joint
- m. radial groove
- n. radial notch
- o. radial tuberosity
- p. styloid process of radius
- q. styloid process of ulna
- r. surgical neck
- s. trochlea
- t. trochlear notch

Circle the correct term for each pair in parentheses:

The humerus is a [right/left] bone in (anterior/posterior) view. The radius and ulna are [right/left] bones in (anterior/posterior) view.

Bones of the Pelvic Girdle and Lower Limb

7. Compare the pectoral and pelvic girdles by choosing appropriate descriptive terms from the key.

Key:  
- a. flexibility most important  
- b. massive  
- c. lightweight  
- d. insecure axial and limb attachments  
- e. secure axial and limb attachments  
- f. weight-bearing most important

Pectoral:  [a, c, d]  Pelvic:  [b, e, f]  

8. What organs are protected, at least in part, by the pelvic girdle?  

Uterus (female), urinary bladder, small intestine, rectum
9. Distinguish between the true pelvis and the false pelvis. _The true pelvis is the region inferior to the pelvic brim, which is encircled by bone. The false pelvis is the area medial to the flaring iliac bones and lies superior to the pelvic brim._

10. Use letters from the key to identify the bone markings on this illustration of an articulated pelvis. Make an educated guess as to whether the illustration shows a male or female pelvis and provide two reasons for your decision.

   ![Illustration of an articulated pelvis]

   **Key:**
   - a. acetabulum
   - b. ala of sacrum
   - c. anterior superior iliac spine
   - d. iliac crest
   - e. iliac fossa
   - f. ischial spine
   - g. pelvic brim
   - h. pubic crest
   - i. pubic symphysis
   - j. sacroiliac joint
   - k. sacrum

   This is a _female_ (male/female) pelvis because:

   _Acetabula are close together; pubic angle/arch is less than 90°; narrow sacrum, heart-shaped pelvic inlet._

11. Deduce why the pelvic bones of a four-legged animal such as the cat or pig are much less massive than those of the human.

   _The pelvic girdle does not have to carry the entire weight of the trunk in the quadruped animal._

12. A person instinctively curls over his abdominal area in times of danger. Why? _Abdominal area organs receive the least protection from the skeletal system._

13. For what anatomical reason do many women appear to be slightly knock-kneed? _The pelvis is broader and the acetabula and ilia are more laterally positioned. Thus, the femur runs downward to the knee more obliquely than in the male._

   How might this anatomical arrangement contribute to knee injuries in female athletes? _The more oblique angle in females causes greater forces on the anterior cruciate ligament (ACL) during knee rotation, and the smaller female intercondylar notch can pinch the ACL during twisting or hyperextended movements. Both events can cause a tear or rupture of the ACL._

14. What does _fallen arches_ mean? _A weakening of the tendons and ligaments supporting the arches of the foot._
15. Match the bone names and markings in column B with the descriptions in column A.

<table>
<thead>
<tr>
<th>Column A</th>
<th>Column B</th>
</tr>
</thead>
<tbody>
<tr>
<td>i; ilium</td>
<td>a. acetabulum</td>
</tr>
<tr>
<td>k; ischium</td>
<td>b. calcaneus</td>
</tr>
<tr>
<td>t; pubis</td>
<td>c. femur</td>
</tr>
<tr>
<td>s; pubic symphysis</td>
<td>d. fibula</td>
</tr>
<tr>
<td>h; iliac crest</td>
<td>e. gluteal tuberosity</td>
</tr>
<tr>
<td>a; acetabulum</td>
<td>f. greater and lesser trochanters</td>
</tr>
<tr>
<td>u; sacroiliac joint</td>
<td>g. greater sciatic notch</td>
</tr>
<tr>
<td>c; femur</td>
<td>h. iliac crest</td>
</tr>
<tr>
<td>d; fibula</td>
<td>i. ilium</td>
</tr>
<tr>
<td>x; tibia</td>
<td>j. ischial tuberosity</td>
</tr>
<tr>
<td>c; femur</td>
<td>k. ischium</td>
</tr>
<tr>
<td>x; tibia</td>
<td>l. lateral malleolus</td>
</tr>
<tr>
<td>y; tibial tuberosity</td>
<td>m. lesser sciatic notch</td>
</tr>
<tr>
<td>r; patella</td>
<td>n. linea aspera</td>
</tr>
<tr>
<td>s; tibia</td>
<td>o. medial malleolus</td>
</tr>
<tr>
<td>x; tibia</td>
<td>p. metatarsals</td>
</tr>
<tr>
<td>a; medial malleolus</td>
<td>q. obturator foramen</td>
</tr>
<tr>
<td>l; lateral malleolus</td>
<td>r. patella</td>
</tr>
<tr>
<td>b; calcaneus</td>
<td>s. pubic symphysis</td>
</tr>
<tr>
<td>w; tarsals</td>
<td>t. pubis</td>
</tr>
<tr>
<td>p; metatarsals</td>
<td>u. sacroiliac joint</td>
</tr>
<tr>
<td>q; obturator foramen</td>
<td>v. talus</td>
</tr>
<tr>
<td>e; gluteal tuberosity</td>
<td>w. tarsals</td>
</tr>
<tr>
<td>f; greater and lesser trochanters</td>
<td>x. tibia</td>
</tr>
<tr>
<td>v; talus</td>
<td>y. tibial tuberosity</td>
</tr>
<tr>
<td>t; tibial tuberosity</td>
<td>1. fuse to form the coxal bone</td>
</tr>
<tr>
<td>k; ischium</td>
<td>2. “sit-down” bone of the coxal bone</td>
</tr>
<tr>
<td>s; pubic symphysis</td>
<td>3. point where the coxal bones join anteriorly</td>
</tr>
<tr>
<td>h; iliac crest</td>
<td>4. superiormost margin of the coxal bone</td>
</tr>
<tr>
<td>a; acetabulum</td>
<td>5. deep socket in the coxal bone that receives the head of the thigh bone</td>
</tr>
<tr>
<td>u; sacroiliac joint</td>
<td>6. joint between axial skeleton and pelvic girdle</td>
</tr>
<tr>
<td>c; femur</td>
<td>7. longest, strongest bone in body</td>
</tr>
<tr>
<td>d; fibula</td>
<td>8. thin lateral leg bone</td>
</tr>
<tr>
<td>x; tibia</td>
<td>9. heavy medial leg bone</td>
</tr>
<tr>
<td>c; femur</td>
<td>10. bones forming knee joint</td>
</tr>
<tr>
<td>x; tibia</td>
<td>11. point where the patellar ligament attaches</td>
</tr>
<tr>
<td>r; patella</td>
<td>12. kneecap</td>
</tr>
<tr>
<td>x; tibia</td>
<td>13. shinbone</td>
</tr>
<tr>
<td>a; medial malleolus</td>
<td>14. medial ankle projection</td>
</tr>
<tr>
<td>l; lateral malleolus</td>
<td>15. lateral ankle projection</td>
</tr>
<tr>
<td>b; calcaneus</td>
<td>16. largest tarsal bone</td>
</tr>
<tr>
<td>w; tarsals</td>
<td>17. ankle bones</td>
</tr>
<tr>
<td>p; metatarsals</td>
<td>18. bones forming the instep of the foot</td>
</tr>
<tr>
<td>q; obturator foramen</td>
<td>19. opening in hip bone formed by the pubic and ischial rami</td>
</tr>
<tr>
<td>e; gluteal tuberosity</td>
<td>20. sites of muscle attachment on the proximal femur</td>
</tr>
<tr>
<td>f; greater and lesser trochanters</td>
<td>21. tarsal bone that “sits” on the calcaneus</td>
</tr>
<tr>
<td>v; talus</td>
<td>22. weight-bearing bone of the leg</td>
</tr>
<tr>
<td>x; tibia</td>
<td>23. tarsal bone that articulates with the tibia</td>
</tr>
</tbody>
</table>
16. Match the terms in the key with the appropriate leader lines on the drawings of the femur and the tibia and fibula. Also decide if these bones are right or left bones and whether the view shown is an anterior or a posterior view.

**Key:**

- a. distal tibiofibular joint
- b. fovea capitis
- c. gluteal tuberosity
- d. greater trochanter
- e. head of femur
- f. head of fibula
- g. intercondylar eminence
- h. intertrochanteric crest
- i. lateral condyle
- j. lateral epicondyle
- k. lateral malleolus
- l. lesser trochanter
- m. medial condyle
- n. medial epicondyle
- o. medial malleolus
- p. neck of femur
- q. proximal tibiofibular joint
- r. tibial anterior border
- s. tibial tuberosity

Circle the correct term for each pair in parentheses:

The femur is a (right or left) bone in (anterior or posterior) view. The tibia and fibula are (right or left) bones in (anterior or posterior) view.

**Summary of Skeleton**

17. Identify all indicated bones (or groups of bones) in the diagram of the articulated skeleton on page 163.
EXERCISE

The Fetal Skeleton

Time Allotment: 1/2 hour.

Laboratory Materials

Ordering information is based on a lab size of 24 students, working in groups of 4. A list of supply house addresses appears in Appendix A.

Fetal skull
Fetal skeleton
Adult skeleton

Advance Preparation

1. Set out an isolated fetal skull and fetal skeleton in a demonstration area, unless enough are available for each group. If you don’t already know it, figure out the approximate age of the fetus, since someone is sure to ask. Developmental charts are usually available in developmental anatomy texts.

2. Have an adult articulated skeleton available.

Answers to Pre-Lab Quiz (p. 165)

1. more
2. d, all of the above
3. d, four or more
4. a, the process of bone formation

Answers to Activity Questions

Activity: Examining a Fetal Skeleton and Skull (pp. 165–166)

2. Yes, the fetal and adult skulls have the same bones, although the fetal frontal bone is bipartite as opposed to the single frontal bone seen in the adult skull.

   The fetal face is foreshortened and overshadowed by the cranium; the maxillae and mandible are very tiny.

   In the adult skull the cranium is proportionately smaller and the facial skeleton proportionately larger.
The Fetal Skeleton

1. Are the same skull bones seen in the adult also found in the fetal skull? Yes

2. How does the size of the fetal face compare to its cranium? Face is foreshortened, overshadowed by the large cranium. Maxillae and mandible are very tiny.

   How does this compare to the adult skull? In the adult the cranium is proportionately smaller and the facial bones are proportionately larger and more prominent.

3. What are the outward conical projections on some of the fetal cranial bones? These are ossification (growth) centers.


   What is its fate? Progressively ossified; replaced by a suture.

   What is the function of the fontanels in the fetal skull? Allow fetal skull to be compressed slightly during birth passage; allow for fetal (and infant) brain growth.

5. Describe how the fetal skeleton compares with the adult skeleton in the following areas:

   vertebrae: In the fetus, only the primary curvatures (thoracic and sacral) are present.

   coxal bones: In the fetus the ilium, ischium, and pubis are separate bones. In the adult they form the hip bones (ossa coxae, or coxal bones).

   carpals and tarsals: Not ossified in the fetus.

   sternum: Its component parts are not fused in the fetus.

   frontal bone: Bipartite superiorly in the fetus; fused in the adult.

   patella: May be absent in the fetus; if present, is unossified.

   thoracic cage: Compressed laterally, forming a pointed anterior rib cage surface in the fetus.
6. How does the size of the fetus’s head compare to the size of its body? The head is disproportionately large.

7. Using the terms listed, identify each of the fontanels shown on the fetal skull below.

Key:

a. anterior fontanel
b. mastoid fontanel
c. posterior fontanel
d. sphenoidal fontanel
Articulations and Body Movements

Time Allotment: 1 hour.


A.D.A.M.® Interactive Anatomy 4.0 (AIA: CD-ROM, DVD)
Anatomy of a Runner (Structure and Function of the Lower Limb) (DE: 38 minutes, DVD)
Bones and Joints (FHS: 20 minutes, VHS, DVD, 3-year streaming webcast)
Practice Anatomy Lab™ 2.0 (PAL) (BC: CD-ROM, Website)

Laboratory Materials

Ordering information is based on a lab size of 24 students, working in groups of 4. A list of supply house addresses appears in Appendix A.

Articulated skeleton
Skull
Fresh diarthrotic beef joint or preserved joints
Disposable gloves
Anatomical charts of joint types
X rays of normal and arthritic joints
Water balloons and clamps
X-ray viewing box
Functional models of hip, shoulder, and knee joints
X ray of child’s bone showing the cartilaginous growth plate (if available)

Advance Preparation

1. If you have a local source, obtain a sagittally sawed, fresh diarthrotic beef joint from a butcher or meat-packing company. Refrigerate or freeze until use. Preserved joints could be used instead. Have disposable gloves available.
2. Have available the articulated skeleton and isolated skull.
3. Set out any available anatomical charts of joint types, models of joint types, etc., that are available.
4. Display any available X rays of normal and arthritic joints.
5. There are several methods of joint classification. If your text and the lab manual use different systems, decide on the preferred system for your course.
6. Have water balloons and clamps available.

Comments and Pitfalls

1. Some students may have trouble interpreting the movements in Figure 13.5. It may help to have the students perform all of these movements together during lab.
2. Students may be confused by movement at the shoulder joint. Flexion occurs when the arm is moved forward and upward, and extension returns the arm to the anatomical position.
Answers to Pre-Lab Quiz (p. 169)

1. Holds bones together; allows the rigid skeleton some flexibility so that gross body movements can occur
2. c, amount of movement allowed by the joint
3. synovial
4. fibrous
5. true
6. insertion
7. a, ball-and-socket
8. a, abduction
9. rotation
10. false

Answers to Activity Questions

Activity 4: Demonstrating the Importance of Friction-Reducing Structures (p. 173)

4. The fluid-filled sac greatly reduces the friction between the two surfaces. The water balloon represents a synovial cavity, bursae, or tendon sheaths. The fists represent two articulating bones on opposite sides of a synovial cavity. They may also represent muscles, tendons, or ligaments in the case of bursae and tendon sheaths.

Activity 6: Demonstrating Uniaxial, Biaxial, and Multiaxial Movements (pp. 174–175)

1. **Name of joint (any two of these)**
   - elbow (hinge) joint
   - radioulnar (pivot)
   - atlas and dens of axis (pivot)
   - finger (interphalangeal)
   - ankle
   - toe (interphalangeal)
   - temporomandibular
   **Movement allowed**
   - flexion and extension
   - rotation
   - flexion
   - flexion and extension
   - flexion and extension
   - flexion and extension
   - flexion and extension
   - rotation

2. **Name of joint (any two)**
   - carpometacarpal of digit 1
   - knuckles (metacarpophalangeal)
   - atlanto-occipital
   - wrist
   - knee
   - metatarsophalangeal
   **Movement allowed**
   - flexion, extension
   - flexion, extension
   - flexion, extension
   - flexion, extension
   - flexion, extension
   - flexion, extension
   **Movement allowed**
   - abduction, adduction
   - abduction, adduction
   - lateral flexion, circumduction
   - abduction, adduction
   - rotation
   - abduction, adduction

3. **Name of joint (any two)**
   - shoulder
   - hip
   - sternoclavicular
   **Movement allowed**
   - flexion, extension
   - flexion, extension
   - moves in all axes
   **Movement allowed**
   - abduction, adduction
   - abduction, adduction
   - circumduction, rotation
   - circumduction, rotation

1. Holds bones together; allows the rigid skeleton some flexibility so that gross body movements can occur
2. c, amount of movement allowed by the joint
3. synovial
4. fibrous
5. true
6. insertion
7. a, ball-and-socket
8. a, abduction
9. rotation
10. false
Articulations and Body Movements

Fibrous, Cartilaginous, and Synovial Joints

1. Use key responses to identify the joint types described below.

   Key: a. cartilaginous  b. fibrous  c. synovial

   1. typically allows a slight degree of movement
   2. includes joints between the vertebral bodies and the pubic symphysis
   3. essentially immovable joints
   4. sutures are the most remembered examples
   5. characterized by cartilage connecting the bony portions
   6. all characterized by a fibrous articular capsule lined with a synovial membrane surrounding a joint cavity
   7. all are freely movable or diarthrotic
   8. bone regions are united by fibrous connective tissue
   9. include the hip, knee, and elbow joints

2. Describe the tissue type and function of the following structures in relation to a synovial joint and label the structures indicated by leader lines in the diagram.

   ligament: Dense fibrous connective tissue; attaches bones together; reinforces joints

   tendon: Dense fibrous connective tissue attaching muscle to bone; reinforces the joint capsule as it spans a joint

   articular cartilage: Hyaline cartilage; reduces friction where bones articulate

   synovial membrane: Loose connective tissue; produces synovial fluid which decreases friction within the joint capsule

   bursa: Fluid-filled synovial sac which cushions the tendon where it crosses the bone
3. Match the synovial joint categories in column B with their descriptions in column A.

<table>
<thead>
<tr>
<th>Column A</th>
<th>Column B</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. joint between the axis and atlas</td>
<td>a. ball and socket</td>
</tr>
<tr>
<td>2. hip joint</td>
<td>b. condyloid</td>
</tr>
<tr>
<td>3. intervertebral joints (between articular processes)</td>
<td>c. gliding</td>
</tr>
<tr>
<td>4. joint between forearm bones and wrist</td>
<td>d. hinge</td>
</tr>
<tr>
<td>5. elbow</td>
<td>e. pivot</td>
</tr>
<tr>
<td>6. interphalangeal joints</td>
<td>f. saddle</td>
</tr>
<tr>
<td>7. intercarpal joints</td>
<td></td>
</tr>
<tr>
<td>8. joint between talus and tibia/fibula</td>
<td></td>
</tr>
<tr>
<td>9. joint between skull and vertebral column</td>
<td></td>
</tr>
<tr>
<td>10. joint between jaw and skull</td>
<td></td>
</tr>
<tr>
<td>11. joints between proximal phalanges and metacarpal bones</td>
<td></td>
</tr>
<tr>
<td>12. a multiaxial joint</td>
<td></td>
</tr>
<tr>
<td>13. biaxial joints</td>
<td></td>
</tr>
<tr>
<td>14. uniaxial joints</td>
<td></td>
</tr>
</tbody>
</table>

4. Indicate the number of planes in which each joint can move.

One uniaxial joints Two biaxial joints Three or more multiaxial joints

5. What characteristics do all joints have in common? All consist of bony regions held together by fibrous or cartilaginous connective tissue, or by a joint capsule.

**Selected Synovial Joints**

6. Which joint, the hip or the knee, is more stable? **Hip**

Name two important factors that contribute to the stability of the hip joint.

Deep socket for femur and strongly reinforced articular capsule

Name two important factors that contribute to the stability of the knee.

The menisci and ligaments and tendons crossing joint
7. The diagram shows a frontal section of the hip joint. Identify its major structural elements by using the key letters.

![Diagram of the hip joint]

Key:
- a. acetabular labrum
- b. articular capsule
- c. articular cartilage
- d. coxal bone
- e. head of femur
- f. ligamentum teres
- g. synovial cavity

8. The shoulder joint is built for mobility. List four factors that contribute to the large range of motion at the shoulder:

1. _______________________________________________________________________________________________
2. _______________________________________________________________________________________________
3. _______________________________________________________________________________________________
4. _______________________________________________________________________________________________

9. In which direction does the shoulder usually dislocate? ______________________________________________________

Movements Allowed by Synovial Joints

10. Which letter of the adjacent diagram marks the origin of the muscle? ______A____ Which letter marks the insertion? ______B____

Insert the words origin and insertion into the following sentence:

During muscle contraction, the ______insertion_______ moves toward the ______origin_______.
11. Complete the descriptions below the diagrams by inserting the type of movement in each answer blank.

(a) flexion ______ of the elbow
(b) extension ______ of the knee
(c) abduction ______ of the shoulder
(d) adduction ______ of the hip
(e) circumduction ______ of the shoulder
(f) inversion ______ of the foot
(g) rotation ______ of the head
(h) pronation ______ of the hand

Joint Disorders

12. What structural joint changes are common to the elderly? Degenerative changes (adhesions and bone spurs) begin to “sprout up” in diarthrotic joints; intervertebral discs begin to degenerate. These changes lead to increased joint stiffness and pain.

13. Define the following terms.

sprain: Ligaments reinforcing a joint are damaged by excessive stretching, or torn away from the bony attachment.

dislocation: Bones are forced out of their normal positions in a joint cavity.

14. What types of tissue damage might you expect to find in a dislocated joint?

Torn or stressed ligaments and inflammation. The joint capsule and ligaments may remain stretched.
Microscopic Anatomy and Organization of Skeletal Muscle

**Time Allotment:** 1 1/2 hours.

**Multimedia Resources:** See Appendix B for Guide to Multimedia Resource Distributors. See Exercise 6A for histology listings.

- *Human Musculature Videotape* (BC: 23 minutes, VHS)
- *Muscles and Joints: Muscle Power* (FHS: 26 minutes, VHS, DVD, 3-year streaming webcast)
- *The New Living Body: Muscles* (FHS: 20 minutes, VHS, DVD, 3-year streaming webcast)
- *Practice Anatomy Lab™ 2.0 (PAL)* (BC: CD-ROM, Website)
- *The Skeletal and Muscular Systems* (part of The Human Body Systems video series) (EN: 24 minutes, VHS)

**Solutions:**

*Saline Solution, 0.9%*

Weigh out 0.9 gram of NaCl. Add distilled water to a final volume of 100 milliliters.

**Laboratory Materials**

*Ordering information is based on a lab size of 24 students, working in groups of 4. A list of supply house addresses appears in Appendix A.*

- Fresh chicken breast or thigh
- 6–12 dropper bottles of physiologic saline (mammalian, 0.9%)
- 3-D models of skeletal muscle cells (if available)
- 24 compound microscopes, lens paper, lens cleaning solution
- Microscope slides and coverslips
- 24 forceps
- 48 dissecting needles
- 24 slides of skeletal muscle (longitudinal and cross sections)
- 24 slides of neuromuscular junctions
- 3-D model of skeletal muscle showing neuromuscular junction (if available)

**Advance Preparation**

1. Purchase chicken breasts or thighs from the meat market (one per lab). Refrigerate until used. Cut or tear the meat into small strips just before the lab. Provide gloves.
2. Set out forceps, dissecting needles, 0.9% saline solution in dropper bottles, and microscope slides and coverslips for each student. Designate an organic matter disposal area.
3. Set out prepared slides of skeletal muscle (longitudinal and cross sections), and slides showing neuromuscular (myoneural) junctions. (Because the latter slides are expensive, a demonstration microscope is an alternative to providing a slide for each student.) Set out lens paper and lens cleaning solution. Have compound microscopes available.
4. Set out any available models of skeletal muscle cells and neuromuscular junctions.
Comments and Pitfalls

1. Students may have difficulty observing the muscle banding pattern. This is usually because the light intensity is set too high and the iris diaphragm is not closed down.

2. Emphasize the importance of understanding the organization and terminology of muscle structure. The organization and terminology of the nerves are very similar.

Answers to Pre-Lab Quiz (p. 187)

1. c, it is one of the major components of hollow organs
2. fibers
3. true
4. actin, myosin
5. b, endomysium
6. b, a tendon
7. neuromuscular (myoneural) junction
8. true

Answers to Activity Questions

Activity 1: Examining Skeletal Muscle Cell Anatomy (p. 190)

4. The banding pattern and limits of the cells are much more clear on the prepared slides.
Microscopic Anatomy and Organization of Skeletal Muscle

Skeletal Muscle Cells and Their Packaging into Muscles

1. Use the items in the key to correctly identify the structures described below.

   g: perimysium  1. connective tissue ensheathing a bundle of muscle cells
   c: fascicle  2. bundle of muscle cells
   i: sarcomere  3. contractile unit of muscle
   d: fiber  4. a muscle cell
   a: endomysium  5. thin reticular connective tissue surrounding each muscle cell
   h: sarcolemma  6. plasma membrane of the muscle fiber
   e: myofibril  7. a long filamentous organelle with a banded appearance found within muscle cells
   f: myofilament  8. actin- or myosin-containing structure
   k: tendon  9. cord of collagen fibers that attaches a muscle to a bone

   Key:
   a. endomysium
   b. epimysium
   c. fascicle
   d. fiber
   e. myofibril
   f. myofilament
   g. perimysium
   h. sarcolemma
   i. sarcomere
   j. sarcoplasm
   k. tendon

2. List three reasons why the connective tissue wrappings of skeletal muscle are important.

   The connective tissue wrappings (a) bundle the muscle fibers together, increasing coordination of their activity; (b) add strength to the muscle; and (c) provide a route for entry and exit of blood vessels and nerves to the muscle fibers.

3. Why are there more indirect—that is, tendinous—muscle attachments to bone than there are direct attachments?

   They conserve space (less bulky than fleshy muscle attachments) and are more durable than muscle tissue where bony prominences must be spanned.

4. How does an aponeurosis differ from a tendon structurally? An aponeurosis is a sheet of white fibrous connective tissue; a tendon is a band or cord of the same tissue.

   How is an aponeurosis functionally similar to a tendon? Both serve to attach muscles to bones or to other muscles.
5. The diagram illustrates a small portion of several myofibrils. Using letters from the key, correctly identify each structure indicated by a leader line or a bracket.

**Key:**

- a. A band
- b. actin filament
- c. I band
- d. myosin filament
- e. T tubule
- f. terminal cisterna
- g. triad
- h. sarcomere
- i. Z disc

6. On the following figure, label a blood vessel, endomysium, epimysium, a fascicle, a muscle cell, perimysium, and the tendon.
### The Neuromuscular Junction

7. Complete the following statements:

The junction between a motor neuron’s axon terminal and the muscle cell membrane is called a(n) __1__ junction. A motor neuron and all of the skeletal muscle cells it stimulates is called a(n) __2__. The actual gap between the axon terminal and the muscle cell is called a(n) __3__. Within the axon terminal are many small vesicles containing a neurotransmitter substance called __4__. When the __5__ reaches the ends of the axon, the neurotransmitter is released and diffuses to the muscle cell membrane to combine with receptors there. The combining of the neurotransmitter with the muscle membrane receptors causes the membrane to become permeable to both sodium and potassium. The greater influx of sodium ions results in __6__ of the membrane. Then contraction of the muscle cell occurs.

8. The events that occur at a neuromuscular junction are depicted below. Identify by labeling every structure provided with a leader line.

![Neuromuscular Junction Diagram](image)

**Key:**
- a. axon terminal
- b. mitochondrion
- c. muscle fiber
- d. myelinated axon
- e. sarcolemma
- f. synaptic cleft
- g. T tubule
- h. vesicle containing ACh
**Gross Anatomy of the Muscular System**

**Time Allotment:** 2–3 hours in lab plus time outside of lab.

**Multimedia Resources:** See Appendix B for Guide to Multimedia Resource Distributors.
- *A.D.A.M.® Interactive Anatomy 4.0* (AIA: CD-ROM, DVD)
- *Anatomy of a Runner (Structure and Function of the Lower Limb)* (DE: 38 minutes, DVD)
- *Human Musculature Videotape* (BC: 23 minutes, VHS)
- *Major Skeletal Muscles and their Actions* (DE: 19 minutes, VHS, DVD)
- *The New Living Body: Muscles* (FHS: 20 minutes, VHS, DVD, 3-year streaming webcast)
- *Practice Anatomy Lab™ 2.0 (PAL)* (BC: CD-ROM, Website)

**Laboratory Materials**

*Ordering information is based on a lab size of 24 students, working in groups of 4. A list of supply house addresses appears in Appendix A.*

<table>
<thead>
<tr>
<th>Item</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prosected human cadaver (if available)</td>
<td></td>
</tr>
<tr>
<td>Human torso models and/or anatomical charts of muscles</td>
<td>6–12 tubes of body (or face) paint</td>
</tr>
<tr>
<td>Disposable gloves</td>
<td>6–12 1-inch-wide art brushes</td>
</tr>
</tbody>
</table>

**Advance Preparation**

1. Set out models of the human torso and upper and lower limbs. It helps to have the muscles labeled on some of the models. Have model keys available.
2. Set out anatomical charts of human musculature.
3. If possible, have a prosected human cadaver available. Be prepared to inform students as to which muscles should be identified.
4. Set out functional knee and hip models available from biology supply companies.

**Comments and Pitfalls**

1. Identification of the intercostal and abdominal oblique muscles will be much easier if students carefully observe muscle fiber direction.

**Answers to Pre-Lab Quiz (p. 197)**

1. a, agonist
2. Direction of muscle fibers, relative size of muscles, location of muscle, number of origins, location of origin and insertion, shape of muscle, action of muscle
3. true
4. c, trunk
5. a, lower limb
6. a, biceps brachii
7. c, rectus abdominis
8. gastrocnemius
9. b, gluteus maximus
Classification of Skeletal Muscles

1. Several criteria were given for the naming of muscles. Match the criteria (column B) to the muscle names (column A). Note that more than one criterion may apply in some cases.

<table>
<thead>
<tr>
<th>Column A</th>
<th>Column B</th>
</tr>
</thead>
<tbody>
<tr>
<td>e, g</td>
<td>1. gluteus maximus</td>
</tr>
<tr>
<td>a, g</td>
<td>2. adductor magnus</td>
</tr>
<tr>
<td>d, e</td>
<td>3. biceps femoris</td>
</tr>
<tr>
<td>e, f</td>
<td>4. transversus abdominis</td>
</tr>
<tr>
<td>a, c, e</td>
<td>5. extensor carpi ulnaris</td>
</tr>
<tr>
<td>b</td>
<td>6. trapezius</td>
</tr>
<tr>
<td>e, f</td>
<td>7. rectus femoris</td>
</tr>
<tr>
<td>e, f</td>
<td>8. external oblique</td>
</tr>
</tbody>
</table>

2. Match the key terms to the muscles and movements described below.

**Key:**
- a: prime mover (agonist)
- b: antagonist
- c: synergist
- d: fixator

- a: prime mover
  1. term for the biceps brachii during elbow flexion
- c: synergist
  2. term that describes the relation of brachialis to biceps brachii during elbow flexion
- b: antagonist
  3. term for the triceps brachii during elbow flexion
- b: antagonist
  4. term for the iliopsoas during hip extension
- a: prime mover
  5. term for the gluteus maximus during hip extension when walking up stairs
- d: fixator
  6. term for the rotator cuff muscles and deltoid when the elbow is flexed and the hand grabs a tabletop to lift the table
Muscles of the Head and Neck

3. Using choices from the key at the right, correctly identify muscles provided with leader lines on the diagram.

Key:
(a) buccinator
(b) corrugator supercili
(c) depressor anguli oris
(d) depressor labii inferioris
(e) epicranius (frontal belly)
(f) epicranius (occipital belly)
(g) levator labii superioris
(h) masseter
(i) mentalis
(j) orbicularis oculi
(k) orbicularis oris
(l) platysma
(m) trapezius
(n) zygomaticus major and minor

4. Using the key provided in question 3, identify the muscles described next.

1. used in smiling
2. used to suck in your cheeks
3. used in blinking and squinting
4. used to pout (pulls the corners of the mouth downward)
5. raises your eyebrows for a questioning expression

6. used to form the vertical frown crease on the forehead
7. your “kisser”
8. prime mover to raise the mandible
9. tenses skin of the neck during shaving
Muscles of the Trunk

5. Correctly identify both intact and transected (cut) muscles depicted in the diagram, using the key given at the right. (Not all terms will be used in this identification.)

Key:

a. biceps brachii
b. brachialis
c. deltoïd (cut)
d. external intercostals
e. external oblique
f. internal oblique
g. latissimus dorsi
h. pectoralis major
i. pectoralis minor
j. rectus abdominis
k. rhomboïds
l. serratus anterior
m. subscapularis
n. transversus abdominis
o. trapezius

6. Using the key provided in question 5 above, identify the major muscles described next.

   j    1. a major spine flexor
   g    2. prime mover for arm extension
   h    3. prime mover for arm flexion
e, f, n, (j) 4. assume major responsibility for forming the abdominal girdle (three pairs of muscles)
c    5. prime mover of shoulder abduction
   g, h 6. important in shoulder adduction; antagonists of the shoulder abductor (two muscles)
l    7. moves the scapula forward and rotates scapula upward
d    8. small, inspiratory muscles between the ribs; elevate the ribs
   o    9. extends the head
   k    10. pull the scapulae medially
**Muscles of the Upper Limb**

7. Using terms from the key on the right, correctly identify all muscles provided with leader lines in the diagram. (Note that not all the listed terms will be used in this exercise.)

![Diagram of muscles of the upper limb]

**Key:**

- a. biceps brachii
- b. brachialis
- c. brachioradialis
- d. extensor carpi radialis longus
- e. extensor digitorum
- f. flexor carpi radialis
- g. flexor carpi ulnaris
- h. flexor digitorum superficialis
- i. flexor pollicis longus
- j. palmaris longus
- k. pronator quadratus
- l. pronator teres
- m. supinator
- n. triceps brachii

8. Use the key provided in question 7 to identify the muscles described next.

- **a** 1. flexes the forearm and supinates the hand
- **m** 2. synergist for supination of hand
- **h, c** 3. forearm flexors; no role in supination (two muscles)
- **n** 4. elbow extensor
- **f** 5. power wrist flexor and abductor
- **h** 6. flexes wrist and middle phalanges
- **k, l** 7. pronate the hand (two muscles)
- **i** 8. flexes the thumb
- **d** 9. extends and abducts the wrist
- **e** 10. extends the wrist and digits
- **j** 11. flat muscle that is a weak wrist flexor; tenses skin of the palm
Muscles of the Lower Limb

9. Using the terms from the key on the right, correctly identify all muscles provided with leader lines in the diagram below. (Not all listed terms will be used in this exercise.)

Key:

a. adductor group
b. biceps femoris
c. extensor digitorum longus
d. fibularis brevis
e. fibularis longus
f. flexor hallucis longus
g. gastrocnemius
h. gluteus maximus
i. gluteus medius
j. rectus femoris
k. semimembranosus
l. semitendinosus
m. soleus
n. tensor fasciae latae
o. tibialis anterior
p. tibialis posterior
q. vastus lateralis

10. Use the key terms in question 9 to respond to the descriptions below.

f. flexes the great toe and inverts the foot

d, e. lateral compartment muscles that plantar flex and evert the foot (two muscles)

i, n. abduct the thigh to take the “at ease” stance (two muscles)

h. used to extend the hip when climbing stairs

g, m. prime movers of plantar flexion (two muscles) of the foot

p. prime mover of inversion of the foot

o. prime mover of dorsiflexion of the foot

a. adduct the thigh, as when standing at attention

c. extends the toes

b, k, l. extend thigh and flex knee (three muscles)

j. extends knee and flexes thigh
General Review: Muscle Recognition

11. Identify the lettered muscles in the diagram of the human anterior superficial musculature by matching the letter with one of the following muscle names:

- 1. adductor longus
- 2. biceps brachii
- 3. brachioradialis
- 4. deltoid
- 5. extensor digitorum longus
- 6. external oblique
- 7. fibularis longus
- 8. flexor carpi radialis
- 9. flexor carpi ulnaris
- 10. frontalis
- 11. gastrocnemius
- 12. gracilis
- 13. iliopsoas
- 14. internal oblique
- 15. latissimus dorsi
- 16. masseter
- 17. orbicularis oculi
- 18. orbicularis oris
- 19. palmaris longus
- 20. pectineus
- 21. pectoralis major
- 22. platysma
- 23. pronator teres
- 24. rectus abdominis
- 25. rectus femoris
- 26. sartorius
- 27. serratus anterior
- 28. soleus
- 29. sternocleidomastoid
- 30. sternohyoid
- 31. temporalis
- 32. tensor fasciae latae
- 33. tibialis anterior
- 34. transversus abdominis
- 35. trapezius
- 36. triceps brachii
- 37. vastus lateralis
- 38. vastus medialis
- 39. zygomaticus
12. Identify each of the lettered muscles in this diagram of the human posterior superficial musculature by matching its letter to one of the following muscle names:

- t 1. adductor magnus
- u 2. biceps femoris
- b 3. brachialis
- c 4. brachioradialis
- m 5. deltoid
- d 6. extensor carpi radialis longus
- f 7. extensor carpi ulnaris
- g 8. extensor digitorum
- q 9. external oblique
- e 10. flexor carpi ulnaris
- i 11. gastrocnemius
- s 12. gluteus maximus
- r 13. gluteus medius
- v 14. gracilis
- h 15. iliotibial tract (tendon)
- n 16. infraspinatus
- p 17. latissimus dorsi
- j 18. occipitalis
- x 19. semimembranosus
- w 20. semitendinosus
- k 21. sternocleidomastoid
- o 22. teres major
- l 23. trapezius
- a 24. triceps brachii
General Review: Muscle Descriptions

13. Identify the muscles described by completing the following statements.

1. The __________, __________, __________, and __________ are commonly used for intramuscular injections (four muscles).

2. The insertion tendon of the __________ group contains a large sesamoid bone, the patella.

3. The triceps surae insert in common into the __________ tendon.

4. The bulk of the tissue of a muscle tends to lie __________ to the part of the body it causes to move.

5. The extrinsic muscles of the hand originate on the __________.

6. Most flexor muscles are located on the __________ aspect of the body; most extensors are located __________. An exception to this generalization is the extensor-flexor musculature of the __________.
Skeletal Muscle Physiology: Frogs and Human Subjects

This exercise may be divided into two parts. The first demonstrates muscle contraction at the cellular level, and the second investigates contraction of the muscle as a whole. If desired, this exercise can be done in conjunction with Exercise 18A (Neurophysiology of Nerve Impulses) to save animals. Alternatively, the instructor may prefer to have the class observe the computer simulation of this material (PhysioEx™ 8.0 Exercise 16B, Skeletal Muscle Physiology).

Suggestion for Alternative Equipment
Instructions for using PowerLab equipment can be found on www.myaandp.com.

Time Allotment:
ATP Muscle Kit: 1 hour+ (depends largely on dissecting dexterity of students).
Muscle Fatigue in Humans: 1/2 hour.
Induction of Contraction in the Frog Gastrocnemius Muscle: 2 hours+.


Muscles and Joints: Muscle Power (FHS: 26 minutes, VHS, DVD, 3-year streaming webcast)
Muscular System at Work: The Inner Athlete (FHS: 25 minutes, VHS, DVD, 3-year streaming webcast)

Solutions:
Ringer’s Solution, Frog
• 6.50 grams sodium chloride
• 0.14 gram potassium chloride
• 0.12 gram calcium chloride
• 0.20 gram sodium bicarbonate
Combine salts in a flask and add distilled water to make 1 liter of solution.

Laboratory Materials
Ordering information is based on a lab size of 24 students, working in groups of 4. A list of supply house addresses appears in Appendix A.

1 or 2 ATP muscle kits
6 petri dishes
1 box of microscope slides and coverslips
25 millimeter rulers
12–24 compound microscopes, lens paper, lens cleaning solution
6 watches or timers
Copies of textbooks or other heavy books
24–48 pointed glass probes (teasing needles)
6 glass marking pencils
6 100-milliliter beakers of distilled water
12–24 stereomicroscopes
6 50-milliliter beakers
Ringer’s solution, frog
6 metal needle probes
6 medicine droppers
6 pairs of scissors
Cotton thread
6 forceps
6 glass or porcelain plates
Advance Preparation—ATP Muscle Kit

1. Order the ATP muscle kits (Carolina) to be delivered no more than seven days before the lab. One kit provides generously for eight students. Extra vials of the chemical solutions can be ordered separately (Carolina) and will reduce waiting time. Just before the lab begins, cut the muscle bundles into 2-centimeter lengths and place the accompanying glycerol in a petri dish.

2. Glass dissecting needles can be made from glass stirring rods. Use a Bunsen burner with a flame spreader attachment. Holding a stirring rod with oven mitts, heat the center while turning the rod until the flamed area glows orange. Pull the ends gently but firmly apart until the glass separates. With practice, fine-tipped needles can be made.

Comments and Pitfalls

1. Students may have great difficulty separating the muscle bundles into individual fibers. Often two or three fibers remain together and it is the best they can do.

2. Remind the students to keep the fibers in a pool of glycerol to prevent them from drying out.

3. Sometimes the fibers curl as they contract. Caution the students to measure the uncurled length of the fiber.

4. Occasionally there is great variability in the results (probably due to technical errors). Try rinsing the slides and glass needles in distilled water before use. This is a good exercise to collect class data and have the students compare individual results with the class results. You can discuss the importance of controlled experiments and repeated trials.

Advance Preparation—Frog Gastrocnemius Muscle

1. If animal maintenance facilities are limited, order frogs to be delivered about 2–3 days prior to the date of the lab exercise. Healthy frogs can be maintained for a short time in a clean aquarium with a small amount of chlorinated water that is changed daily. Provide the frogs with a rock extending above the water line. Northern frogs require slightly cooler conditions (10–15°C) than southern frogs (15–20°C). One frog per lab group should be sufficient.

2. Designate a disposal area for the frogs. Have disposable gloves available for handling the frogs.

3. Pith frogs as needed, or if you prefer to have students pith their own frogs, provide them with copies of the pithing instructions on p. 99.

4. Set up work stations according to the amount of equipment available. Ideally there should be four students to a group. Each work station should include: a computer and associated equipment or a physiograph and associated equipment, a beaker of frog Ringer's solution, a medicine dropper, scissors, a glass needle, cotton thread, forceps, and a glass or porcelain plate.

5. Acquaint students with the operation of the recording equipment. Once the students are comfortable with the equipment, they should proceed with the experiment. Taking time here is worthwhile.

   a. Physiograph. There are several different brands of physiographs in use. It is best to consult the manual that comes with your equipment for specific details of operation. Have the students locate the switch regulating paper speed and practice running the paper at different speeds. The paper should then be rewound for future use. The students should also test the time marker at different settings with the paper running, and depress the event marker to observe the
response. They should understand that the event marker will be automatically depressed when stimuli are applied to
the muscle preparation. Be sure the ink is flowing smoothly through the writing tips, and be sure the tips are adjust-
ed to record on horizontal lines of the paper grid.

b. BIOPAC®. It is helpful to have experienced student assistants to help with BIOPAC®. Introduce students to the basic
features of BIOPAC® use before beginning this lab exercise.

Comments and Pitfalls

1. Students often fail to keep the muscle moist. Someone in each group should be in charge of keeping the
muscle moist.
2. If the muscle is not lined up vertically on the equipment, it pulls at an angle.
3. Students may forget to record data. One person in each group should be the designated recorder.
4. Sometimes the ink does not flow smoothly. To help avoid this, test the equipment before beginning the
experiment.
5. When determining the effect of load on skeletal muscle, remind students to loosen the afterload screw (if
present) on the muscle lever.
6. If the sensitivity control or gain on the physiograph is at its most sensitive setting, you may have electrical
interference.
7. If students are having trouble obtaining a muscle response, have them check to be sure that the connec-
tions are not loose and that the stimulator electrode is making contact with the muscle.

Advance Preparation for the Kymograph

1. Set up work stations according to the amount of equipment available. Ideally there should be four students
to a group. Acquaint students with the operation of the equipment.
2. If smoked paper is to be used for kymograph recording, set up an area in a fume hood for smoking the
paper, another hooded area with glazing fluid or fixative, and a line and clips for drying the paper.

Comments and Pitfalls

1. Kymograph paper is smoked in a fume hood using a smoky flame produced by passing natural gas
through benzene. Because benzene is a known carcinogen, alternative recording methods should be
sought. Muscle levers and signal magnets with ink recording tips can be purchased. If the budget is tight,
small right-angled felt-tip markers can be attached to each smoke-writing stylus for satisfactory results.
Students should practice putting paper tightly on the drum and lining up the signal magnet and muscle
lever writing tips. If the muscle lever is equipped with an afterload screw, have the students adjust it to
bring the muscle lever to a horizontal position. Be sure the ink is flowing smoothly (if applicable). Have
the students set the signal magnet to deliver one pulse per second, and calculate the drum speed in
mm/sec for each setting.
2. Students may brush against the smoked paper before it has been fixed and destroy the recordings. If shel-
lac is used as the glazing fluid, be sure students put paper into the shellac with the smoked side up. Spray
lacquers are easier to use.

Answers to Pre-Lab Quiz (pp. 235–236)

1. cations
2. c, influx of Na+
3. c, repolarization
4. twitch
5. true
6. true
7. a, tetanus
8. a, oxygen debt in the tissue after prolonged activity
Answers to Activity Questions

Activity 1: Observing Muscle Fiber Contraction (pp. 237–238)

8. The contracted fiber appears wider and the edges appear scalloped. The I and H zones (or bands) have disappeared.

10. Generally there is little or no contraction with ATP alone. There is no contraction with the salt solutions alone. Maximum contraction occurs in the presence of ATP and the proper concentrations of potassium and magnesium ions.

It is expected that not all groups will obtain exactly the same results. The observed differences may be explained by inadvertent damage occurring to the muscle cells during separation, failure to separate completely to individual cells, and imprecision in measurements.

Activity 2: Demonstrating Muscle Fatigue in Humans (p. 238)

7. As load increases, the period of contraction shortens as the muscle fatigues more quickly.

Activity 3: Inducing Contraction in the Frog Gastrocnemius Muscle (pp. 241–243)

Observing Graded Muscle Response to Increased Stimulus Intensity

4. As the voltage increases, more motor units respond. The name for this is motor unit recruitment.

5. Once maximal stimulus is reached, all the motor units are contracting. Additional voltage has no effect.

Inducing Muscle Fatigue

4. After a period of rest, the muscle contracts again upon stimulation. A physiological basis for this may be that accumulated lactic acid diffuses out of the cells, raising the pH and allowing the enzymes necessary for ATP production to function again and the Na⁺-K⁺ pump to restore correct ionic distribution.
Activity 4: Electromyography in a Human Subject Using BIOPAC® (pp. 244–252)

Part 1: Temporal and Multiple Motor Unit Summation, Data Analysis

7. The intensity of each of the values increases with increasing force of muscle contraction. The maximum voltage is reflective of the number of motor units being activated. The p-p value gradually increases, reflecting an increased number of active motor units.

Part 2: Force Measurement and Fatigue, Repeat Data Analysis for the Nondominant Forearm

4. There may or may not be a difference in the maximal force between the forearms, but usually the maximal force in the dominant forearm is 10–20% greater than in the nondominant forearm. Muscle cells are amitotic. When a muscle gets larger in diameter, it is because of an increase in size (diameter) of the muscle cells, not because of an increase in the number of muscle cells. One normally observes more rapid fatigue in the nondominant forearm.

Kymograph setup for frog gastrocnemius experiments
Skeletal Muscle Physiology: Frogs and Human Subjects

Muscle Activity

1. The following group of incomplete statements refers to a muscle cell in the resting state just before stimulation. Complete each statement by choosing the correct response from the key items.

Key:
- a. Na⁺ diffuses out of the cell
- b. K⁺ diffuses out of the cell
- c. Na⁺ diffuses into the cell
- d. K⁺ diffuses into the cell
- e. inside the cell
- f. outside the cell
- g. relative ionic concentrations on the two sides of the membrane
- h. electrical conditions
- i. activation of the sodium-potassium pump, which moves K⁺ into the cell and Na⁺ out of the cell
- j. activation of the sodium-potassium pump, which moves Na⁺ into the cell and K⁺ out of the cell

There is a greater concentration of Na⁺ outside the cell; there is a greater concentration of K⁺ inside the cell. When the stimulus is delivered, the permeability of the membrane at that point is changed; and activation of the sodium-potassium pump, initiating the depolarization of the membrane. Almost as soon as the depolarization wave has begun, a repolarization wave follows it across the membrane. This occurs as relative ionic concentrations on the two sides of the membrane. Repolarization restores the electrical conditions of the resting cell membrane. The activation of the sodium-potassium pump is (are) reestablished by activation of the sodium-potassium pump, which moves Na⁺ into the cell and K⁺ out of the cell.

2. Number the following statements in the proper sequence to describe the contraction mechanism in a skeletal muscle cell. Number 1 has already been designated.

- 1 Depolarization occurs, and the action potential is generated.
- 2 The action potential, carried deep into the cell by the T tubules, triggers the release of calcium ions from the sarcoplasmic reticulum.
- 3 The calcium ion concentrations at the myofilaments increase; the myofilaments slide past one another, and the cell shortens.
- 4 The concentration of the calcium ions at the myofilaments decreases as they are actively transported into the sarcoplasmic reticulum.
- 5 The muscle cell relaxes and lengthens.

3. Refer to your observations of muscle fiber contraction on pages 237–238 to answer the following questions.

a. Did your data support your hypothesis? yes/no

b. Explain your observations fully. Optimal muscle contraction requires Mg²⁺, K⁺, and ATP. Without ATP (the energy source) no contraction can occur once energy stores are exhausted. Mg²⁺ and K⁺ are necessary for ATPase activity.
c. Draw a relaxed and a contracted sarcomere below.

Inducing Contraction in the Frog Gastrocnemius Muscle

4. Why is it important to destroy the brain and spinal cord of a frog before conducting physiological experiments on muscle contraction? 

\[\text{Renders the frog unable to feel pain and prevents reflex movements that would confuse experimental results.}\]

5. What kind of stimulus (electrical or chemical) travels from the motor neuron toward skeletal muscle?  

\[\text{Electrical}\]

What kind of stimulus (electrical or chemical) travels from the axon terminal to the sarcolemma?  

\[\text{Chemical}\]

6. Give the name and duration of each of the three phases of the muscle twitch, and describe what is happening during each phase.

a. \(\text{latent}\) \(2.78\) msec, \(\text{electrical/chemical changes preparatory to contraction, i.e., depolarization, release of Ca}^{2+}\)

b. \(\text{contraction}\) \(23.33\) msec, \(\text{muscle shortens due to sliding of myofilaments}\)

c. \(\text{relaxation}\) \(174.90\) msec, \(\text{Ca}^{2+}\) is reabsorbed by the sarcoplasmic reticulum, the muscle cells lengthen and relax.

7. Use the items in the key to identify the conditions described.

**Key:**

a. \(\text{maximal stimulus}\)

b. \(\text{multiple motor unit summation}\)

c. \(\text{subthreshold stimulus}\)

d. \(\text{tetanus}\)

e. \(\text{threshold stimulus}\)

f. \(\text{wave summation}\)

\(\text{d}\) 1. sustained contraction without any evidence of relaxation

\(\text{c}\) 2. stimulus that results in no perceptible contraction

\(\text{e}\) 3. stimulus at which the muscle first contracts perceptibly

\(\text{a}\) 4. increasingly stronger contractions owing to stimulation at a rapid rate

\(\text{b}\) 5. increasingly stronger contractions owing to increased stimulus strength

\(\text{a}\) 6. weakest stimulus at which all muscle cells in the muscle are contracting
8. Complete the following statements by writing the appropriate words on the correspondingly numbered blanks at the right.

   When a weak but smooth muscle contraction is desired, a few motor units are stimulated at a(n) \( \underline{1} \) rate. If blue litmus paper is pressed to the cut surface of a fatigued muscle, the paper color changes to red, indicating low pH. This situation is caused by the accumulation of \( \underline{2} \) in the muscle. Within limits, as the load on a muscle is increased, the muscle contracts \( \underline{3} \) (more/less) strongly.

   1. very rapid
   2. lactic acid
   3. more

9. During the frog experiment on muscle fatigue, how did the muscle contraction pattern change as the muscle began to fatigue?

   The distance of the contraction peak from the baseline continued to decrease.

   How long was stimulation continued before fatigue was apparent? (student data)

   If the sciatic nerve that stimulates the living frog’s gastrocnemius muscle had been left attached to the muscle and the stimulus had been applied to the nerve rather than the muscle, would fatigue have become apparent sooner or later?

   Sooner

   Explain your answer. Fatigue of the neuromuscular junctions generally occurs before a muscle becomes fatigued and unable to contract.

10. What will happen to a muscle in the body when its nerve supply is destroyed or badly damaged?

   The muscle becomes flaccid, paralyzed, and eventually atrophies. Nerve stimulation is necessary for viable muscles.

11. Explain the relationship between the load on a muscle and its strength of contraction. Strength of contraction increases as the load increases until the load becomes excessive.

12. The skeletal muscles are maintained in a slightly stretched condition for optimal contraction. How is this accomplished?

   By the manner in which they are attached to the skeleton.

   Why does stretching a muscle beyond its optimal length reduce its ability to contract? (Include an explanation of the events at the level of the myofilaments.) Overstretching prevents myosin cross bridge interaction since the myofilaments no longer overlap. If the cross bridges cannot make contact, no sliding force (contraction) can be generated.

13. If the length but not the tension of a muscle is changed, the contraction is called an isotonic contraction. In an isometric contraction, the tension is increased but the muscle does not shorten. Which type of contraction did you observe most often during the laboratory experiments? Isotonic
**Electromyography in a Human Subject Using BIOPAC®**

14. If you were a physical therapist applying a constant voltage to the forearm, what might you observe if you gradually increased the *frequency* of stimulatory impulses, keeping the voltage constant each time?

   *One is likely to observe an increase in the duration of motor unit activation.*

15. Describe what is meant by the term *motor unit recruitment*. *Motor unit recruitment refers to the process by which an increasing number of motor units in a muscle are activated by gradually increasing levels of stimulation (e.g., voltage).*

16. Describe the physiological processes occurring in the muscle cells that account for the gradual onset of muscle fatigue.

    *A deficit in ATP, an accumulation of lactic acid, and ionic imbalances all contribute to muscle fatigue.*

17. Given that most subjects use their dominant forearm far more than their nondominant forearm, what does this indicate about degree of activation of motor units and these factors: muscle fiber diameter, maximum muscle fiber force, and time to muscle fatigue? (You may need to use your textbook for help with this one.)

    *Generally, since people use their dominant forearm more, the muscle fibers in that arm are activated for more prolonged periods. Thus, increase in muscle fiber diameter (muscular hypertrophy) usually results, allowing for increased force. Increased activity generally leads to increased respiratory and contractual efficiency, resulting in a greater time to muscle fatigue.*

18. Define *dynamometry*. *Dynamometry is the process of measuring force.*

19. How might dynamometry be used to assess patients in a clinical setting?

    *Dynamometry can assist the clinician in the assessment of muscle function by allowing for the study of contractual deficits and the recovery of muscle function.*
Histology of Nervous Tissue

Time Allotment: 1 hour.


The Nervous System: Nerves at Work (FHS: 27 minutes, VHS, DVD, 3-year streaming webcast)
Practice Anatomy Lab™ 2.0 (PAL) (BC: CD-ROM, Website)

Laboratory Materials
Ordering information is based on a lab size of 24 students, working in groups of 4. A list of supply house addresses appears in Appendix A.

24 compound microscopes, lens paper, immersion oil, lens cleaning solution  Model of neuron (if available)  24 slides of ox spinal cord smear, teased myelinated fibers, Purkinje cells (cerebellum), pyramidal cells (cerebrum), dorsal root ganglion, and nerve cross section

Advance Preparation
1. Set out slides of ox spinal cord smear and teased myelinated fibers, Purkinje cells (cerebellum), pyramidal cells (cerebrum), dorsal root ganglion, and nerve cross section.
2. Set out lens paper, immersion oil, and lens cleaning solution. Have compound microscopes available.
3. Set out models of neurons, if available.

Comments and Pitfalls
1. Students may focus on the wrong cells. Encourage them to look at the histology images in Exercise 17, use histology atlases, and help each other.
2. Students may have difficulty with the connective tissue sheaths. Remind them of the similarities to muscle terminology.

Answers to Pre-Lab Quiz (p. 257)
1. two  6. myelin
2. c, satellite cells and Schwann cells  7. tracts
3. Neurons  8. b, Multipolar
4. c, dendrites  9. Efferent
5. true  10. a, endoneurium

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Answers to Activity Questions

Activity 1: Identifying Parts of a Neuron (p. 261)

3. The nodes are at regular intervals. Action potentials will occur at regular intervals along the axon as local currents open voltage-gated sodium channels. This allows the electrical signal to jump from node to node and travel very fast.

Activity 2: Studying the Microscopic Structure of Selected Neurons (p. 262)

The Purkinje and pyramidal cells are multipolar. The dorsal root ganglion neurons are unipolar.
Histology of Nervous Tissue

1. The basic functional unit of the nervous system is the neuron. What is the major function of this cell type?

   To generate and transmit nerve impulses

2. Name four types of neuroglia in the CNS, and list a function for each of these cells. (You will need to consult your textbook for this.)

<table>
<thead>
<tr>
<th>Types</th>
<th>Functions</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. microglia</td>
<td>a. phagocytosis of debris (dead cells, bacteria, etc.)</td>
</tr>
<tr>
<td>b. oligodendrocytes</td>
<td>b. form myelin around axons in the CNS</td>
</tr>
<tr>
<td>c. astrocytes</td>
<td>c. support the neurons; may serve nutritive function and help regulate the chemical environment of the neurons</td>
</tr>
<tr>
<td>d. ependymal cells</td>
<td>d. line cavities of the brain (and spinal cord); aid in circulation of cerebrospinal fluid</td>
</tr>
</tbody>
</table>

Name the PNS glial cell that forms myelin. Schwann cell

Name the PNS glial cell that surrounds dorsal root ganglion neurons. Satellite cell

3. Match each statement with a response chosen from the key.

   Key: a. afferent neuron  
   b. central nervous system  
   c. efferent neuron  
   d. ganglion  
   e. interneuron  
   f. neuroglia  
   g. neurotransmitters  
   h. nerve  
   i. nuclei  
   j. peripheral nervous system  
   k. synapse  
   l. tract  

   b  1. the brain and spinal cord collectively  
   f  2. specialized supporting cells in the CNS  
   k  3. junction or point of close contact between neurons  
   l  4. a bundle of nerve processes inside the CNS  
   e  5. neuron serving as part of the conduction pathway between sensory and motor neurons  
   j  6. ganglia and spinal and cranial nerves  
   d  7. collection of nerve cell bodies found outside the CNS  
   c  8. neuron that conducts impulses away from the CNS to muscles and glands

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9. neuron that conducts impulses toward the CNS from the body periphery

10. chemicals released by neurons that stimulate or inhibit other neurons or effectors

**Neuron Anatomy**

4. Match the following anatomical terms (column B) with the appropriate description or function (column A).

<table>
<thead>
<tr>
<th>Column A</th>
<th>Column B</th>
</tr>
</thead>
<tbody>
<tr>
<td>c</td>
<td>1. region of the cell body from which the axon originates</td>
</tr>
<tr>
<td>b</td>
<td>2. secretes neurotransmitters</td>
</tr>
<tr>
<td>d (g)</td>
<td>3. receptive region of a neuron</td>
</tr>
<tr>
<td>e</td>
<td>4. insulates the nerve fibers</td>
</tr>
<tr>
<td>g</td>
<td>5. site of the nucleus and is the most important metabolic area</td>
</tr>
<tr>
<td>f</td>
<td>6. may be involved in the transport of substances within the neuron</td>
</tr>
<tr>
<td>h</td>
<td>7. essentially rough endoplasmic reticulum, important metabolically</td>
</tr>
<tr>
<td>a</td>
<td>8. impulse generator and transmitter</td>
</tr>
</tbody>
</table>

5. Draw a “typical” multipolar neuron in the space below. Include and label the following structures on your diagram: cell body, nucleus, nucleolus, Nissl bodies, dendrites, axon, axon collateral branch, myelin sheath, nodes of Ranvier, axon terminals, and neurofibrils.

![Neuron Diagram](image)

6. What substance is found in synaptic vesicles of the axon terminal? neurotransmitters

What role does this substance play in neurotransmission? Carries electrical impulse from one neuron to the next
7. What anatomical characteristic determines whether a particular neuron is classified as unipolar, bipolar, or multipolar?

*The number of processes issuing from the cell body*

Make a simple line drawing of each type here.

Unipolar neuron  Bipolar neuron  Multipolar neuron

8. Correctly identify the sensory (afferent) neuron, interneuron (association neuron), and motor (efferent) neuron in the figure below.

Which of these neuron types is (are) unipolar? Sensory neuron

Which is (are) most likely multipolar? Motor neuron, interneuron

9. Describe how the Schwann cells form the myelin sheath and the neurilemma encasing the nerve processes.

*Schwann cells begin to wrap themselves around the axon in jelly roll fashion, thus forming a tight coil of membranous material which forms the myelin sheath. The neurilemma is the bulge of Schwann cell cytoplasm external to the myelin sheath and the outermost (exposed) Schwann cell membrane.*
Structure of a Nerve

10. What is a nerve?  
A bundle of axons wrapped in connective tissue. Extends to and/or from the CNS and body viscera or peripheral structures.

11. State the location of each of the following connective tissue coverings.
   - Endoneurium: Surrounds axons
   - Perineurium: Surrounds a bundle of axons
   - Epineurium: Surrounds all of the axons contributing to a nerve

12. What is the function of the connective tissue wrappings found in a nerve?  
To protect and insulate the delicate nerve fibers

Nerve containing both motor (efferent) and sensory (afferent) fibers

14. Identify all indicated parts of the nerve section.
If desired, part of this investigation of the nerve impulse may be done in conjunction with Exercise 16A (Skeletal Muscle Physiology) to save animals.

Time Allotment: 1–11/2 hours (more if oscilloscope is used).

See Exercise 6A for histology listings.

Brain and Nervous System: Your Information Superhighway (FHS: 31 minutes, VHS, DVD, 3-year streaming webcast)
Nerve Impulse Conduction (IM: 29 minutes, DVD)

Solutions:

Hydrochloric Acid (HCl), 0.01%
Add 0.27 milliliter of 1N HCl (Carolina) to 90 milliliters of distilled water. Add distilled water to a final volume of 100 milliliters. Or, beginning with 37% HCl (d 1.2), prepare a 1N solution by adding 8 milliliters of 37% HCl to 90 milliliters of distilled water. Add distilled water to a final volume of 100 milliliters.

Ringer's Solution, Frog
• 6.50 grams sodium chloride
• 0.14 gram potassium chloride
• 0.12 gram calcium chloride
• 0.20 gram sodium bicarbonate
Combine salts in flask and add distilled water to make a liter of solution.

Tubocurarine, 0.5%
Weigh out 0.125 gram of D-tubocurarine chloride. Add distilled water to make 25 milliliters. Label: Poison. Use extreme care. Note: Solution should be placed in a serum bottle (Aldrich) for use.

Laboratory Materials

Ordering information is based on a lab size of 24 students, working in groups of 4. A list of supply house addresses appears in Appendix A.

12 live frogs (*Rana pipiens*)
6 dissecting trays and dissection kits
Disposable gloves
12 dropper bottles of Ringer’s solution, frog
6 small ice baths
12 glass rods or probes
Thread
6 ring stands and 12 clamps
12 glass slides or glass plates
6 platinum electrodes
6 stimulators
6 pieces of filter paper
6 dropper bottles of 0.01% HCl
NaCl crystals
Advance Preparation

1. Order frogs to be delivered 2–3 days prior to the date of the lab, if animal maintenance facilities are limited. Frogs may be pithed just prior to the lab to save time (see Exercise 16A). Each group will need two to three frogs. Have disposable gloves available for handling the frogs.

2. Set out for each group dissecting instruments and tray, safety glasses, two dropper bottles of Ringer’s solution, frog (at room temperature and iced), a small ice bath, thread, several glass rods or glass probes, a laboratory stand and two clamps, several glass slides or glass plates, platinum electrode, stimulator, filter paper, a dropper bottle of 0.01% HCl solution, NaCl crystals, heat-resistant mitts or a slide holder, a Bunsen burner, absorbent cotton, and a disposable pipet and bulb. Have a small container of ether available. Note: Ether is highly flammable and should be used with care in a fume hood.

3. For Claude Bernard’s experiment, set out disposable gloves, a frog board, thread, and a 1-cc syringe with small-gauge needle. Have a small container of 0.5% tubocurarine solution available. Note: Tubocurarine is extremely toxic. Wear disposable gloves when handling the tubocurarine.

4. If oscilloscopes are to be used, set out nerve chambers, set up the oscilloscopes, and provide instructions. Allow time for the students to become familiar with the equipment.

Comments and Pitfalls

1. Be sure the muscle nerve preparation is kept moist and not touched by metal dissection equipment. Be careful that the nerve does not get stretched or damaged during dissection and setup.

2. Ether has a very low ignition temperature. Conduct ether experiments in a lab hood. If a hood is not available, do this part of the experiment with the windows open and after all Bunsen burners have been put out. Do not attempt to put out an ether fire with water; use a CO₂ extinguisher. Order ether in small amounts and do not store it for long periods of time. Keep it in an explosion-proof refrigerator when not in use.

3. When performing Claude Bernard’s experiment, students may need to increase the stimulus intensity when testing the muscles, as muscle threshold is generally higher than nerve threshold.

Answers to Pre-Lab Quiz (p. 269)

1. conductivity 5. a, gastrocnemius and sciatic
2. a, depolarization 6. false
3. b, K⁺ 7. oscilloscope
4. a, absolute refractory period

Answers to Activity Questions

Activity 1: Eliciting a Nerve Impulse (p. 272)

2. Repeated stimuli should cause the muscle to contract to tetanus.
3. Mechanical stimulation should result in muscle contraction.
4. HCl and NaCl should both cause muscle contraction.
5. Thermal stimulation also results in muscle contraction. These experiments indicate that a variety of stimuli can result in conduction of an impulse.

Activity 2: Inhibiting the Nerve Impulse (pp. 272–274)

2. (Ether) The anesthetized part of the nerve does not respond, but the unanesthetized area distal to the anesthetized area responds to the stimulus, resulting in muscle contraction.

3. (Ether) Ether exerts its blocking effect on the nerve fibers. The muscle was still able to contract when the nerve was stimulated beyond the anesthetized section.

4. (Curare) Eventually the nonligated muscle will show reduced or no contraction in response to the stimulus. Curare travels throughout the frog’s circulatory system and eventually finds its way to neuromuscular junctions. The left muscle is not affected because the ligation cuts off circulation to the tissue in that area. The right muscle does not respond to nervous stimulation because the curare blocks the acetylcholine receptor sites in the neuromuscular junction.

5. (Curare) Both gastrocnemius muscles should respond to direct stimulation, as direct stimulation of the muscle does not require action at the neuromuscular junction. The difference between the right and left nerve response is the result of the curare block to the acetylcholine receptor sites. When the muscles are stimulated directly, the stimulus bypasses the chemically gated channels that respond to acetylcholine. Curare acts at the neuromuscular junction by blocking the acetylcholine receptor sites. Note: It is beyond the scope of this lab to prove that the nerve to the right muscle is still conducting an impulse.

Activity 3: Visualizing the Action Potential with an Oscilloscope (pp. 274–275)

7. The amplitude of the compound action potential will increase until maximal amplitude is reached.

9. Reversing the nerve (distal to proximal) should still give a recording on the oscilloscope. Action potentials can travel in either direction along an axon. The usual “forward” direction of the action potential is determined by the site of origin of the signal and the refractory period that follows the passage of the action potential.
Neurophysiology of Nerve Impulses: Wet Lab

The Nerve Impulse

1. Match the terms in column B to the appropriate definition in column A.

<table>
<thead>
<tr>
<th>Column A</th>
<th>Column B</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. period of depolarization of the neuron membrane during which it cannot respond to a second stimulus</td>
<td>a. absolute refractory period</td>
</tr>
<tr>
<td>c. reversal of the resting potential due to an influx of sodium ions</td>
<td>b. action potential</td>
</tr>
<tr>
<td>e, d. period during which potassium ions diffuse out of the neuron due to a change in membrane permeability</td>
<td>c. depolarization</td>
</tr>
<tr>
<td>d. period of repolarization when only a strong stimulus will elicit an action potential</td>
<td>d. relative refractory period</td>
</tr>
<tr>
<td>f. mechanism in which ATP is used to move sodium out of the cell and potassium into the cell; restores the resting membrane voltage and intracellular ionic concentrations</td>
<td>e. repolarization</td>
</tr>
<tr>
<td></td>
<td>f. sodium-potassium pump</td>
</tr>
</tbody>
</table>

2. Define the term **depolarization**. An *increase in the membrane potential as the membrane becomes less negative inside, moving toward zero at a specific site on an axon or muscle cell membrane.*

How does an action potential differ from simple depolarization? An *action potential is a large transient depolarization event that is conducted along the membrane of a neuron or muscle cell. It does not decrease in strength with distance from the initial site of stimulation.*

3. Would a substance that decreases membrane permeability to sodium increase or decrease the probability of generating an action potential? Why? *Decrease; with stimulation, sodium enters the cell, causing depolarization, and anything that blocks sodium’s entry prevents the change in membrane potential toward zero that is necessary to generate an action potential.*

4. The diagram here represents a section of an axon. Complete the figure by illustrating an area of resting membrane potential, an area of depolarization, and local current flow. Indicate the direction of the depolarization wave.
Physiology of Nerve Fibers: Eliciting and Inhibiting the Nerve Impulse

5. Respond appropriately to each question posed below. Insert your responses in the corresponding numbered blanks to the right.

1–3. Name three types of stimuli that resulted in action potential generation in the sciatic nerve of the frog.

4. Which of the stimuli resulted in the most effective nerve stimulation?

5. Which of the stimuli employed in that experiment might represent types of stimuli to which nerves in the human body are subjected?

6. What is the usual mode of stimulus transfer in neuron-to-neuron interactions?

7. Since the action potentials themselves were not visualized with an oscilloscope during this initial set of experiments, how did you recognize that impulses were being transmitted?

6. How did the site of action of ether and tubocurarine differ? Ether exerts its blocking effect on the nerve, while

tubocurarine blocks the ACh receptor site of the muscle.

In the curare experiment, why was one of the frog’s legs ligated? As a control to prevent the tubocurarine (in the blood) from reaching that muscle.

Visualizing the Action Potential with an Oscilloscope

7. Explain why the amplitude of the compound action potential recorded from the frog sciatic nerve increased when the voltage of the stimulus was increased above the threshold value. More and more muscle fibers were being recruited (multiple motor unit summation).

8. What was the effect of cold temperature (flooding the nerve with iced Ringer’s solution) on the functioning of the sciatic nerve tested? Cold temperature increases the threshold for excitation and may result in complete inexcitability of the nerve.

9. When the nerve was reversed in position, was the impulse conducted in the opposite direction? Yes

How can this result be reconciled with the concept of one-way conduction in neurons? Action potentials can travel in either direction along an axon. The usual “forward” direction of the action potential is determined by the site of origin of the signal and the refractory period that follows the passage of the action potential.
Gross Anatomy of the Brain and Cranial Nerves

**Time Allotment:** 2 hours.

**Multimedia Resources:** See Appendix B for Guide to Multimedia Resource Distributors.

- *A.D.A.M.® Interactive Anatomy 4.0* (AIA: CD-ROM, DVD)
- *Anatomy of the Human Brain* (FHS: 35 minutes, VHS, DVD, 3-year streaming webcast)
- *Animated Neuroscience and the Action of Nicotine, Cocaine, and Marijuana in the Brain* (FHS: 25 minutes, VHS, DVD, 3-year streaming webcast)
- *The Brain* (FHS: 20 minutes, VHS, DVD, 3-year streaming webcast)
- *The Brain* (NIMCO: 30 minutes, VHS, DVD)
- *Brain and Nervous System: Your Information Superhighway* (FHS: 31 minutes, VHS, DVD, 3-year streaming webcast)
- *The Human Brain in Situ* (FHS: 19 minutes, VHS, DVD, 3-year streaming webcast)
- *The Human Nervous System: Human Brain and Cranial Nerves Videotape* (BC: 28 minutes, VHS)
- *Practice Anatomy Lab™ 2.0* (PAL) (BC: CD-ROM, Website)
- *Sheep Brain Dissection* (WNS: 22 minutes, VHS, DVD)

**Laboratory Materials**

*Ordering information is based on a lab size of 24 students, working in groups of 4. A list of supply house addresses appears in Appendix A.*

<table>
<thead>
<tr>
<th>Item</th>
<th>Quantity</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Human brain models (dissectable)</td>
<td>1</td>
<td>12 dissecting kits</td>
</tr>
<tr>
<td>3-D model of ventricles</td>
<td>1</td>
<td>Disposable gloves</td>
</tr>
<tr>
<td>Preserved human brains (if available)</td>
<td>1</td>
<td>24 pairs of safety glasses</td>
</tr>
<tr>
<td>Coronally sectioned human brain slice (if available)</td>
<td>1</td>
<td>Soap, sponges, and disinfectant</td>
</tr>
<tr>
<td>12 preserved sheep brains with meninges and cranial nerves intact</td>
<td>1</td>
<td>Materials as needed for cranial nerves testing: aromatic oils (e.g., vanilla and cloves), eye chart, ophthalmoscope, penlight, safety pin, blunt probes (hot and cold), cotton, ammonia, tuning fork, tongue depressor, and solutions of 10% sugar, 10% salt, vinegar (1% acetic acid), and 0.1% quinine.</td>
</tr>
<tr>
<td>12 dissecting trays</td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>

**Advance Preparation**

1. Make arrangements for appropriate storage, disposal, and cleanup of dissection materials. Check with the Department of Health or the Department of Environmental Protection, or their counterparts, for state regulations.

2. Designate a disposal container for organic debris, and a dishwashing area with hot soapy water, sponges, and a lab disinfectant such as 10% bleach solution or Wavicide-01 (Carolina) for washing down the lab benches.

3. Set out disposable gloves and safety glasses.

4. Set out dissectible human brain models (ideally one per group), and preserved human brains.

5. Set out dissection kits, dissection trays, and sheep brains with meninges and cranial nerves intact.
6. For testing cranial nerve function, set out dropper bottles of oil of cloves and vanilla, eye chart, ophthalmoscope, penlight, safety pins, blunt probes (hot and cold), cotton, salty, sweet, sour, and bitter solutions, cotton swabs, ammonia, tuning forks, and tongue depressors. Set out autoclave bag for disposables.

Comments and Pitfalls
1. Students who are not careful readers confuse or do not distinguish between cerebellar and cerebral.
2. Hasty removal of the meninges removes the pituitary gland before its connection to the brain by the infundibulum can be established; occasionally even the optic chiasma is lost. Encourage the students to go slowly and use the scalpel sparingly.
3. The arachnoid meninx may be hard to identify, as it is usually poorly preserved.

Answers to Pre-Lab Quiz (pp. 279–280)
1. central nervous system
2. cerebral hemispheres
3. false
4. b, diencephalon
5. medulla oblongata
6. b, cerebellum
7. gray matter
8. b, meninges
9. false
10. Twelve

Answers to Activity and Dissection Questions
Activity 3: Identifying and Testing the Cranial Nerves (pp. 289–291)
3. The trigeminal ganglion, associated with the trigeminal nerve (CN V), is located between the pons and the greater wing of the sphenoid bone. The geniculate ganglion, associated with the facial nerve (CN VII), is in the inner ear cavity. The inferior ganglion, associated with the glossopharyngeal nerve (CN IX), is near the parotid salivary gland. The superior ganglion, associated with the glossopharyngeal nerve (CN IX), is just external to the jugular foramen. The spiral ganglion, associated with the vestibulocochlear nerve (CN VIII), is in the cochlea. The vestibular ganglion, associated with the vestibulocochlear nerve (CN VIII), is in the inner ear.

Dissection: The Sheep Brain (pp. 292–296)
1. The sheep’s cerebral hemispheres are smaller than those of the human.

Ventral Structures
1. The olfactory bulbs are larger in the sheep. The sense of smell is more important to sheep than it is to humans for both protection and locating food.

Dorsal Structures
1. The sheep cerebral fissures are not as deep.
2. The falx cerebelli is not present in the sheep.
4. The corpora quadrigemina are reflex centers for visual and auditory stimuli.

Internal Structures
2. The sheep fornix is large in relation to the size of the sheep’s brain when compared with the fornix of the human brain. The fornix links regions of the limbic system, which provides strong emotional response to odors, among other things. Sheep have a more acute sense of smell than humans and rely more on smell to alert them to danger, food sources, etc.
Gross Anatomy of the Brain and Cranial Nerves

The Human Brain

1. Match the letters on the diagram of the human brain (right lateral view) to the appropriate terms listed at the left.

- **h** 1. frontal lobe
- **b** 2. parietal lobe
- **j** 3. temporal lobe
- **f** 4. precentral gyrus
- **c** 5. parieto-occipital sulcus
- **a** 6. postcentral gyrus
- **i** 7. lateral sulcus
- **g** 8. central sulcus
- **e** 9. cerebellum
- **k** 12. pons

2. In which of the cerebral lobes are the following functional areas found?

- Auditory cortex: **temporal**
- Olfactory cortex: **temporal**
- Primary motor cortex: **frontal**
- Visual cortex: **occipital**
- Primary sensory cortex: **parietal**
- Broca’s area: **frontal**

3. Which of the following structures are not part of the brain stem? (Circle the appropriate response or responses.)

   - Cerebral hemispheres
   - Pons
   - Midbrain
   - Cerebellum
   - Medulla
   - Diencephalon

4. Complete the following statements by writing the proper word or phrase on the corresponding blanks at the right.

   - A(n) **1. gyrus** is an elevated ridge of cerebral tissue. The convolutions seen in the cerebrum are important because they increase the **2. surface area**. Gray matter is composed of **3. neuron cell bodies**. White matter is composed of **4. myelinated fibers**. A fiber tract that provides for communication between different parts of the same cerebral hemisphere is called a(n) **5. association tract**, whereas one that carries impulses from the cerebrum to lower CNS areas is called a(n) **6. projection** tract. The lentiform nucleus along with the caudate nuclei are collectively called the **7. basal ganglia (corpus striatum)**.
5. Identify the structures on the following sagittal view of the human brain stem and diencephalon by matching the numbered areas to the proper terms in the list.

<table>
<thead>
<tr>
<th>Number</th>
<th>Term</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>(small part of) cerebral hemisphere</td>
</tr>
<tr>
<td>2</td>
<td>corpus callosum</td>
</tr>
<tr>
<td>3</td>
<td>fornix</td>
</tr>
<tr>
<td>4</td>
<td>hypothalamus</td>
</tr>
<tr>
<td>5</td>
<td>intermediate mass</td>
</tr>
<tr>
<td>6</td>
<td>mammillary bodies</td>
</tr>
<tr>
<td>7</td>
<td>n. optic chiasma</td>
</tr>
<tr>
<td>8</td>
<td>p. pituitary gland</td>
</tr>
<tr>
<td>9</td>
<td>r. septum pellucidum</td>
</tr>
<tr>
<td>10</td>
<td>q. pons</td>
</tr>
<tr>
<td>11</td>
<td>s. thalamus</td>
</tr>
</tbody>
</table>

6. Using the terms from question 5, match the appropriate structures with the descriptions given below.

<table>
<thead>
<tr>
<th>Number</th>
<th>Term</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>site of regulation of body temperature and water balance; most important autonomic center</td>
</tr>
<tr>
<td>2</td>
<td>consciousness depends on the function of this part of the brain</td>
</tr>
<tr>
<td>3</td>
<td>located in the midbrain; contains reflex centers for vision and audition</td>
</tr>
<tr>
<td>4</td>
<td>responsible for regulation of posture and coordination of complex muscular movements</td>
</tr>
<tr>
<td>5</td>
<td>important synapse site for afferent fibers traveling to the sensory cortex</td>
</tr>
<tr>
<td>6</td>
<td>contains autonomic centers regulating blood pressure, heart rate, and respiratory rhythm, as well as coughing, sneezing, and swallowing centers</td>
</tr>
<tr>
<td>7</td>
<td>large commissure connecting the cerebral hemispheres</td>
</tr>
<tr>
<td>8</td>
<td>fiber tract involved with olfaction</td>
</tr>
<tr>
<td>9</td>
<td>connects the third and fourth ventricles</td>
</tr>
<tr>
<td>10</td>
<td>encloses the third ventricle</td>
</tr>
</tbody>
</table>
7. Embryologically, the brain arises from the rostral end of a tubelike structure that quickly becomes divided into three major regions. Groups of structures that develop from the embryonic brain are listed below. Designate the embryonic origin of each group as the hindbrain, midbrain, or forebrain.

- **forebrain**
  1. the diencephalon, including the thalamus, optic chiasma, and hypothalamus

- **hindbrain**
  2. the medulla, pons, and cerebellum

- **forebrain**
  3. the cerebral hemispheres

8. What is the function of the basal ganglia? *They are involved in the regulation, modulation, and refinement of voluntary motor activity.*

9. What is the corpus striatum, and how is it related to the fibers of the internal capsule? *The fibers of the internal capsule pass between the diencephalon and the basal ganglia and through parts of the basal ganglia, giving them a striped appearance.* Therefore, the basal ganglia are referred to as the corpus striatum, or “striped body.”

10. A brain hemorrhage within the region of the right internal capsule results in paralysis of the left side of the body. Explain why the left side (rather than the right side) is affected. *Because most of the motor fibers cross over to the opposite side at the level of the medulla oblongata.*

11. Explain why trauma to the base of the brain is often much more dangerous than trauma to the frontal lobes. (Hint: Think about the relative functioning of the cerebral hemispheres and the brain stem structures. Which contain centers more vital to life?)

*Trauma to the base of the brain might damage the medulla oblongata, which contains vital respiratory, cardiac, and vasomotor centers. Also, the reticular activating system, which helps to maintain consciousness, spans the length of the brain stem.*

12. In “split brain” experiments, the main commissure connecting the cerebral hemispheres is cut. First, name this commissure. *Corpus callosum*

Then, describe what results (in terms of behavior) can be anticipated in such experiments. (Use an appropriate reference if you need help with this one!)

*The disconnection of verbal naming and mathematical functions of the left side of the brain from the spatial recognition abilities of the right side (e.g., associating names with faces); some patients report that they no longer dream; isolated patients are mute for a brief time after surgery and have difficulty controlling the left side of the body. Tasks that require coordination of the right and left sides of body (using a manual can opener, riding a bike, tying your shoes) are very difficult. They require great visual attention and have to be relearned.*
Meninges of the Brain

13. Identify the meningeal (or associated) structures described below:

- **dura mater**
  - outermost meninx covering the brain; composed of tough fibrous connective tissue

- **pia mater**
  - innermost meninx covering the brain; delicate and highly vascular

- **arachnoid villi**
  - structures instrumental in returning cerebrospinal fluid to the venous blood in the dural sinuses

- **choroid plexus**
  - structure that forms the cerebrospinal fluid

- **arachnoid mater**
  - middle meninx; like a cobweb in structure

- **dura mater**
  - its outer layer forms the periosteum of the skull

- **falx cerebri**
  - a dural fold that attaches the cerebrum to the crista galli of the skull

- **tentorium cerebelli**
  - a dural fold separating the cerebrum from the cerebellum

Cerebrospinal Fluid

14. Label the structures involved with circulation of cerebrospinal fluid on the accompanying diagram.

Cerebrospinal fluid flows from the fourth ventricle into the central canal of the spinal cord and the (1) space surrounding the brain and spinal cord. From this space it drains through the (2) into the (3).

Add arrows to the figure above to indicate the flow of cerebrospinal fluid from its formation in the lateral ventricles to the site of its exit from the fourth ventricle. Then fill in the blanks in the following paragraph.

Cerebrospinal fluid flows from the fourth ventricle into the central canal of the spinal cord and the (1) space surrounding the brain and spinal cord. From this space it drains through the (2) into the (3).

1. **subarachnoid**
2. **arachnoid villi**
3. **dural sinuses**
Cranial Nerves

15. Using the terms below, correctly identify all structures indicated by leader lines on the diagram.

a. abducens nerve (VI)  j. longitudinal fissure  s. pituitary gland
b. accessory nerve (XI)  k. mammillary body  t. pons
c. cerebellum  l. medulla oblongata  u. spinal cord
d. cerebral peduncle  m. oculomotor nerve (III)  v. temporal lobe of cerebral hemisphere
e. decussation of the pyramids  n. olfactory bulb  w. trigeminal nerve (V)
f. facial nerve (VII)  o. olfactory tract  x. trochlear nerve (IV)
g. frontal lobe of cerebral hemisphere  p. optic chiasma  y. vagus nerve (X)
h. glossopharyngeal nerve (IX)  q. optic nerve (II)  z. vestibulocochlear nerve (VIII)
i. hypoglossal nerve (XII)  r. optic tract
16. Provide the name and number of the cranial nerves involved in each of the following activities, sensations, or disorders.

1. rotating the head
   - accessory (XI)
   - vestibulocochlear (VIII)
   - facial (VII)

2. smelling a flower
   - olfactory (I)

3. raising the eyelids; pupillary constriction
   - oculomotor (III)

4. slows the heart; increases motility of the digestive tract
   - vagus (X)

5. involved in Bell’s palsy (facial paralysis)
   - trigeminal (V)

6. chewing food
   - facial (VII)

7. listening to music; seasickness
   - vestibulocochlear (VIII)

8. secretion of saliva; tasting well-seasoned food
   - lingual (II)

9. involved in “rolling” the eyes (three nerves—provide numbers only)
   - III, IV, VI

10. feeling a toothache
    - trigeminal (V)

11. reading the newspaper
    - optic (II)

12. purely sensory in function (three nerves—provide numbers only)
    - I, II, VIII

Dissection of the Sheep Brain

17. In your own words, describe the firmness and texture of the sheep brain tissue as observed when cutting into it.

- Very soft; much like thickened oatmeal in consistency.

Because formalin hardens all tissue, what conclusions might you draw about the firmness and texture of living brain tissue?

- It must be very soft and fragile.

18. When comparing human and sheep brains, you observe some profound differences between them. Record your observations in the chart below.

<table>
<thead>
<tr>
<th>Structure</th>
<th>Human</th>
<th>Sheep</th>
</tr>
</thead>
<tbody>
<tr>
<td>Olfactory bulb</td>
<td>Smaller</td>
<td>Relatively much larger</td>
</tr>
<tr>
<td>Pons/medulla relationship</td>
<td>Pons large; anterior to medulla; medulla relatively smaller</td>
<td>Pons small; anterior to medulla; medulla relatively large</td>
</tr>
<tr>
<td>Location of cranial nerve III</td>
<td>Medial; located in the fold of the peduncle</td>
<td>Medial; located on top of the peduncle</td>
</tr>
<tr>
<td>Mammillary body</td>
<td>Two; posterior to optic chiasma</td>
<td>One relatively large one; posterior to optic chiasma</td>
</tr>
<tr>
<td>Corpus callosum</td>
<td>Thick bundle in human; fornix is thinner than corpus callosum</td>
<td>Relatively thin in sheep; fornix is the same size or slightly thicker than the corpus callosum</td>
</tr>
<tr>
<td>Intermediate mass of thalamus</td>
<td>Smaller</td>
<td>Relatively larger</td>
</tr>
<tr>
<td>Relative size of superior and inferior colliculi</td>
<td>Smaller</td>
<td>Larger, especially the superior colliculi</td>
</tr>
<tr>
<td>Pineal gland</td>
<td>Smaller</td>
<td>Relatively larger</td>
</tr>
</tbody>
</table>
Electroencephalography

Time Allotment: 30 minutes for each subject. Allow additional time if students are not acquainted with the recording equipment.

Laboratory Materials

Ordering information is based on a lab size of 24 students, working in groups of 4. A list of supply house addresses appears in Appendix A.

- 6 oscilloscopes and EEG lead-selector boxes or 6 physiographs and high-gain preamplifiers
- 6 containers of electrode gel
- 6 sets of EEG electrodes and leads
- 6 containers of collodion gel or long elastic EEG straps
- Cot (if available) or pillow
- BIOPAC® apparatus: BIOPAC® MP36 (or MP35/30) data acquisition unit, PC or Mac computer, BIOPAC® Student Lab Software, electrode lead set, disposable vinyl electrodes, Lycra™ swim cap (such as Speedo™ brand) or supportive wrap (such as 3M™ Coban™ Self-Adhering Support Wrap), a cot or lab bench, and pillow

Advance Preparation

1. Prepare a set of instructions for the particular recording equipment you will be using. If you are using a physiograph or BIOPAC®, students may be familiar with it from Exercise 16 A. Be sure to include instructions on correct calibration of the equipment so that meaningful recordings can be made.
2. Set out recording equipment. This can be either an oscilloscope and EEG selector box, a physiograph and high-gain preamplifier, or a BIOPAC® data acquisition unit.
3. Prepare a quiet, dimly lit space with a cot. Have electrodes, electrode leads, electrode gel, and collodion gel available. Long elastic EEG straps or adhesive bandages may be used in place of the collodion.

Comments and Pitfalls

1. It is very important to choose subjects who can relax.
2. Clean the area where the electrode will be attached to provide a better contact.

Answers to Pre-Lab Quiz (p. 303)

1. a, electrical activity of the brain
2. Beta waves
3. true
4. a, the earlobe
5. b, breathe rapidly
Answers to Activity Questions

Activity 1: Observing Brain Wave Patterns Using an Oscilloscope or Physiograph (pp. 304–305)

5. The frequency of the brain waves should increase and the amplitude should decrease. It may be characterized as a beta rhythm if the amplitude decreases and the frequency is in the range of 15 to 30 cycles per second.

6. The frequency of the brain waves should increase to become beta waves.

7. Hyperventilation results in alkalosis, which causes overexcitability of the nervous system. The tracings may resemble those of an epileptic seizure.

Activity 2: Electroencephalography Using BIOPAC® (pp. 308–309)

17. The alpha rhythm is observed when the subject is relaxed with the eyes closed, and it usually diminishes when the eyes are open.

The beta rhythm is usually most pronounced when the eyes are open and attentive, or when the subject is performing mental tasks.

The alpha waveforms are greater during the segments recorded when the subject’s eyes are closed; the beta waveforms are slightly more pronounced during the signal recorded when the subject’s eyes are opened as well as during the segment when the subject’s eyes are reclosed. The alpha signal appears more varied than the beta signal.

The delta and theta rhythms are the most varied, especially under these subject conditions. They are most easily observed when the subject makes the transition from mild sleep to deep sleep. It is unlikely that a significant difference can be discerned under these conditions.
Electroencephalography

Brain Wave Patterns and the Electroencephalogram

1. Define EEG. A record of the electrical activity of the brain.

2. Identify the type of brain wave pattern described in each statement below.
   - delta: below 4 Hz; slow, large waves; normally seen during deep sleep
   - alpha: rhythm generally apparent when an individual is in a relaxed, nonattentive state with the eyes closed
   - beta: correlated to the alert state; usually about 15 to 30 Hz

3. What is meant by the term alpha block? A change from an alpha rhythm to increased frequency waves as a result of increased alertness, mental concentration, excitement, etc.

4. List at least four types of brain lesions that may be determined by EEG studies. Epileptic foci, infections, tumors, abscesses, blood clots

5. What is the common result of hypoactivity or hyperactivity of the brain neurons? Unconsciousness

Observing Brain Wave Patterns

6. How was alpha block demonstrated in the laboratory experiment? By clapping your hands, which caught the attention of the subject.

7. What was the effect of mental concentration on the brain wave pattern? (Should have) increased the frequency of the brain waves from the level of the alpha rhythm.

8. What effect on the brain wave pattern did hyperventilation have? Produced a fast, irregular pattern.
Electroencephalography Using BIOPAC®

9. Observe the average frequency of the waves you measured for each rhythm. Did the calculated average for each fall within the specified range indicated in the introduction to encephalograms?

*The average should fall within the normal range.*

10. Suggest the possible advantages and disadvantages of using electroencephalography in a clinical setting.

*EEG is a useful tool in the clinical setting to assess cerebral activity in generalized brain regions. Because EEG is indirectly recording, via the scalp, the activity of millions of nerve cells simultaneously, it is less effective in assessing the function of very specific regions of the brain.*
Spinal Cord, Spinal Nerves, and the Autonomic Nervous System

**Time Allotment:** 1 1/2 hours (1 hour can be completed outside of lab).

**Multimedia Resources:** See Appendix B for Guide to Multimedia Resource Distributors. See Exercise 6A for histology listings.

*Brain and Nervous System: Your Information Superhighway* (FHS: 31 minutes, VHS, DVD, 3-year streaming webcast)

*The Human Nervous System: The Spinal Cord and Nerves Videotape* (BC: 28 minutes, VHS)

*The Peripheral Nervous System* (IM: 29 minutes, VHS)

*Practice Anatomy Lab™ 2.0* (BC: CD-ROM, Website)

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**Laboratory Materials**

*Ordering information is based on a lab size of 24 students, working in groups of 4. A list of supply house addresses appears in Appendix A.*

<table>
<thead>
<tr>
<th>Spinal cord model (cross section)</th>
<th>12–24 stereomicroscopes</th>
<th>lead set, disposable vinyl electrodes, conduction gel, and nine 8 1/2 × 11-inch sheets of paper of different colors (white, black, red, blue, green, yellow, orange, brown, and purple)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3-D laboratory charts or models of spinal cord, spinal nerves, and sympathetic chain</td>
<td>24 compound microscopes, lens paper, lens cleaning solution</td>
<td></td>
</tr>
<tr>
<td>24 red pencils</td>
<td>24 slides of spinal cord (cross section)</td>
<td></td>
</tr>
<tr>
<td>24 blue pencils</td>
<td>Disposable gloves</td>
<td></td>
</tr>
<tr>
<td>12–24 preserved spinal cord sections with meninges and roots intact (cow, or maybe saved from sheep brain dissection in Exercise 19)</td>
<td>24 pairs of safety glasses</td>
<td></td>
</tr>
<tr>
<td>12–24 dissecting trays and dissecting kits</td>
<td>BIOPAC® MP36 (or MP35/30) data acquisition unit, PC or Mac computer, BIOPAC® Student Lab Software, respiratory transducer belt, GSR finger leads, electrode</td>
<td></td>
</tr>
</tbody>
</table>

---

**Advance Preparation**

1. Make arrangements for appropriate storage, disposal, and cleanup of dissection materials. Check with the Department of Health or the Department of Environmental Protection, or their counterparts, for state regulations.
2. Designate a disposal container for organic debris, and a dishwashing area with hot soapy water and sponges. Provide a lab disinfectant such as Wavicide-01 (Carolina) for washing down the lab benches.
3. Set out disposable gloves and safety glasses.
4. Set out dissection tools, trays, and spinal cord sections from cow specimens or saved from the brain dissection.
5. Set out charts and models of the spinal cord, and red and blue pencils.
6. Set out slides of spinal cord cross section, lens paper, and lens cleaning solution.
7. Set out dissecting microscopes. Have compound microscopes available.
8. Check to be sure that the diagram of the spinal tracts in the text you are using is similar to that in Figure 21.3. If there are differences, decide which you will use and make the appropriate adjustments to the assignment if necessary.
9. Set out equipment and materials for the BIOPAC® activity. Introduce your students to the basic features of the equipment prior to beginning the lab activity.

Comments and Pitfalls
1. Students may have trouble distinguishing between gray and white matter in the spinal cord dissection. A drop or two of methylene blue stain with a water rinse may help.

Answers to Pre-Lab Quiz (pp. 313–314)
1. a, conus medularis 6. true
2. c, 31 7. c, plexuses
3. gray 8. b, brachial
4. false 9. a, autonomic
5. sensory 10. d, sympathetic

Answers to Activity Questions
Activity 2: Identifying Spinal Cord Tracts (p. 317)
Labels for Figure 21.3

Left (top to bottom) - Ascending Tracts
Dorsal columns
  Fasciculus gracilis
Dorsal columns
  Fasciculus cuneatus
Dorsal spinocerebellar tract
Ventral spinocerebellar tract
Lateral spinothalamic tract
Ventral spinothalamic tract

Right (top to bottom) - Descending Tracts
Lateral reticulospinal tract
  Lateral corticospinal tract
Rubrospinal tract
  Medial reticulospinal tract
Ventral corticospinal tract
Vestibulospinal tract
Tectospinal tract

Dorsal columns - joint, muscle position sense, fine touch localization (fasciculus gracilis: lower trunk and limbs, fasciculus cuneatus: neck, upper trunk, and limbs)
Dorsal spinocerebellar - proprioception
Ventral spinocerebellar - proprioception
Lateral spinothalamic - pain and temperature
Ventral spinothalamic - pressure and crude touch
Lateral corticospinal - cross in medulla, stimuli to skeletal muscles (pyramidal)
Ventral corticospinal - cross at level of synapse, stimuli to skeletal muscles (pyramidal)
Rubrospinal - some upper limb movement
Tectospinal - mediate head movements toward visual targets
Vestibulospinal - posture and balance
Medial reticulospinal - muscle tone and visceral motor functions
Lateral reticulospinal - muscle tone and visceral motor functions

**Dissection: Spinal Cord (pp. 317–318)**

1. The third meninx is the pia mater, which adheres closely to the surface of the brain and spinal cord.
2. The dorsal horns are more tapered than the ventral horns.
3. The central canal is more oval than circular. It is lined with ependymal cells. In a living specimen it contains cerebrospinal fluid. Students may observe that the dorsal medial sulcus touches the dorsal gray commissure (gray matter) of the spinal cord. Neuron cell bodies can be seen in the ventral horn of the spinal cord. The large neurons are motor neurons; others are interneurons.

**Activity 5: Comparing Sympathetic and Parasympathetic Effects (p. 328)**

<table>
<thead>
<tr>
<th>Organ or function</th>
<th>Parasympathetic effect</th>
<th>Sympathetic effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heart</td>
<td><em>Decreases rate</em></td>
<td><em>Increases rate and force</em></td>
</tr>
<tr>
<td>Bronchioles of lungs</td>
<td><em>Constricts</em></td>
<td><em>Dilates</em></td>
</tr>
<tr>
<td>Digestive tract activity</td>
<td><em>Increases motility; secretion</em></td>
<td><em>Decreases activity; closes sphincters</em></td>
</tr>
<tr>
<td>Urinary bladder</td>
<td><em>Contracts wall; relaxes sphincter</em></td>
<td><em>Relaxes wall; constricts sphincter</em></td>
</tr>
<tr>
<td>Iris of the eye</td>
<td><em>Constricts pupil</em></td>
<td><em>Dilates pupil</em></td>
</tr>
<tr>
<td>Blood vessels (most)</td>
<td><em>Little or no effect</em></td>
<td><em>Constricts most vessels</em></td>
</tr>
<tr>
<td>Penis/clitoris</td>
<td><em>Causes erection</em></td>
<td><em>Causes ejaculation</em></td>
</tr>
<tr>
<td>Sweat glands</td>
<td><em>No effect</em></td>
<td><em>Stimulates secretion</em></td>
</tr>
<tr>
<td>Adrenal medulla</td>
<td><em>No effect</em></td>
<td><em>Stimulates medulla to secrete epinephrine and norepinephrine</em></td>
</tr>
<tr>
<td>Pancreas</td>
<td><em>Stimulates insulin secretion</em></td>
<td><em>Decreases insulin secretion</em></td>
</tr>
</tbody>
</table>

**Activity 6: Exploring the Galvanic Skin Response within a Polygraph Using BIOPAC® (pp. 328–334)**

12. It is likely that the most significant changes will be observed when the face is touched.

There may or may not be a significant change after each color presentation.

The responses will vary from student to student depending on the affective nature of the question.

Colors can affect mood that can be observed through a subsequent change in autonomic activity.

Specific questions might elicit an emotional response that can be observed through a subsequent change in autonomic activity.
Spinal Cord, Spinal Nerves, and the Autonomic Nervous System

Anatomy of the Spinal Cord

1. Match each anatomical term in the key to the descriptions given below.

Key: a. cauda equina b. conus medullaris c. filum terminale d. foramen magnum

d 1. most superior boundary of the spinal cord
c 2. meningeal extension beyond the spinal cord terminus
b 3. spinal cord terminus
a 4. collection of spinal nerves traveling in the vertebral canal below the terminus of the spinal cord

2. Match the key letters on the diagram with the following terms.

k 1. arachnoid mater n 6. dorsal root of spinal nerve f 11. spinal nerve
a 2. central canal j 7. dura mater m 12. ventral horn
b 3. dorsal horn i 8. gray commissure p 13. ventral ramus of spinal nerve
h 4. dorsal ramus of spinal nerve d 9. lateral horn e 14. ventral root of spinal nerve
f 5. dorsal root ganglion l 10. pia mater b 15. white matter
3. Choose the proper answer from the following key to respond to the descriptions relating to spinal cord anatomy.

Key: a. sensory  b. motor  c. both sensory and motor  d. interneurons

\[ \begin{align*}
&d. \quad 1. \text{ neuron type found in dorsal horn} \\
&b. \quad 4. \text{ fiber type in ventral root} \\
&b. \quad 2. \text{ neuron type found in ventral horn} \\
&a. \quad 5. \text{ fiber type in dorsal root} \\
&a. \quad 3. \text{ neuron type in dorsal root ganglion} \\
&c. \quad 6. \text{ fiber type in spinal nerve}
\end{align*} \]

4. Where in the vertebral column is a lumbar puncture generally done?  
Between L₃ and L₄ or L₄ and L₅. Why is this the site of choice?  
The spinal cord ends at the level of L₄; thus there is little chance of damaging it below that level.

5. The spinal cord is enlarged in two regions, the cervical and the lumbar regions. What is the significance of these enlargements?  
Nerves serving the limbs issue from these regions of the spinal cord.

6. How does the position of the gray and white matter differ in the spinal cord and the cerebral hemispheres?  
In the spinal cord, the white matter surrounds the gray matter. In the cerebral hemisphere, there is an outer “rind” of gray matter and deep to that is white matter with a few scattered islands of gray matter.

7. From the key, choose the name of the tract that might be damaged when the following conditions are observed. (More than one choice may apply.)

<table>
<thead>
<tr>
<th></th>
<th>1. uncoordinated movement</th>
<th>2. lack of voluntary movement</th>
<th>3. tremors, jerky movements</th>
<th>4. diminished pain perception</th>
<th>5. diminished sense of touch</th>
</tr>
</thead>
<tbody>
<tr>
<td>d, e, f</td>
<td>a. dorsal columns (fasciculus cuneatus and fasciculus gracilis)</td>
<td>b. lateral corticospinal tract</td>
<td>c. ventral corticospinal tract</td>
<td>d. tectospinal tract</td>
<td>e. rubrospinal tract</td>
</tr>
<tr>
<td>b, c</td>
<td>f. vestibulospinal tract</td>
<td>g. lateral spinothalamic tract</td>
<td>h. ventral spinothalamic tract</td>
<td>i. dorsal spinocerebellar tract</td>
<td>j. ventral spinocerebellar tract</td>
</tr>
</tbody>
</table>

Dissection of the Spinal Cord

8. Compare and contrast the meninges of the spinal cord and the brain.  
Both the spinal cord and the brain have three meninges: pia mater, arachnoid mater, and dura mater. In the brain the dura mater has two layers—periosteal and meningeal. The spinal cord has only the meningeal layer. In the spinal cord there exists an epidural space between the vertebral bone and the dura, but the dura of the brain is tightly adhered to the skull.

9. How can you distinguish between the dorsal and ventral horns?  
The ventral horns are wider than the dorsal horns. The dorsal horns extend closer to the edge of the spinal cord.
Spinal Nerves and Nerve Plexuses

10. In the human, there are 31 pairs of spinal nerves, named according to the region of the vertebral column from which they issue. The spinal nerves are named below. Indicate how they are numbered.

- cervical nerves \( C_1 - C_8 \)
- lumbar nerves \( L_1 - L_5 \)
- thoracic nerves \( T_1 - T_{12} \)
- sacral nerves \( S_1 - S_5 \)

11. The ventral rami of spinal nerves \( C_1 \) through \( T_1 \) and \( T_{12} \) through \( S_4 \) take part in forming _plexuses_, which serve the _limbs and anterior trunk_ of the body. The ventral rami of \( T_2 \) through \( T_{12} \) run between the ribs to serve the _intercostal muscles_. The dorsal rami of the spinal nerves serve _the posterior body trunk_.

12. What would happen if the following structures were damaged or transected? (Use the key choices for responses.)

   _Key:_  
   a. loss of motor function  
   b. loss of sensory function  
   c. loss of both motor and sensory function

   - \( b \) 1. dorsal root of a spinal nerve  
   - \( a \) 2. ventral root of a spinal nerve  
   - \( c \) 3. ventral ramus of a spinal nerve

13. Define _plexus_. _A complex network of joining and diverging nerves._

14. Name the major nerves that serve the following body areas.

   - _cervical_  
     1. head, neck, shoulders (name plexus only)
   - _phrenic_  
     2. diaphragm
   - _sciatic_  
     3. posterior thigh
   - _common fibular, tibial, sural, medial and lateral plantar_  
     4. leg and foot (name two)
   - _median, ulnar_  
     5. anterior forearm muscles (name two)
   - _radial, musculocutaneous_  
     6. arm muscles (name two)
   - _lumbar_  
     7. abdominal wall (name plexus only)
   - _femoral_  
     8. anterior thigh
   - _ulnar_  
     9. medial side of the hand

The Autonomic Nervous System

15. For the most part, sympathetic and parasympathetic fibers serve the same organs and structures. How can they exert antagonistic effects? (After all, nerve impulses are nerve impulses—aren’t they?)

   _They release different neurotransmitters, which bind to different receptors._
16. Name three structures that receive sympathetic but not parasympathetic innervation.

Adrenal glands, arrector pili muscles, and sweat glands. (Most blood vessels receive only sympathetic innervations.)

17. A pelvic splanchnic nerve contains (circle one):

a. preganglionic sympathetic fibers  
   c. preganglionic parasympathetic fibers
b. postganglionic sympathetic fibers    
   d. postganglionic parasympathetic fibers

18. The following chart states a number of conditions. Use a check mark to show which division of the autonomic nervous system is involved in each.

<table>
<thead>
<tr>
<th>Sympathetic division</th>
<th>Condition</th>
<th>Parasympathetic division</th>
</tr>
</thead>
<tbody>
<tr>
<td>✓ (ganglionic fibers)</td>
<td>Secreteres norepinephrine; adrenergic fibers</td>
<td>✓ (preganglionic and ganglionic fibers)</td>
</tr>
<tr>
<td>✓ (preganglionic fibers)</td>
<td>Secreteres acetylcholine; cholinergic fibers</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>Long preganglionic axon; short postganglionic axon</td>
<td>✓</td>
</tr>
<tr>
<td>✓</td>
<td>Short preganglionic axon; long postganglionic axon</td>
<td>✓</td>
</tr>
<tr>
<td>✓</td>
<td>Arises from cranial and sacral nerves</td>
<td>✓</td>
</tr>
<tr>
<td>✓</td>
<td>Arises from spinal nerves T₁ through L₃</td>
<td>✓</td>
</tr>
<tr>
<td>✓</td>
<td>Normally in control</td>
<td>✓</td>
</tr>
<tr>
<td>✓</td>
<td>“Fight-or-flight” system</td>
<td>✓</td>
</tr>
<tr>
<td>✓</td>
<td>Has more specific control (Look it up!)</td>
<td>✓</td>
</tr>
</tbody>
</table>

Galvanic Skin Response Using BIOPAC®

19. Describe exactly how, from a physiological standpoint, GSR can be correlated with activity of the autonomic nervous system.

The autonomic nervous system controls sweat glands of the skin. Increased moisture on the skin decreases its electrical resistance, which can be recorded.

20. Based on this brief and unprofessional exposure to a polygraph, explain why this might not be an exact tool for testing the sincerity and honesty of a subject.

It is not possible to state with certainty that every subject who lies will have an absolutely predictable autonomic nervous system response. For this reason, although GSR is useful as an investigative tool, it is not accepted as an exact measurement tool.
Suggestion for Alternative Equipment
Intelixtool®, PowerLab®, and iWorks® may be used as alternatives to this traditional exercise. Instructions for these software programs can be found on www.myaandp.com.

Time Allotment: 1 hour.

Decision (FHS: 28 minutes, VHS, DVD, 3-year streaming webcast)

Solutions:
Bleach Solution, 10%
Measure out 100 milliliters of bleach. Add water (undistilled) to a final volume of 1 liter.

Laboratory Materials
Ordering information is based on a lab size of 24 students, working in groups of 4. A list of supply house addresses appears in Appendix A.

<table>
<thead>
<tr>
<th>Item</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>6 reflex hammers</td>
<td></td>
</tr>
<tr>
<td>6 sharp pencils</td>
<td></td>
</tr>
<tr>
<td>6 small pieces of sterile absorbent cotton</td>
<td></td>
</tr>
<tr>
<td>6 tongue depressors</td>
<td></td>
</tr>
<tr>
<td>6 metric rulers</td>
<td></td>
</tr>
<tr>
<td>6 reaction time rulers (if available)</td>
<td></td>
</tr>
<tr>
<td>6 flashlights</td>
<td></td>
</tr>
<tr>
<td>6 beakers (100 or 250 milliliter)</td>
<td></td>
</tr>
<tr>
<td>6 10- or 25-milliliter graduated cylinders</td>
<td></td>
</tr>
<tr>
<td>6 dropper bottles of lemon juice</td>
<td></td>
</tr>
<tr>
<td>6 packages of wide-range pH paper</td>
<td></td>
</tr>
<tr>
<td>Disposable autoclave bag</td>
<td></td>
</tr>
<tr>
<td>6 wash bottles of 10% bleach</td>
<td></td>
</tr>
<tr>
<td>Large laboratory bucket of 10% bleach</td>
<td></td>
</tr>
<tr>
<td>Cot (if available)</td>
<td></td>
</tr>
<tr>
<td>BIOPAC® MP36 (or MP35/30) data acquisition unit, PC or Mac computer, BIOPAC® Student Lab Software, hand switch, headphones</td>
<td></td>
</tr>
</tbody>
</table>

Advance Preparation
1. Fill a large laboratory bucket with 10% bleach solution and set out an autoclave bag for disposable items. Set out wash bottles of 10% bleach solution.
2. For each group, set out a reflex hammer, a sharp pencil, a small piece of sterile absorbent cotton, a tongue depressor, a metric ruler, a 12-inch ruler or reaction time ruler, a flashlight, a 100- or 250-milliliter beaker, a 10- or 25-milliliter graduated cylinder, a dropper bottle of lemon juice, and wide-range pH paper.
3. Set out equipment and materials for the BIOPAC® activity. Introduce your students to the basic features of the equipment prior to beginning the lab activity.
Comments and Pitfalls

1. Be sure that the same student does all parts of the stretch reflex experiment.
2. Pupillary reflexes are more easily tested on subjects with light-colored irises.
3. Students do not always distinguish between the general term “pupillary reflexes” and the pupillary light reflex. Emphasize that the pupillary light reflex and the consensual response are both examples of pupillary reflexes.
4. Students often erroneously try to catch the ruler with their hands rather than between the thumb and forefinger in Activity 9. Also, be sure that the same subject does all four parts of this experiment.

Answers to Pre-Lab Quiz (p. 339)

1. A reflex is a rapid, predictable, involuntary motor response to a stimulus.
2. Somatic
3. d, sensory neuron
4. false
5. c, tendon
6. d, salivary
7. papillary light reflex, consensual reflex
8. glands
9. false

Answers to Activity Questions

Activity 1: Initiating Stretch Reflexes (pp. 342–343)

1. The leg swings forward as the quadriceps muscles contract. (The hamstrings are reciprocally inhibited.) The femoral nerve is carrying the impulses.
2. The response is usually greater than the first response. Mental distraction seems to increase the reflex response.
3. The response during other muscle activity is usually more vigorous due to increased facilitation in the spinal cord.
4. Fatigue results in a less vigorous response. Muscle function is responsible. This is probably due to changes in pH, ATP, and Ca^{2+} levels in the muscle. Excitation-contraction coupling is hindered, reducing the response of the muscle cells to nervous stimulation.
5. Plantar flexion due to the contraction of the triceps surae (gastrocnemius and soleus muscles) is the result. Contraction of the gastrocnemius muscle usually results in plantar flexion of the foot.

Activity 2: Initiating the Crossed-Extensor Reflex (p. 343)

The subject withdraws the pricked hand by flexion of the elbow. Then the other elbow extends. The extensor part of the reflex is relatively slow, probably due to the fact that many association neurons are involved.

Activity 3: Initiating the Plantar Reflex (p. 343)

The normal response is downward flexion (curling) and adduction of the toes.

Activity 4: Initiating the Corneal Reflex (pp. 343–344)

The subject blinks. The function is to protect the eye. The subject experiences discomfort (if not pain) because the cornea lacks pressure receptors but is richly supplied with pain receptors.

Activity 5: Initiating the Gag Reflex (p. 344)

The posterior pharyngeal walls elevate as pharyngeal muscles contract, and the subject gags.
Activity 6: Initiating Pupillary Reflexes (p. 344)

3. The left pupil contracts (the pupillary light reflex).
4. The right pupil also contracts. The contralateral (consensual) reflex indicates that there is some connection between the pathways for each eye. This is a test of the parasympathetic nervous system. These responses protect the retina from damage by bright light.

Activity 7: Initiating the Ciliospinal Reflex (p. 345)

1. The left pupil dilates, the right pupil does not.
2. Sympathetic innervation of the irises does not seem to be as closely integrated as parasympathetic innervation since a contralateral response was not observed.

Activity 8: Initiating the Salivary Reflex (p. 345)

3. The volume of saliva is much greater after stimulation with lemon juice. The final saliva pH should be close to the initial reading (usually pH 6–7). It is much less acidic than the reading 10 seconds after the application of lemon juice, as saliva contains sodium bicarbonate. The copious thin watery secretion is the result of parasympathetic stimulation.

Activity 9: Testing Reaction Time for Basic and Acquired Reflexes (pp. 345–346)

3. Addition of a signal word should increase reaction time because it takes time to discriminate the words.
4. The large variation in reaction time is due to the variation in the ability of the subject to formulate a response to the stimulus word.

Activity 10: Measuring Reaction Time Using BIOPAC® (pp. 346–348)

5. It is possible that there will be a difference between Segment 1 and Segment 2. If Segment 2 appears to be faster, this is likely due to the learning that occurred from the experience acquired during Segment 1. Responses may be more rapid during Segment 4 than in Segment 3 for the same reason.
Human Reflex Physiology

The Reflex Arc
1. Define reflex. A rapid, predictable, involuntary motor response to a stimulus that is mediated over a neural pathway called a reflex arc.

2. Name five essential components of a reflex arc: receptor, sensory neuron, integration center, motor neuron, and effector.

3. In general, what is the importance of reflex testing in a routine physical examination? Allows the condition of the nervous system to be assessed. Pathology is indicated by exaggeration, distortion, or absence of reflexes normally present.

Somatic and Autonomic Reflexes
4. Use the key terms to complete the statements given below.

Key: a. abdominal reflex b. Achilles reflex c. ciliospinal reflex d. corneal reflex e. crossed-extensor reflex f. gag reflex g. patellar reflex h. plantar reflex i. pupillary light reflex

Reflexes classified as somatic reflexes include the a, b, d, e, f, g, and h.

Of these, the simple stretch reflexes are b and g, and the superficial cord reflexes are a and h.

Reflexes classified as autonomic reflexes include c and i.

5. Name two cord-mediated reflexes. Achilles reflex (crossed-extensor reflex is also cord mediated) and patellar reflex (crossed-extensor reflex is also cord mediated).

6. Can the stretch reflex be elicited in a pithed animal (that is, an animal in which the brain has been destroyed)? Yes, in a singly pithed frog in which the cord is intact.

Explain your answer. It is a cord-mediated reflex (initiated and executed at the spinal cord level).
7. Trace the reflex arc, naming efferent and afferent nerves, receptors, effectors, and integration centers, for the two reflexes listed. (Hint: Remember which nerve innervates the anterior thigh, and which nerve innervates the posterior thigh.)

patellar reflex: \(\text{Proprioceptors (stretch receptors) in the quadriceps muscle} \rightarrow \text{afferent fibers of femoral nerve} \rightarrow \text{spinal cord} \rightarrow \text{efferent fibers of femoral nerve} \rightarrow \text{quadriceps muscle}\)

Achilles reflex: \(\text{Proprioceptors (stretch receptors) in the gastrocnemius muscle} \rightarrow \text{afferent fibers of sciatic nerve} \rightarrow \text{spinal cord} \rightarrow \text{efferent fibers of sciatic nerve} \rightarrow \text{gastrocnemius (triceps surae) muscle}\)

8. Three factors that influence the rapidity and effectiveness of reflex arcs were investigated in conjunction with patellar reflex testing—mental distraction, effect of simultaneous muscle activity in another body area, and fatigue.

Which of these factors increases the excitatory level of the spinal cord? \textit{Simultaneous muscle activity, mental distraction}

Which factor decreases the excitatory level of the muscles? \textit{Muscle fatigue (exercise)}

When the subject was concentrating on an arithmetic problem, did the change noted in the patellar reflex indicate that brain activity is necessary for the patellar reflex or only that it may modify it? \textit{Only that it may modify it. It will occur in any case.}

9. Name the division of the autonomic nervous system responsible for each of the reflexes listed.

ciliospinal reflex: \textit{sympathetic} salivary reflex: \textit{parasympathetic}
pupillary light reflex: \textit{parasympathetic}

10. The pupillary light reflex, the crossed-extensor reflex, and the corneal reflex illustrate the purposeful nature of reflex activity. Describe the protective aspect of each.

pupillary light reflex: \textit{Protects the retina from excessive illumination, which is damaging to the photoreceptors.}

corneal reflex: \textit{Protects the eye from trauma.}

crossed-extensor reflex: \textit{Withdraws the injured limb from the painful stimulus while simultaneously extending the opposite limb. If the upper limbs are involved, extension of the opposite limb acts to push the stimulus away. If the lower limbs are involved, extension of the opposite limb prepares the limb to receive the body weight.}

11. Was the pupillary consensual response contralateral or ipsilateral? \textit{Contralateral}

Why would such a response be of significant value in this particular reflex? \textit{Usually, if a light source is intense, both eyes are illuminated.}
12. Differentiate between the types of activities accomplished by somatic and autonomic reflexes. Autonomic reflexes involve the activation of smooth or cardiac muscle and glands. Somatic reflexes involve the activation of skeletal muscles.

13. Several types of reflex activity were not investigated in this exercise. The most important of these are autonomic reflexes, which are difficult to illustrate in a laboratory situation. To rectify this omission, complete the following chart, using references as necessary.

<table>
<thead>
<tr>
<th>Reflex</th>
<th>Organ involved</th>
<th>Receptors stimulated</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>Micturition</td>
<td>Bladder</td>
<td>Stretch receptors in the bladder wall</td>
<td>Impulse goes to cord (afferent fibers) and returns (efferent fibers), causing bladder contraction and relaxation of its internal sphincter.</td>
</tr>
<tr>
<td>(urination)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hering-Breuer</td>
<td>Lungs</td>
<td>Stretch receptors in the lungs</td>
<td>Upon excessive inspiration, afferent impulses are sent to the pons and medulla oblongata, which in turn send efferent impulses to terminate the inspiratory effort.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Defecation</td>
<td>Rectum</td>
<td>Stretch receptors in the rectal walls (colon terminus)</td>
<td>Afferent impulses to the sacral region of the cord followed by efferent impulses to the muscles of the rectum and the anal sphincters to initiate feces evacuation.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carotid sinus</td>
<td>Carotid artery</td>
<td>Pressure receptors in the carotid sinus</td>
<td>When arterial pressure increases excessively, sensory impulses travel to the cardioinhibitory center in the medulla oblongata, which in turn sends efferent impulses via the vagus nerve to slow the heart, thus decreasing its rate and the blood pressure.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Reaction Time of Basic and Learned or Acquired Reflexes

14. How do basic and learned or acquired reflexes differ? Although there is no clear-cut distinction, basic reflexes are generally inborn and use a specific reflex arc. Learned or acquired reflexes are the result of practice and repetition, involving more neural pathways and higher intellectual activities.

15. Name at least three factors that may modify reaction time to a stimulus. Receptor sensitivity, nerve conduction velocity, and the number of neurons and synapses involved.

16. In general, how did the response time for the learned activity performed in the laboratory compare to that for the simple patellar reflex? The response time for the learned activity was much longer.

17. Did the response time without verbal stimuli decrease with practice? Yes. Explain the reason for this. The subject was anticipating the stimulus.

18. Explain, in detail, why response time increased when the subject had to react to a word stimulus. Choice and decision-making about the response involved and the large number of synapses involved increased the response time.

19. When measuring reaction time in the BIOPAC® activity, was there a difference in reaction time when the stimulus was predictable versus unpredictable? Explain your answer. It is most likely that the reaction time will be shorter during the segments with predictable, evenly spaced stimuli than during the random segments. The subject can more easily predict the onset of the stimulus, reducing reaction time.
**General Sensation**

**Time Allotment:** 11/2 hours.

**Multimedia Resources:** See Appendix B for Guide to Multimedia Resource Distributors.

*Touch* (part of the NOVA Mystery of the Senses series) (IM: 60 minutes each, 5-piece DVD set)

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**Laboratory Materials**

*Ordering information is based on a lab size of 24 students, working in groups of 4. A list of supply house addresses appears in Appendix A.*

- 24 compound microscopes, lens paper, lens cleaning solution, immersion oil
- 24 slides (longitudinal sections) of Pacinian corpuscles, Meissner’s corpuscles, Golgi tendon organs, and muscle spindles
- 12 blunt probes
- Large beaker of ice water with chipped ice
- Hot water bath set at 45°C, laboratory thermometer
- 6 sets of red, black, and blue fine-point felt-tipped markers
- 6 Von Frey’s hairs or sharp pencils
- 6 calipers or esthesiometers
- 6 millimeter rulers
- 12 blunt probes (one per group) in a small water bath set at 45°C
- Place half of the blunt probes in a beaker containing chipped ice and water
- Place the remaining blunt probes in a beaker containing chipped ice and water
- Set out black, red, and blue felt-tipped markers, Von Frey’s hairs or sharp pencils, calipers or two-point discriminators or esthesiometers (sometimes called anesthesiometers), and millimeter rulers (one each per group)
- Have at least four nickels or quarters available
- For each group, set out three large finger bowls or beakers, a thermometer, and paper towels. Have ice water available

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**Comments and Pitfalls**

1. Remind the students to use caution when adjusting the width of the calipers or two-point discriminators in the two-point discrimination test. Caution the students against dragging the sharp tips along the surface of the skin. Wooden toothpicks may be substituted for calipers.

2. If a student has Raynaud’s disease and is the subject in the Referred Pain experiment (Activity 7), he or she may experience temporary numbness of the hand. This experiment works best on subjects with thin arms.
3. Use water-based, felt-tipped pens or have some sort of stain remover available.
4. Adaptation of the hand to ice water may take longer than two minutes. You may wish to warn students that it may be painful to keep their hands in the ice water long enough to experience adaptation.

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### Answers to Pre-Lab Quiz (p. 353)

1. sight, hearing, equilibrium, smell, or taste
2. a, Exteroceptors
3. true
4. b, in the dermal papillae of hairless skin
5. a, deep pressure and vibrations
6. true
7. Tactile localization
8. b, adaptation
9. b, elbow in ice water to test the ulnar nerve response

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### Answers to Activity Questions

**Activity 2: Determining the Two-Point Threshold (p. 356)**
Fingertips and lips usually have the greatest density of touch receptors.

**Activity 3: Testing Tactile Localization (pp. 356–357)**
2. The ability to locate the stimulus should not improve with repeated trials because the receptor density remains unchanged.

**Activity 4: Plotting the Relative Density and Location of Touch and Temperature Receptors (p. 357)**
6. Touch receptors and cold receptors are both more abundant than heat receptors. Touch receptors will probably appear to be the most abundant.

**Activity 5: Demonstrating Adaptation of Touch Receptors (pp. 357–358)**
3. The pressure sensation returns when coins are added to the stack. The same receptors are probably being used. Generator potentials are graded and stronger stimuli produce larger potentials and thus increased frequency of nerve impulses.
4. The sensation is greater when the hair springs back. Without adaptation there would be continuous impulses from and awareness of the bending hairs.

**Activity 6: Demonstrating Adaptation of Temperature Receptors (p. 358)**
1. The water will feel warm to the left hand. After the left hand has been in the warm water for one minute the water will feel much less warm; the water will feel very warm to the right hand. Yes, adaptation has occurred in the left hand.
3. After two minutes the warm water will begin to feel lukewarm to the right hand. The hand in the ice water may hurt and the experiment may have to go longer than two minutes to observe adaptation. Adaptation to the cold seems to take longer. The right hand adapts more quickly.
4. The water feels cool to the right hand and warm to the left hand.

**Activity 7: Demonstrating the Phenomenon of Referred Pain (p. 359)**
Initially the elbow feels cold and then begins to hurt. After a while a tingling sensation can be felt in the fingers and the palm of the hand. The fingers may then begin to ache. The ulnar nerve serves several hand and finger muscles as well as the skin of a portion of the hand. All above sensations fade during the three minutes after removal.
General Sensation

Structure of General Sensory Receptors

1. Differentiate between interoceptors and exteroceptors relative to location and stimulus source.
   - Interceptor: In viscera or deep in body tissues; internal stimuli
   - Exteroceptor: At or close to the body surface; stimuli in external environment

2. A number of activities and sensations are listed in the chart below. For each, check whether the receptors would be exteroceptors or interoceptors; and then name the specific receptor types. (Because visceral receptors were not described in detail in this exercise, you need only indicate that the receptor is a visceral receptor if it falls into that category.)

<table>
<thead>
<tr>
<th>Activity or sensation</th>
<th>Exteroceptor</th>
<th>Interoceptor</th>
<th>Specific receptor type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Backing into a sun-heated iron railing</td>
<td>✓</td>
<td></td>
<td>Pain receptors</td>
</tr>
<tr>
<td>Someone steps on your foot</td>
<td>✓</td>
<td>✓</td>
<td>Pain receptors</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Pacinian corpuscles</td>
</tr>
<tr>
<td>Reading a book</td>
<td>✓</td>
<td></td>
<td>Rods/cones of the eye (photoreceptors)</td>
</tr>
<tr>
<td>Leaning on your elbows</td>
<td></td>
<td>✓</td>
<td>Pacinian corpuscles</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Proprioceptors</td>
</tr>
<tr>
<td>Doing sit-ups</td>
<td></td>
<td>✓</td>
<td>Proprioceptors</td>
</tr>
<tr>
<td>The “too full” sensation</td>
<td></td>
<td>✓</td>
<td>Visceral receptors (stretch)</td>
</tr>
<tr>
<td>Seasickness</td>
<td>✓</td>
<td></td>
<td>Equilibrium apparatus of the inner ear</td>
</tr>
</tbody>
</table>

Receptor Physiology

3. Explain how the sensory receptors act as transducers. Convert other energy types, e.g., pressure (mechanical energy), to the electrical nerve impulse

4. Define stimulus. An irritant capable of producing a response

5. What was demonstrated by the two-point discrimination test? The relative density of touch receptors in various body areas (lips, fingertips, etc.)

How well did your results correspond to your predictions? Answers may vary.

What is the relationship between the accuracy of the subject’s tactile localization and the results of the two-point discrimination test? Areas with the most accurate tactile localization were demonstrated to have the smallest two-point thresholds.
6. Define **punctate distribution.** *Having specific localization or found at certain discrete points*

7. Several questions regarding general sensation are posed below. Answer each by placing your response in the appropriately numbered blanks to the right.

   1. Which cutaneous receptors are the most numerous?
   
   2.–3. Which two body areas tested were most sensitive to touch?
   
   4.–5. Which two body areas tested were least sensitive to touch?
   
   6. Which appear to be more numerous—receptors that respond to cold or to heat?
   
   7.–9. Where would referred pain appear if the following organs were receiving painful stimuli—(7) gallbladder, (8) kidneys, and (9) appendix? (Use your textbook if necessary.)
   
   10. Where was referred pain felt when the elbow was immersed in ice water during the laboratory experiment?
   
   11. What region of the cerebrum interprets the kind and intensity of stimuli that cause cutaneous sensations?

8. Define **adaptation of sensory receptors.** *Decline in receptor sensitivity and stimulation with prolonged unchanging stimuli*

9. Why is it advantageous to have pain receptors that are sensitive to all vigorous stimuli, whether heat, cold, or pressure?

   *Because all of these stimuli, if excessive, cause tissue damage.*

   Why is the nonadaptability of pain receptors important? *Pain is a warning of actual or potential tissue damage.*

10. Imagine yourself without any cutaneous sense organs. Why might this be very dangerous? *Many external stimuli (heat, cold, pressure) which can threaten homeostasis might go undetected, and proper protective measures might not be taken.*

11. Define **referred pain.** *An experience in which pain is perceived as coming from a site other than that receiving the painful stimulus*

   What is the probable explanation for referred pain? (Consult your textbook or an appropriate reference if necessary.)

   *Both the site of referred pain and the visceral region receiving the actual painful stimulus are innervated by different sensory neurons that then stimulate the same interneurons in a specific spinal segment of the cord. These sensations are then interpreted by the somatosensory cortex.*
Special Senses: Vision

Time Allotment: 2 hours.

See Exercise 6A for histology listings.

A.D.A.M.® Interactive Anatomy 4.0 (AIA: CD-ROM, DVD)
The Eye: Structure, Function, and Control of Movement (FHS: 54 minutes, VHS, DVD)
Eyes and Ears (FHS: 28 minutes, VHS, DVD, 3-year streaming webcast)
Practice Anatomy Lab™ 2.0 (PAL) (BC: CD-ROM, Website)
The Senses (FHS: 20 minutes, VHS, DVD, 3-year streaming webcast)
Sheep Eye Dissection (WNS: 15 minutes, VHS, DVD)
Vision (part of the NOVA Mystery of the Senses series) (IM: 60 minutes each, 5-piece DVD set)

Solutions:
Bleach Solution, 10%
Measure out 100 milliliters of bleach. Add water (undistilled) to a final volume of 1 liter.

Laboratory Materials
Ordering information is based on a lab size of 24 students, working in groups of 4. A list of supply house addresses appears in Appendix A.

- Dissectible eye model and/or chart of eye anatomy
- 6–12 Ishihara’s color plates
- Ophthalmoscope (if available)
- 12–24 preserved cow or sheep eyes
- 6 metric rulers/meter sticks
- 6 test tubes
- 12–24 dissecting pans and dissecting kits
- 6 common (straight) pins
- 6 laboratory lamps, penlights, or flashlights
- 24 compound microscopes, lens paper, lens cleaning solution
- Snellen eye chart and chalk
- 24 slides (longitudinal section) of eye showing retinal layers
- Disposable gloves
- 24 pairs of safety glasses
- Soap, sponges, and disinfectant
- 6 pencils

Advance Preparation
1. Make arrangements for appropriate storage and disposal of dissection materials. Check with the Department of Health or the Department of Environmental Protection for state regulations.
2. Designate a disposal container for organic debris and a dishwashing area with hot soapy water and sponges. Provide lab disinfectant such as Wavicide-01 (biology supply company) or 10% bleach solution for washing down the lab benches.
3. Set out disposable gloves and safety glasses.
4. Set out dissecting kits, dissecting pans, and preserved cow or sheep eyes. Plan for groups of two or individual dissections.
5. Set out dissectible eye models and/or eye anatomy charts.
6. Set out slides of the eye showing retinal layers, lens paper, and lens cleaning solution. Have compound microscopes available. As an alternative, set up a demonstration slide of the retina.

7. Hang up a Snellen eye chart in a well-lit part of the room. Measure back 20 feet from the chart and mark the distance on the floor with masking tape.

8. Set out Ishihara's color plates.

9. Set out a box of common pins.

10. Set out test tubes, pencils, metric rulers, and meter sticks (one each per group).

11. Set out several laboratory lamps, penlights, or bright flashlights.

12. Set out the ophthalmoscopes (check to be sure ophthalmoscope batteries are working).

**Comments and Pitfalls**

1. Preserved cow eyes are often misshapen, and inexperienced students may need help locating and identifying the cornea at the beginning of the dissection.

2. Some students will have difficulty with the ophthalmoscope. Remind the subject to look straight ahead at a fixed object while the examiner looks through the pupil at a slight angle. Caution the examiner to limit illuminating the retina to **one minute or less**. Switch to the other eye if necessary. Do not examine the macula for more than one second at a time.

3. For demonstration of the blind spot, emphasize that the dot disappears when the right eye is tested, and the X disappears when the left eye is tested. Some student is sure to claim that he/she has no blind spot in the left eye as the dot never disappeared!

**Answers to Pre-Lab Quiz (pp. 363–364)**

1. c, palpebrae  
6. aqueous humor

2. conjunctiva  
7. cones

3. d, six  
8. b, bipolar

4. c, cornea  
9. true

5. optic disc  
10. a, accommodation

**Answers to Activity Questions**

**Activity 1: Identifying Accessory Eye Structures (p. 365)**

Right eye: medial rectus  
Left eye: lateral rectus (and on occasion the superior or inferior oblique)

**Dissection: The Cow (Sheep) Eye (pp. 368–369)**

6. The optic disc.

**Activity 4: Predicting the Effects of Visual Pathway Lesions (pp. 370–371)**

A lesion in the right optic nerve affects medial and lateral vision of the right eye. (The person is blind in the right eye.)

A sagittal lesion through the optic chiasma affects medial vision in both eyes. (The lateral peripheral vision is diminished.) Sagittal lesions also eliminate binocular vision.

A lesion in the left optic tract affects left lateral and right medial vision. (While looking straight ahead, nothing is seen in the far right visual field.)

A lesion in the visual area of the right cerebral cortex affects right lateral and left medial vision. (While looking straight ahead, nothing is seen in the far left visual field.)
Activity 10: Tests for Binocular Vision (p. 374)
It is much easier to put the pencil in the test tube with both eyes open.

Activity 11: Demonstrating Reflex Activity of Intrinsic and Extrinsic Eye Muscles (pp. 374–375)

Photopupillary Reflex
When exposed to bright light, the pupil constricts. The pupil of the opposite eye will also be slightly constricted.

Accommodation Pupillary Reflex
As the eye focuses on printed material, the pupil constricts. This reduces divergent light rays and aids in formation of a sharper image. It also restricts the amount of light entering the eye.

Convergence Reflex
The eyeballs will both move medially to focus on the object. This reflex keeps the image focused on the fovea.
Anatomy of the Eye

1. Name five accessory eye structures that contribute to the formation of tears and/or aid in lubrication of the eyeball, and then name the major secretory product of each. Indicate which has antibacterial properties by circling the correct secretory product.

<table>
<thead>
<tr>
<th>Accessory structures</th>
<th>Product</th>
</tr>
</thead>
<tbody>
<tr>
<td>lacrimal glands</td>
<td>saline solution; lysozyme</td>
</tr>
<tr>
<td>conjunctiva</td>
<td>mucus</td>
</tr>
<tr>
<td>tarsal or meibomian glands</td>
<td>oily secretion</td>
</tr>
<tr>
<td>caruncle</td>
<td>whitish, oily secretion</td>
</tr>
<tr>
<td>ciliary glands</td>
<td>sweat</td>
</tr>
</tbody>
</table>

2. The eyeball is wrapped in adipose tissue within the orbit. What is the function of the adipose tissue?

To package, protect, and cushion the eyeball in the bony orbit

3. Why does one often have to blow one’s nose after crying?

Because tears drain into the nasal cavities via the nasolacrimal ducts.

4. Identify the extrinsic eye muscle predominantly responsible for each action described below.

- lateral rectus 1. turns the eye laterally
- medial rectus 2. turns the eye medially
- inferior oblique 3. turns the eye up and laterally
- inferior rectus 4. turns the eye inferiorly and medially
- superior rectus 5. turns the eye superiorly and medially
- superior oblique 6. turns the eye down and laterally

5. What is a sty? Inflammation of a small oil or sweat gland associated with the eye exterior

Conjunctivitis? Inflammation of the conjunctiva
6. Correctly identify each lettered structure in the diagram by writing the letter next to its name in the numbered list.

   c  1. anterior chamber
   l  2. anterior segment
   t  3. bipolar neurons
   f  4. choroid
   p  5. ciliary body and processes
   e  6. ciliary muscle
   a  7. cornea
   j  8. dura mater
   q  9. fovea centralis
   u  10. ganglion cells
   o  11. iris
   b  12. lens
   r  13. optic disc
   k  14. optic nerve
   s  15. photoreceptors
   n  16. posterior chamber
   i  17. retina
   h  18. sclera
   d  19. scleral venous sinus
   m  20. suspensory ligaments (ciliary zonule)
   g  21. posterior segment

Notice the arrows drawn close to the left side of the iris in the diagram above. What do they indicate?

*The flow of aqueous humor from the ciliary processes of the ciliary body to the scleral venous sinus (canal of Schlemm).*

7. The iris is composed primarily of two smooth muscle layers, one arranged radially and the other circularly.

Which of these dilates the pupil? *The radial layer*

8. You would expect the pupil to be dilated in which of the following circumstances? Circle the correct response(s).
   a. in bright light   b. in dim light   c. focusing for near vision   d. observing distant objects

9. The intrinsic eye muscles are controlled by the (circle the correct response):
   autonomic nervous system   somatic nervous system
10. Match the key responses with the descriptive statements that follow.

Key:  

- a. aqueous humor  
- b. choroid  
- c. ciliary body  
- d. ciliary processes of the ciliary body  
- e. cornea  
- f. fovea centralis  
- g. iris  
- h. lens  
- i. optic disc  
- j. retina  
- k. sclera  
- l. scleral venous sinus  
- m. vitreous humor

1. fluid filling the anterior segment of the eye  
2. the “white” of the eye  
3. part of the retina that lacks photoreceptors  
4. modification of the choroid that controls the shape of the crystalline lens and contains the ciliary muscle  
5. drains the aqueous humor from the eye  
6. layer containing the rods and cones  
7. substance occupying the posterior segment of the eyeball  
8. forms the bulk of the heavily pigmented vascular layer  
9. smooth muscle structures (2)  
10. area of critical focusing and discriminatory vision  
11. form (by filtration) the aqueous humor  
12. light-bending media of the eye (4)  
13. anterior continuation of the sclera—your “window on the world”  
14. composed of tough, white, opaque, fibrous connective tissue

Microscopic Anatomy of the Retina

11. The two major layers of the retina are the epithelial and neural layers. In the neural layer, the neuron populations are arranged as follows from the pigmented epithelial layer to the vitreous humor. (Circle the proper response.)

- bipolar cells, ganglion cells, photoreceptors  
- photoreceptors, ganglion cells, bipolar cells  
- ganglion cells, bipolar cells, photoreceptors  
- photoreceptors, bipolar cells, ganglion cells

12. The axons of the ganglion cells form the optic nerve, which exits from the eyeball.

13. Complete the following statements by writing either rods or cones on each blank.

The dim light receptors are the ________. Only ________ are found in the fovea centralis, whereas mostly ________ are found in the periphery of the retina. ________ are the photoreceptors that operate best in bright light and allow for color vision.
Dissection of the Cow (Sheep) Eye

14. What modification of the choroid that is not present in humans is found in the cow eye? **Tapetum lucidum**
   What is its function? *To reflect light that enters the eye, thus increasing light stimulation of the retina under dim light conditions.*

15. What does the retina look like? *Thin yellowish-white or tan membrane. (Often becomes crumpled during dissection of the eye.)*
   At what point is it attached to the posterior aspect of the eyeball? **At the optic disc**

Visual Pathways to the Brain

16. The visual pathway to the occipital lobe of the brain consists most simply of a chain of five cells. Beginning with the photoreceptor cell of the retina, name them and note their location in the pathway.

1. photoreceptor cell; retina  
2. bipolar cell; retina  
3. ganglion cell; retina  
4. neuron; lateral geniculate nucleus of the thalamus  
5. cortical neuron; visual cortex of the cerebral hemisphere(s)

17. Visual field tests are done to reveal destruction along the visual pathway from the retina to the optic region of the brain. Note where the lesion is likely to be in the following cases.

   Normal vision in left eye visual field; absence of vision in right eye visual field: **Right optic nerve**
   Normal vision in both eyes for right half of the visual field; absence of vision in both eyes for left half of the visual field: **Right optic tract (or right visual cortex)**

18. How is the right optic *tract* anatomically different from the right optic *nerve*? **The right optic nerve contains fibers from the right eye only. The right optic tract contains fibers from the lateral aspect of the right eye and the medial aspect of the left eye.**

Visual Tests and Experiments

19. Match the terms in column B with the descriptions in column A.

<table>
<thead>
<tr>
<th>Column A</th>
<th>Column B</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>g</em>: refraction</td>
<td>a. accommodation</td>
</tr>
<tr>
<td><em>a</em>: accommodation</td>
<td>b. astigmatism</td>
</tr>
<tr>
<td><em>d</em>: emmetropia</td>
<td>c. convergence</td>
</tr>
<tr>
<td><em>e</em>: hyperopia</td>
<td>d. emmetropia</td>
</tr>
<tr>
<td><em>f</em>: myopia</td>
<td>e. hyperopia</td>
</tr>
<tr>
<td><em>b</em>: astigmatism</td>
<td>f. myopia</td>
</tr>
<tr>
<td><em>c</em>: convergence</td>
<td>g. refraction</td>
</tr>
</tbody>
</table>

   *light bending*  
   *ability to focus for close (less than 20 feet) vision*  
   *normal vision*  
   *inability to focus well on close objects (farsightedness)*  
   *nearsightedness*  
   *blurred vision due to unequal curvatures of the lens or cornea*  
   *medial movement of the eyes during focusing on close objects*
20. Complete the following statements:

In farsightedness, the light is focused __1__ the retina. The lens required to treat myopia is a __2__ lens. The “near point” increases with age because the __3__ of the lens decreases as we get older. A convex lens, like that of the eye, produces an image that is upside down and reversed from left to right. Such an image is called a __4__ image.

1. behind
2. concave
3. elasticity
4. real

21. Use terms from the key to complete the statements concerning near and distance vision.

Key: a. contracted b. decreased c. increased d. relaxed e. taut

During distance vision, the ciliary muscle is __d__, the suspensory ligament is __e__, the convexity of the lens is __b__, and light refraction is __b__. During close vision, the ciliary muscle is __a__, the suspensory ligament is __d__, lens convexity is __c__, and light refraction is __c__.

22. Explain why vision is lost when light hits the blind spot. This area lacks photoreceptors.

23. Using your Snellen eye test results, answer the following questions.

Is your visual acuity normal, less than normal, or better than normal? The answers may vary.

Explain your answer. ____________________________________________________________________
__________________________________________________________________________________

Explain why each eye is tested separately when using the Snellen eye chart. There is usually a slight difference in the visual acuity of the two eyes.

Explain 20/40 vision. Poorer than normal vision. Able to read #40 letters at 20 feet. The normal eye reads these letters at 40 feet.
__________________________________________________________________________________

Explain 20/10 vision. Better than normal vision. Can read #10 letters at 20 feet. The normal eye would have to be 10 feet away to read these letters.
__________________________________________________________________________________

24. Define astigmatism. Blurred vision due to unequal curvatures of the lens or cornea.

How can it be corrected? With specially ground (circularly ground) lenses.


What causes it? Decreased function of an increasingly inelastic lens.
26. To which wavelengths of light do the three cone types of the retina respond maximally?
   red, blue, and green

27. How can you explain the fact that we see a great range of colors even though only three cone types exist?
   When more than one cone type is stimulated simultaneously, intermediate colors (of the visible spectrum) are seen.

28. Explain the difference between binocular and panoramic vision. Binocular—visual fields overlap considerably but not completely; therefore, slightly different views are received by each eye. Panoramic—little or no overlap of visual fields; therefore, each eye “sees” a different view.
   What is the advantage of binocular vision? Allows for depth perception.
   What factor(s) are responsible for binocular vision? The slight difference between the visual fields of the two eyes and the partial crossover at the optic chiasma.

29. In the experiment on the convergence reflex, what happened to the position of the eyeballs as the object was moved closer to the subject’s eyes? Eyeballs turned medially.
   What extrinsic eye muscles control the movement of the eyes during this reflex? Medial recti
   What is the value of this reflex? Allows the image to be precisely focused on the fovea of each eye.

30. In the experiment on the photopupillary reflex, what happened to the pupil of the eye exposed to light?
   It constricted. What happened to the pupil of the nonilluminated eye? It constricted.
   Explanation? Regulation of pupil constriction by the parasympathetic division of the autonomic nervous system is coordinated (i.e., consensual) and prevents overillumination of the delicate retinal cells.

31. Why is the ophthalmoscopic examination an important diagnostic tool? Allows noninvasive examination of the retinal condition and vasculature.

32. Many college students struggling through mountainous reading assignments are told that they need glasses for “eyestrain.” Why is it more of a strain on the extrinsic and intrinsic eye muscles to look at close objects than at far objects?
   No accommodation or convergence is required for distant vision.
Exercise 25

Special Senses: Hearing and Equilibrium

Time Allotment: 1 hour.

See Exercise 6A for histology listings.

- The Ear: Hearing and Balance (IM: 29 minutes, DVD)
- Eyes and Ears (FHS: 28 minutes, VHS, DVD, 3-year streaming webcast)
- Hearing (FHS: 30 minutes, VHS, DVD, 3-year streaming webcast)
- Hearing (part of the NOVA Mystery of the Senses series) (IM: 60 minutes each, 5-piece DVD set)
- Practice Anatomy Lab™ 2.0 (PAL) (BC: CD-ROM, Website)
- The Senses (FHS: 20 minutes, VHS, DVD, 3-year streaming webcast)

Laboratory Materials

Ordering information is based on a lab size of 24 students, working in groups of 4. A list of supply house addresses appears in Appendix A.

- 3-D dissectible ear models and/or chart of ear anatomy
- 24 compound microscopes, lens paper, lens cleaning solution
- 24 slides of the cochlea
- 1 slide of crista ampullaris receptor of a semicircular canal
- 6 sets of tuning forks (range of frequencies)
- 6 rubber mallets
- Absorbent cotton
- Otoscope (if available), disposable otoscope tips, and alcohol swabs
- Disposable autoclave bag
- 6 metric rulers
- 6 pocket watches or clocks that tick
- White chalk and blackboard or markers and whiteboard
- Audiometer (if available)
- Red and blue pencils
- Rotating stool or chair
- Three coins of different sizes

Advance Preparation

1. Set out dissectible ear models and/or chart of ear anatomy.
2. Set out slides of the cochlea, lens paper, and lens cleaning solution. Have compound microscopes available. Set up a demonstration slide of the crista ampullaris receptor of a semicircular canal.
3. For each group, set out tuning forks, rubber mallet, absorbent cotton, a pocket watch or small clock that ticks, a piece of white chalk or a whiteboard marker, and a metric ruler.
4. If an audiometer is available it can be used instead of the tuning forks to test frequency range of hearing. If necessary, prepare instructions for the use of the audiometer. Set out red and blue pencils.
5. Set out otoscopes (if available), disposable otoscope tips, alcohol swabs, and an autoclave bag.
6. Have a sturdy rotating chair or stool available for the Barany test.
Comments and Pitfalls

1. It is often difficult to find an area quiet enough to get good results with the acuity and sound localization tests. An empty lab or a quiet corner of the hallway might be used.
2. Students should be reminded to simulate conductive deafness while performing the Weber test. Although it is not a specific assignment, they’ll be asked for results in the Review Sheets.
3. Remind the students to strike the tuning forks with the rubber mallet and not against the lab bench.
4. Be sure the students understand how to evaluate the direction of nystagmus before the subject spins. Also remind the subject to keep his or her eyes open! Instruct students who are standing around the stool to place their foot firmly against the stool leg to prevent the stool from tipping over.

Answers to Pre-Lab Quiz (pp. 383–384)

1. three
2. a, auricle
3. tympanic membrane
4. d, stapes
5. a, cochlea
6. otoscope
7. b, Rinne
8. b, inner ear
9. macula/vestibule
10. c, involuntary trailing of eyes in one direction, then rapid movement in the other

Answers to Activity Questions

Activity 4: Conducting Laboratory Tests of Hearing (pp. 387–388)

Acuity Test
The threshold is indefinite.

Sound Localization
No, the sound is less easily located if the source is equidistant from both ears. Sound arriving from spots equidistant from both ears arrives at each ear at the same time and with equal loudness. This does not provide enough information to adequately locate the position of the source.

Frequency Range of Hearing
Generally, high-frequency sounds are heard less clearly, but results depend on the loudness of each of the tuning forks.

Activity 7: Conducting Laboratory Tests on Equilibrium (pp. 391–392)

Balance Test
1. Nystagmus should not be present.
2. The cerebellum integrates input from receptors in the vestibule and semicircular canals, the eyes and somatic receptors, and coordinates skeletal muscle activity and regulates muscle tone.

Barany Test
4. When rotation stops, the direction of nystagmus reverses. If the chair is rotated clockwise, the nystagmus will be counterclockwise. For a few seconds after the chair is stopped, the subject reports a feeling of movement in the same direction and the same speed in which the chair was spun.
Romberg Test

2. Gross swaying movements are not usually observed when the eyes are open.
4. Front-to-back swaying occurs.
   The equilibrium apparatus and proprioceptors are probably functioning normally.
   Visual information is lacking and the result is increased swaying.
   Equilibrium and balance require input from a number of receptors, including proprioceptors, the vestibular apparatus, and the eyes.
### Special Senses:
#### Hearing and Equilibrium

**Anatomy of the Ear**

1. Select the terms from column B that apply to the column A descriptions. Some terms are used more than once.

<table>
<thead>
<tr>
<th>Column A</th>
<th>Column B</th>
</tr>
</thead>
<tbody>
<tr>
<td>d, i, m</td>
<td>a. pharyngotympanic (auditory) tube</td>
</tr>
<tr>
<td>b, k, n</td>
<td>b. cochlea</td>
</tr>
<tr>
<td>e, f, l</td>
<td>c. endolymph</td>
</tr>
<tr>
<td>a</td>
<td>d. external auditory canal</td>
</tr>
<tr>
<td>m</td>
<td>e. incus (anvil)</td>
</tr>
<tr>
<td>k, n</td>
<td>f. malleus (hammer)</td>
</tr>
<tr>
<td>g</td>
<td>g. oval window</td>
</tr>
<tr>
<td>j</td>
<td>h. perilymph</td>
</tr>
<tr>
<td>a</td>
<td>i. pinna (auricle)</td>
</tr>
<tr>
<td>6. contain receptors for the sense of balance</td>
<td>j. round window</td>
</tr>
<tr>
<td>7. transmits the vibratory motion of the stirrup to the fluid in the scala vestibuli of the inner ear</td>
<td>k. semicircular canals</td>
</tr>
<tr>
<td>8. acts as a pressure relief valve for the increased fluid pressure in the scala tympani; bulges into the tympanic cavity</td>
<td>l. stapes (stirrup)</td>
</tr>
<tr>
<td>9. passage between the throat and the tympanic cavity</td>
<td>m. tympanic membrane</td>
</tr>
<tr>
<td>10. fluid contained within the membranous labyrinth</td>
<td>n. vestibule</td>
</tr>
</tbody>
</table>
|                          11. fluid contained within the osseous labyrinth and bathing the membranous labyrinth |}
2. Identify all indicated structures and ear regions in the following diagram.

![Diagram of the ear](image)

3. Match the membranous labyrinth structures listed in column B with the descriptive statements in column A.

<table>
<thead>
<tr>
<th>Column A</th>
<th>Column B</th>
</tr>
</thead>
<tbody>
<tr>
<td>g, j</td>
<td>1. sacs found within the vestibule</td>
</tr>
<tr>
<td>c</td>
<td>2. contains the spiral organ (of Corti)</td>
</tr>
<tr>
<td>g, j</td>
<td>3. sites of the maculae</td>
</tr>
<tr>
<td>h</td>
<td>4. positioned in all spatial planes</td>
</tr>
<tr>
<td>b</td>
<td>5. hair cells of spiral organ (of Corti) rest on this membrane</td>
</tr>
<tr>
<td>i</td>
<td>6. gelatinous membrane overlying the hair cells of the spiral organ (of Corti)</td>
</tr>
<tr>
<td>a</td>
<td>7. contains the crista ampullaris</td>
</tr>
<tr>
<td>f, g, j, k</td>
<td>8. function in static equilibrium</td>
</tr>
<tr>
<td>a, e, h, k</td>
<td>9. function in dynamic equilibrium</td>
</tr>
<tr>
<td>d</td>
<td>10. carries auditory information to the brain</td>
</tr>
<tr>
<td>e</td>
<td>11. gelatinous cap overlying hair cells of the crista ampullaris</td>
</tr>
<tr>
<td>f</td>
<td>12. grains of calcium carbonate in the maculae</td>
</tr>
</tbody>
</table>
4. Sound waves hitting the tympanic membrane (eardrum) initiate its vibratory motion. Trace the pathway through which vibrations and fluid currents are transmitted to finally stimulate the hair cells in the spiral organ (of Corti). (Name the appropriate ear structures in their correct sequence.)

   Tympanic membrane ➔ malleus ➔ incus ➔ stapes ➔ oval window ➔ perilymph ➔ cochlear duct ➔ endolymph ➔ basilar membrane with hair cells

5. Describe how sounds of different frequency (pitch) are differentiated in the cochlea. It is believed that high-frequency (high-pitched) sounds peak close to the oval window while low-frequency (low-pitched) sounds peak near the cochlear apex, disturbing hair cells there (the “Place Principle”).

6. Explain the role of the endolymph of the semicircular canals in activating the receptors during angular motion.

   When angular motion occurs in one direction, the endolymph in a semicircular canal lags behind, pushing the cupula in a direction opposite to that of the angular motion. Depending on the ear, this depolarizes or hyperpolarizes the hair cells, resulting in enhanced or reduced impulses to the brain.

7. Explain the role of the otoliths in perception of static equilibrium (head position).

   When the head position changes, the otoliths move in gelatinous material in response to gravitational pull. This triggers hyperpolarization or depolarization of the hair cells and modifies the rate of impulse transmission along the vestibular nerve.

---

**Laboratory Tests**

8. Was the auditory acuity measurement made during the experiment on page 387 the same or different for both ears? (student response) What factors might account for a difference in the acuity of the two ears?

   Earwax, middle/external ear infection, cochlear nerve damage, etc.—anything that affects sound conduction or nervous system structures associated with hearing.

9. During the sound localization experiment on page 387, note the position(s) in which the sound was least easily located. How can this phenomenon be explained? The usual cues that allow sound to be localized (slight differences in loudness in the two ears and in the time the sound reaches each ear) are missing.

10. In the frequency experiment on page 388, note which tuning fork was the most difficult to hear. Answers may vary.
    What conclusion can you draw? High-frequency sounds are heard less well at low intensity.
11. When the tuning fork handle was pressed to your forehead during the Weber test, where did the sound seem to originate?  

From the ears.

Where did it seem to originate when one ear was plugged with cotton? From the plugged ear.

How do sound waves reach the cochlea when conduction deafness is present? By vibration through bones of the skull.

12. Indicate whether the following conditions relate to conduction deafness (C) or sensorineural deafness (S).

- c 1. can result from the fusion of the ossicles
- s 2. can result from a lesion on the cochlear nerve
- s 3. sound heard in one ear but not in the other during bone and air conduction
- c, s 4. can result from otitis media
- c 5. can result from impacted cerumen or a perforated eardrum
- s 6. can result from a blood clot in the auditory cortex

13. The Rinne test evaluates an individual’s ability to hear sounds conducted by air or bone. Which is more indicative of normal hearing? Air-conducted sound

14. Define nystagmus. Involuntary rolling or trailing of the eyes in one direction and then rapid movement in the opposite direction

Define vertigo. Sensation of dizziness and rotational movement when such movement is not occurring

15. The Barany test investigated the effect that rotatory acceleration had on the semicircular canals. Explain why the subject still had the sensation of rotation immediately after being stopped. The fluids of the inner ear had not yet stopped moving.

16. What is the usual reason for conducting the Romberg test? To determine if proprioceptive impulses are being transmitted up the spinal cord to the brain properly

Was the degree of sway greater with the eyes open or closed? Why? Closed. Visual cues (input) were lacking.

17. Normal balance, or equilibrium, depends on input from a number of sensory receptors. Name them.  

Proprioceptors of the muscles and tendons, vestibular apparatus of the ears, retina of the eye (photoreceptors)

18. What effect does alcohol consumption have on balance and equilibrium? Explain. Alcohol depresses the nervous system and enhances inhibition of reflex and coordination centers, causing a loss of balance and equilibrium.
Special Senses: Olfaction and Taste

Time Allotment: 1 hour.


The Senses of Smell and Taste (NIMCO: 28 minutes, VHS, DVD)
The Senses: Skin Deep (FHS: 28 minutes, VHS, DVD, 3-year streaming webcast)
Smell (part of the NOVA Mystery of the Senses series) (IM: 60 minutes each, 5-piece DVD set)
Smell and Taste (FHS: 30 minutes, VHS, DVD)
Taste (part of the NOVA Mystery of the Senses series) (IM: 60 minutes each, 5-piece DVD set)
Taste (FHS: 30 minutes, VHS, DVD, 3-year streaming webcast)

Laboratory Materials

Ordering information is based on a lab size of 24 students, working in groups of 4. A list of supply house addresses appears in Appendix A.

24 compound microscopes, lens paper, lens cleaning solution
24 slides of nasal olfactory epithelium (longitudinal section)
24 slides of tongue showing taste buds (cross section)
Paper towels
6 small mirrors
6 small packets of granulated sugar
Disposable autoclave bag
18 cotton-tipped swabs
6 dropper bottles of oil of cloves, oil of wintergreen, and oil of peppermint (or corresponding condiment flavors)
Absorbent cotton
Toothpicks
Disposable gloves
6 sets of 5 numbered vials containing common household substances with strong odors (herbs, spices, etc.)
6 flasks of distilled or tap water
6 paper plates
Chipped ice
6 opaque containers of equal-sized food cubes of cheese, apple, raw potato, dried prunes, banana, raw carrot, and hard-cooked egg white (at least 6 of each)
6 nose clips
6 paper cups

Advance Preparation

1. Set out slides of the tongue and the nasal epithelium, lens paper, and lens cleaning solution. Have compound microscopes available. (Or set up demonstration slides of the tongue and nasal epithelium.)
2. Set out for each group paper towels, a small mirror, a packet of granulated sugar, absorbent cotton, dropper bottles of oil of cloves and oil of wintergreen and oil of peppermint (or corresponding flavors from the condiment section of the supermarket), a flask of distilled water, a paper plate, and chipped ice.
3. Set out a disposable autoclave bag, toothpicks, and disposable gloves.
4. Prepare a plate of cubed food items such as cheese, apple, raw potato, dried prunes, banana, raw carrot, and hard-cooked egg white. These foods should be in an opaque container (a foil-lined egg carton works well). Keep covered and refrigerated until used.
5. Set out nose clips and five numbered vials containing common household substances with strong odors (such as cinnamon, garlic, ginger, rosemary, lemon peel, etc.).

6. Prepare an answer key for the five vials and have it available.

Comments and Pitfalls

1. Some students dislike putting cotton in their noses. Substitute good nose clips.
2. Some students may have difficulty getting their noses to adapt to the aromatic oil. Be sure they are following directions carefully and are patient.
3. Subjects for the food tests should not be allowed to see the food.
4. Remind students to use toothpicks to select food cubes. Caution students to alert the instructor and group members about food allergies.

Answers to Pre-Lab Quiz (p. 397)

1. true  
2. c, olfactory epithelium  
3. bipolar  
4. c, papillae  
5. two  
6. sweet, sour, bitter, salty, and umami  
7. false  
8. b, olfactory adaptation

Answers to Activity Questions

Location and Anatomy of Taste Buds (p. 399)

It is easiest to identify fungiform and circumvallate papillae.

Activity 3: Stimulating Taste Buds (p. 400)

Substances must be in aqueous solution to stimulate the taste buds.

Activity 4: Examining the Combined Effects of Smell, Texture, and Temperature on Taste (pp. 400–401)

Effects of Smell and Texture

3. No, some foods can be identified fairly easily by texture. The sense of smell is most important when foods do not have an easily recognizable and unique texture. For example, it is hard to differentiate between raw apple and raw potato.

Effect of Olfactory Stimulation

2. It is hard to distinguish the flavor with the nostrils closed.
3. With the nostrils open it is easy to identify the oil.
6. The subject usually identifies the oil held at the nostrils.
7. Smell seems to be more important for identification in this experiment.

Effect of Temperature

Identification is more difficult by a chilled tongue.

Activity 5: Assessing the Importance of Taste and Olfaction in Odor Identification (p. 402)

4. It is much easier to identify odors without the nose clips. There are only five basic tastes. Other taste sensations depend on olfaction.

Activity 6: Demonstrating Olfactory Adaptation (p. 402)

The adapted nostril should be able to detect the new oil. Adaptation is to the particular scent and not to aromatic oils in general.
Special Senses: Olfaction and Taste

Location and Anatomy of the Olfactory Receptors

1. Describe the location and cellular composition of the olfactory epithelium. A one-inch square area on roof of nasal cavity on each side of nasal septum. Receptor cells (bipolar neurons) surrounded by supporting cells.

2. How and why does sniffing improve your sense of smell? Draws air superiorly into contact with the olfactory mucosa. (Most air entering the nasal passages passes inferior to the receptors.)

Location and Anatomy of Taste Buds

3. Name five sites where receptors for taste are found, and circle the predominant site.
- (tongue papillae)
- epiglottis
- pharynx
- soft palate
- and cheek mucosa

4. Describe the cellular makeup and arrangement of a taste bud. (Use a diagram, if helpful.) A structure consisting of centrally located gustatory (receptor) cells surrounded by supporting cells.

Laboratory Experiments

5. Taste and smell receptors are both classified as chemoreceptors, because they both respond to chemicals in aqueous solution.

6. Why is it impossible to taste substances with a dry tongue? Substances must be in aqueous solution.

7. The basic taste sensations are mediated by specific chemical substances or groups. Name them for the following taste modalities.
   - salt: metal ions, especially Na⁺
   - sour: acids (e.g., lemon juice), specifically H⁺
   - bitter: alkaloids (e.g., caffeine), aspirin
   - sweet: sugars, saccharine, some amino acids, some lead salts
   - umami: the amino acid glutamate
8. Name three factors that influence our appreciation of foods. Substantiate each choice with an example from the laboratory experience.

1. **Smell** Substantiation: Answers may vary.

2. **Texture** Substantiation: Answers may vary.

3. **Temperature** Substantiation: Answers may vary.

Which of the factors chosen is most important? Smell Substantiate your choice with an example from everyday life. Answers may vary.

Expand on your explanation and choices by explaining why a cold, greasy hamburger is unappetizing to most people.

When hot, a hamburger is “juicy” and has an enticing aroma. When cold, the fat congeals, giving the hamburger a greasy taste and texture.

9. How palatable is food when you have a cold? It's not. Explain your answer. Smell is half of taste.

When you have clogged nasal passages, you lack this added sensory input.

10. In your opinion, is olfactory adaptation desirable? Yes. Explain your answer. Continuous unimportant (unchanging) olfactory stimuli would be distracting and (probably) irritating.
Functional Anatomy of the Endocrine Glands

**Time Allotment**: 1 hour+ (depending on detail required for microscopic study); additional work may be completed outside of lab.


* A.D.A.M.® Interactive Anatomy 4.0 (AIA; CD-ROM, DVD)
  * The Endocrine System (IM: 17 minutes, DVD)
  * Endocrine System (WNS: 16 minutes, VHS)
  * Hormonally Yours (FHS: 50 minutes, VHS, DVD, 3-year streaming webcast)
  * Hormone Heaven? (FHS: 50 minutes, VHS, DVD, 3-year streaming webcast)
  * Hormone Hell (FHS: 50 minutes, VHS, DVD, 3-year streaming webcast)
  * Hormones: Messengers (FHS: 27 minutes, VHS, DVD, 3-year streaming webcast)
  * The Neuroendocrine System (IM: 29 minutes, VHS)
  * Practice Anatomy Lab™ 2.0 (PAL) (BC: CD-ROM, Website)
  * Selected Actions of Hormones and Other Chemical Messengers (BC: 15 minutes, VHS)

**Laboratory Materials**

* Ordering information is based on a lab size of 24 students, working in groups of 4. A list of supply house addresses appears in Appendix A.

<table>
<thead>
<tr>
<th>Human torso model</th>
<th>Anatomical chart of human endocrine system</th>
<th>24 slides of anterior pituitary and posterior pituitary (differential staining, if possible), thyroid gland, parathyroid glands, adrenal gland, pancreas (differential staining, if possible)</th>
</tr>
</thead>
<tbody>
<tr>
<td>24 compound microscopes, lens paper, lens cleaning solution</td>
<td>24 compound microscopes, lens paper, lens cleaning solution</td>
<td>24 compound microscopes, lens paper, lens cleaning solution</td>
</tr>
</tbody>
</table>

**Advance Preparation**

1. Set out human torso models and anatomical charts.
2. Set out slides of the anterior pituitary, posterior pituitary, thyroid gland, parathyroid glands, adrenal gland, and pancreas tissue. The anterior and posterior pituitary gland and pancreas slides should be differentially stained, if possible. Set out lens paper and lens cleaning solution. Have compound microscopes available.
Answers to Pre-Lab Quiz (pp. 405–406)

1. A hormone is a chemical messenger that enters the blood for transport throughout the body.
2. endocrine
3. a, hypophysis
4. true
5. d, thyroid
6. glucagon
7. true
8. c, thymus
9. Pancreatic islets
10. b, zona glomerulosa
Functional Anatomy of the Endocrine Glands

Gross Anatomy and Basic Function of the Endocrine Glands

1. Both the endocrine and nervous systems are major regulating systems of the body; however, the nervous system has been compared to an airmail delivery system and the endocrine system to the pony express. Briefly explain this comparison.

   The nervous system uses rapidly propagated electrical “messages,” whereas endocrine system “messages” (hormones) are liberated into the blood to travel much more slowly to the target organs.

2. Define hormone. A chemical substance liberated into the extracellular fluid that enters blood for transport throughout the body.

   Hormones alter “target cell” metabolism in a specific manner.

3. Chemically, hormones belong chiefly to two molecular groups, the steroids and the amino acid–based molecules.

4. Define target organ. Organ responding to a particular hormone in a specific way.

5. If hormones travel in the bloodstream, why don’t all tissues respond to all hormones? The proper “hormone” receptors must be present on the plasma membrane or within the cells for the tissue cells to respond.

6. Identify the endocrine organ described by each of the following statements.

   - **thymus**: 1. located in the throat; bilobed gland connected by an isthmus
   - **testes**: 2. found close to the kidney
   - **pancreas**: 3. a mixed gland, located close to the stomach and small intestine
   - **parathyroids**: 4. paired glands suspended in the scrotum
   - **ovaries**: 5. ride “horseback” on the thyroid gland
   - **thymus**: 6. found in the pelvic cavity of the female, concerned with ova and female hormone production
   - **pineal gland**: 7. found in the upper thorax overlying the heart; large during youth
   - **adrenal gland**: 8. found in the roof of the third ventricle
   - **thyroid gland**: 9. located in the neck; bilobed gland connected by an isthmus
7. The table below lists the functions of many of the hormones you have studied. From the keys below, fill in the hormones responsible for each function, and the endocrine glands that produce each hormone. Glands may be used more than once.

<table>
<thead>
<tr>
<th>Function</th>
<th>Hormone(s)</th>
<th>Gland(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regulate the function of another endocrine gland</td>
<td>1. FSH</td>
<td>anterior pituitary</td>
</tr>
<tr>
<td></td>
<td>2. LH</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3. ACTH</td>
<td></td>
</tr>
<tr>
<td></td>
<td>4. TSH</td>
<td></td>
</tr>
<tr>
<td>Maintenance of salt and water balance in the extracellular fluid</td>
<td>1. aldosterone</td>
<td>adrenal cortex</td>
</tr>
<tr>
<td></td>
<td>2. ADH</td>
<td>hypothalamus</td>
</tr>
<tr>
<td>Directly involved in milk production and ejection</td>
<td>1. oxytocin</td>
<td>posterior pituitary</td>
</tr>
<tr>
<td></td>
<td>2. prolactin</td>
<td>anterior pituitary</td>
</tr>
<tr>
<td>Controls the rate of body metabolism and cellular oxidation</td>
<td>1. T₃/T₄</td>
<td>thyroid</td>
</tr>
<tr>
<td>Regulates blood calcium levels</td>
<td>1. calcitonin</td>
<td>thyroid</td>
</tr>
<tr>
<td></td>
<td>2. PTH</td>
<td>parathyroid</td>
</tr>
<tr>
<td>Regulates blood glucose levels; produced by the same &quot;mixed&quot; gland</td>
<td>1. insulin</td>
<td>pancreas</td>
</tr>
<tr>
<td></td>
<td>2. glucagon</td>
<td></td>
</tr>
<tr>
<td>Released in response to stressors</td>
<td>1. cortisol</td>
<td>adrenal cortex</td>
</tr>
<tr>
<td></td>
<td>2. epinephrine</td>
<td>adrenal medulla</td>
</tr>
<tr>
<td>Drives development of secondary sex characteristics in males</td>
<td>1. testosterone</td>
<td>testes</td>
</tr>
<tr>
<td>Directly responsible for regulation of the menstrual cycle</td>
<td>1. estrogen</td>
<td>ovaries</td>
</tr>
<tr>
<td></td>
<td>2. progesterone</td>
<td></td>
</tr>
</tbody>
</table>

8. Although the pituitary gland is often referred to as the master gland of the body, the hypothalamus exerts some control over the pituitary gland. How does the hypothalamus control both anterior and posterior pituitary functioning?

*Produces “releasing and inhibiting hormones,” which control the production and release of anterior pituitary hormones; forms hormones ADH and oxytocin, which are transported to the posterior pituitary and later released on nervous stimulation from the hypothalamus.*
9. Indicate whether the release of the hormones listed below is stimulated by (A) another hormone; (B) the nervous system (neurotransmitters, or neurosecretions); or (C) humoral factors (the concentration of specific nonhormonal substances in the blood or extracellular fluid). (Use your textbook as necessary.)

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>1. ACTH</td>
<td>C</td>
</tr>
<tr>
<td>C</td>
<td>2. calcitonin</td>
<td>B</td>
</tr>
<tr>
<td>A</td>
<td>3. estrogens</td>
<td>C</td>
</tr>
</tbody>
</table>

10. Name the hormone(s) produced in *inadequate* amounts that directly result in the following conditions. (Use your textbook as necessary.)

\[ PTH \]
1. tetany

\[ ADH \]
2. excessive diuresis without high blood glucose levels

insulin
3. loss of glucose in the urine

growth hormone (GH)
4. abnormally small stature, normal proportions

\[ T_4/T_3 \] (thyroid hormone)
5. low BMR, mental and physical sluggishness

11. Name the hormone(s) produced in *excessive* amounts that directly result in the following conditions. (Use your textbook as necessary.)

growth hormone (GH)
1. large hands and feet in the adult, large facial bones

\[ T_4/T_3 \] (thyroid hormone)
2. nervousness, irregular pulse rate, sweating

\[ PTH \]
3. demineralization of bones, spontaneous fractures

**Microscopic Anatomy of Selected Endocrine Glands**

12. Choose a response from the key below to name the hormone(s) produced by the cell types listed.

Key: a. calcitonin    
     b. GH, prolactin    
     c. glucagon    
     d. glucocorticoids    
     e. insulin    
     f. mineralocorticoids    
     g. PTH    
     h. \( T_4/T_3 \)    
     i. TSH, ACTH, FSH, LH

\[ a \]
1. parafollicular cells of the thyroid

\[ h \]
2. follicular epithelial cells of the thyroid

\[ e \]
3. beta cells of the pancreatic islets (islets of Langerhans)

\[ d \]
6. zona fasciculata cells

\[ f \]
7. zona glomerulosa cells

\[ g \]
8. chief cells

\[ b \]
9. acidophil cells of the anterior pituitary

\[ i \]
5. basophil cells of the anterior pituitary
13. Six diagrams of the microscopic structures of the endocrine glands are presented here. Identify each and name all structures indicated by a leader line or bracket.

(a) Anterior pituitary

(b) Adrenal gland

(c) Pancreatic islet

(d) Thyroid gland

(e) Posterior pituitary

(f) Parathyroid gland
Role of Thyroid Hormone, Pituitary Hormone, Insulin, and Epinephrine: Wet Lab

This exercise contains four experiments illustrating hormone function. Each experiment is discussed separately below.

Selected Actions of Hormones and Other Chemical Messengers (BC: 15 minutes, VHS)

Answers to Pre-Lab Quiz (p. 415)
1. Metabolism is a broad term referring to all chemical reactions that are necessary to maintain life.
2. Catabolism
3. d, Thyroid hormone
4. Control
5. b, increased in individuals with hyperthyroidism
6. c, oxygen
7. true
8. insulin
9. a, Flush the heart of a dissected frog with epinephrine.

ACTIVITY 1: DETERMINING THE EFFECT OF THYROID HORMONE ON METABOLIC RATE

Time Allotment: 1½ hours.

Solutions:
Propylthiouracil, 0.02% Weigh out 0.2 gram of propylthiouracil or PTU (6-propyl-2-thiouracil, Sigma-Aldrich). Add distilled water to make 1 liter of solution. Filter and store in light-resistant containers.
Caution! propylthiouracil is a suspected carcinogen. (Note: If it is difficult to dissolve the PTU, add concentrated NaOH to adjust the pH to 8.0.)

Rat Chow with Thyroid Extract
Grind up sufficient regular laboratory rat chow to feed the required number of animals for 2 weeks (approximately 40 grams chow/rat/day). Add 20 grams of desiccated thyroid powder (Nutri-Meds) for each 1000 grams of rat chow. Mix thoroughly.

Laboratory Materials
Ordering information is based on a lab size of 24 students, working in groups of 4. A list of supply house addresses appears in Appendix A.

6 glass desiccators 6 T-valves Rubber tubing; tubing clamp; scissors
6 manometers Soda lime (desiccant) 7.6-cm (3-inch) pieces of glass tubing
6 glass syringes (20 ml) 6 hardware cloth squares Animal balances
6 two-hole rubber stoppers Petrolatum Heavy animal-handling gloves
Advance Preparation

1. At least 14 days prior to the date of the lab, obtain young rats (about five weeks old) of the same sex. Six rats per lab session should be sufficient. Keep them in clean, well-ventilated surroundings at room temperature. Divide the rats into three groups. Label one group “Group 1—control,” and feed with normal rat chow and water. Label another group “Group 2—experimental group A,” and feed with normal rat chow and drinking water containing 0.02% propylthiouracil*. Label a third group “Group 3—experimental group B,” and feed with rat chow containing 2% desiccated thyroid (by weight) and normal drinking water.

2. For each student group, set out a glass desiccator, manometer, 20-milliliter glass syringe, two-hole cork, clamp, T-valve, soda lime, hardware cloth or porcelain platform, 36 inches of rubber tubing, scissors, two 3-inch pieces of glass tubing, and petrolatum. Be sure that the rubber tubing will form a tight seal with the glass tubing and the nib of the syringe. Set out animal balances (Carolina) and heavy animal-handling gloves.

Comments and Pitfalls

1. Leaks in the respirometer will probably be the biggest problem.

2. Be sure that students use the animal-handling gloves when handling the rats to avoid accidental bites. Be sure the animals are handled gently, and avoid squeezing them. Remove rats from their cages by pulling them by their tails. Then hold them firmly by the skin at the back of the neck.

3. When measuring basal rate, discard readings obtained during periods of rat activity.

ACTIVITY 2: DETERMINING THE EFFECT OF PITUITARY HORMONES ON THE OVARY

**Time Allotment:** 2 hours (1½ hours of waiting time)

**Solutions:**

Physiologic Saline (Amphibian, 0.75%)

Weigh out 7.5 grams of NaCl. Add water (undistilled) to a final volume of 1 liter. Make fresh immediately prior to experiment. (Note: 0.7% saline may also be used.)

Laboratory Materials

*Ordering information is based on a lab size of 24 students, working in groups of 4. A list of supply house addresses appears in Appendix A.*

- 18 female frogs (*Rana pipiens*)
- Disposable gloves
- 12 battery jars
- 12 syringes (2 ml)
- 12 20- to 25-gauge needles
- 6 vials of frog pituitary extract
- 6 small bottles of amphibian physiologic saline
- Spring or pond water
- 6 wax marking pencils
Advance Preparation

1. Order female frogs (two per group) to be delivered close to the date of the exercise (see preparation for the frog experiment in Exercise 16A). Designate a frog disposal area. Set out disposable gloves.
2. For each group set out two syringes with 20- to 25-gauge needles, two battery jars, wax marking pencils, a small bottle of *amphibian physiologic saline*, pond or spring water, and a vial of frog pituitary extract (Carolina).

Comments and Pitfalls

1. Distilled water should be used as a control if the pituitary extract is suspended in water.
2. Injected frogs should be kept in a quiet area.
3. When introducing this exercise, caution students to hold the frog’s body firmly and above its hind legs. Demonstrate the holding and carrying procedure.

Answers to Activity Questions (p. 419)

6. Ovulation is induced in the frog that received the pituitary extract injection. LH is the primary hormone stimulus for ovulation.

ACTIVITY 3: OBSERVING THE EFFECTS OF HYPERINSULINISM

**Time Allotment:** 1/2 hour.

**Solutions:**

- **Glucose, 20%**
  Weigh out 200 grams of glucose. Add distilled water to a final volume of 1 liter.

Laboratory Materials

*Ordering information is based on a lab size of 24 students, working in groups of 4. A list of supply house addresses appears in Appendix A.*

- 500- or 600-ml beakers
- 6 bottles of 20% glucose solution (250 ml)
- Dropper bottle of commercial insulin (400 immunizing units [IU] per 100 ml of H2O)
- 12 finger bowls
- 6 small (1.5–2-inch) freshwater fish (listed in order of preference: guppy, bluegill, or sunfish)
- 6 wax marking pencils

Advance Preparation

1. Prepare a solution of 20% *glucose* and store it in the refrigerator. Purchase or order enough small fish to supply one per group. Set up an aquarium or large beaker with an air stone to maintain the fish.
2. For each group set out a 250-milliliter bottle of 20% *glucose*, a dropper bottle of *insulin*, a glass marking pencil, and two finger bowls.
Comments and Pitfalls

1. The fish may become very agitated and jump out of the bowl or beaker.
2. This exercise may be upsetting to some students, even though the fish recover.

Answers to Activity Questions (pp. 419–420)

2. The fish often becomes very agitated, then loses its sense of balance just before becoming unconscious.
3. The fish will regain consciousness and right itself. The recovery time varies.

ACTIVITY 4: TESTING THE EFFECT OF EPINEPHRINE ON THE HEART

Time Allotment: 1/2 hour.

Solutions:

*Ringer’s Solution, Frog*
- 6.50 grams sodium chloride
- 0.14 gram potassium chloride
- 0.12 gram calcium chloride
- 0.20 gram sodium bicarbonate

Combine salts in flask and add distilled water to make 1 liter of solution.

*Epinephrine (Adrenalin), 1:1000*

Weigh out 0.1 gram of epinephrine (Carolina).
Dissolve in 0.5 milliliter of 1 N HCl.
Add distilled water to a final volume of 100 milliliters.

Caution! Epinephrine is toxic. Label TOXIC.

Laboratory Materials

*Ordering information is based on a lab size of 24 students, working in groups of 4. A list of supply house addresses appears in Appendix A.*

<table>
<thead>
<tr>
<th>Item</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>18 female frogs (<em>Rana pipiens</em>)</td>
<td>18</td>
</tr>
<tr>
<td>6 dissecting pans and dissecting kits</td>
<td>6</td>
</tr>
<tr>
<td>6 dropper bottles of Ringer’s solution, frog</td>
<td>6</td>
</tr>
<tr>
<td>6 dropper bottles of 1:1000 epinephrine</td>
<td>6</td>
</tr>
<tr>
<td>Disposable gloves</td>
<td></td>
</tr>
</tbody>
</table>

Advance Preparation*

1. Order frogs (one per group) to be delivered 2–3 days prior to the date of the experiment (see Exercise 16A). Designate a frog disposal area. To save time, frogs may be pithed just before the lab.
2. For each group set out a dissecting pan, disposable gloves, instruments, a dropper bottle of *frog Ringer’s solution*, and a dropper bottle of *1:1000 epinephrine*. Caution! Epinephrine is toxic. Label the bottle TOXIC.

* If desired, these observations may be deferred and made in conjunction with those in Exercise 34A. This approach also conserves animals.
Comments and Pitfalls

1. Be sure students keep the heart moistened throughout the experiment.

Answers to Activity Questions (p. 420)

6. Epinephrine increases the heart rate. Yes, the epinephrine causes the frog to be very active for 10–30 seconds and then there is decreasing activity for one to several minutes.
Role of Thyroid Hormone, Pituitary Hormone, Insulin, and Epinephrine: Wet Lab

Determining the Effect of Thyroid Hormone on Metabolic Rate

1. In the measurement of oxygen consumption in rats, which group had the highest metabolic rate?
   - Experimental group B
   - Which group had the lowest metabolic rate? Experimental group A

Correlate these observations with the pretreatment these animals received. Group B received chow containing 2% desiccated thyroid containing thyroid hormone, which increased the metabolic rate. Group A received normal chow and drinking water containing 0.02% PTU. PTU inhibits T4 and T3 production.

Which group of rats was hyperthyroid? Group B
Which euthyroid? Control
Which hypothyroid? Group A

2. Since oxygen used = carbon dioxide evolved, how do you know that what you measured was oxygen consumption?
   - CO2 evolved was absorbed by the soda lime; therefore, pressure changes indicated O2 consumption.

3. What did changes in the fluid levels in the manometer arms indicate? Changes in the fluid levels reflected pressure changes, which in turn reflected O2 consumption during the testing period.

4. The techniques used in this set of laboratory experiments probably permitted several inaccuracies. One was the inability to control the activity of the rats. How would changes in their activity levels affect the results observed?
   - Increased activity would lead to increased O2 consumption/metabolic rate, whereas decreased activity would result in lower observed O2 consumption.

Another possible source of error was the lack of control over the amount of food consumed by the rats in the 14-day period preceding the laboratory session. If each of the rats had been force-fed equivalent amounts of food in that 14-day period, which group (do you think) would have gained the most weight?

Group A
Which the least? Group B

Explain your answers. Increasing the metabolic rate increases the rate at which food calories are oxidized by the tissue cells. The faster the rate, the less chance that food calories will be converted to fat, or result in weight gain.
5. TSH, produced by the anterior pituitary, prods the thyroid gland to release thyroid hormone to the blood. Which group of rats can be assumed to have the highest blood levels of TSH? Group A ________ Which the lowest? Group B ________

Explain your reasoning. Group A was producing no thyroid hormone because of PTU inhibition. Group B was receiving exogenous (excess) thyroxine, which would inhibit TSH release.

6. Use an appropriate reference to determine how each of the following factors modifies metabolic rate. Indicate increase by ↑ and decrease by ↓.

- Increased exercise ↑
- Aging ↓
- Infection/fever ↑
- Small/slight stature ↑
- Obesity ↓
- Sex (♂ or ♀) ↑ in ♀

Determining the Effect of Pituitary Hormones on the Ovary

7. In the experiment on the effects of pituitary hormones, two anterior pituitary hormones caused ovulation to occur in the experimental animal. Which of these actually triggered ovulation or egg expulsion?

**LH** ________ The normal function of the second hormone involved, **FSH** ________, is to stimulate follicle (and oocyte) maturation.

8. Why was a second frog injected with saline? To provide a control.

Observing the Effects of Hyperinsulinism

9. Briefly explain what was happening within the fish’s system when the fish was immersed in the insulin solution.

Glucose was being swept out of the blood into the cells. This led to a hypoglycemic reaction, which affects nervous system functioning adversely.

10. What is the mechanism of the recovery process observed? Glucose was added. Increased glucose levels in the blood reversed the effects noted above.

11. What would you do to help a friend who had inadvertently taken an overdose of insulin? Give him/her a glass of orange juice or soda. Why? A sugar source will increase blood glucose levels as explained in #10.

Testing the Effect of Epinephrine on the Heart

12. Based on your observations, what is the effect of epinephrine on the rate of the heartbeat?

It increases the rate of heartbeat. You may also have observed that epinephrine increases the force of the heartbeat.

13. What is the role of this effect in the “fight-or-flight” response?

Promotes faster delivery of blood throughout the body due to the increase in blood pressure.
Blood

Note: For safety reasons, many instructors make the blood tests optional or try to provide alternative experiments. Substituting dog blood, as suggested below, is one option; using prepared slides or artificial blood are others.

Time Allotment: 2 hours.


Bleeding and Coagulation (FHS: 31 minutes, VHS, DVD, 3-year streaming webcast)
Blood (DE: 22 minutes, VHS, DVD)
Blood (FHS: 20 minutes, VHS, DVD, 3-year streaming webcast)
Blood and Immunity (CVB: CD-ROM)
Practice Anatomy Lab™ 2.0 (PAL) (BC: CD-ROM, Website)

Solutions:
Bleach Solution, 10%
Measure out 100 milliliters of household bleach. Add water (undistilled) to a final volume of 1 liter.

Laboratory Materials

Ordering information is based on a lab size of 24 students, working in groups of 4. A list of supply house addresses appears in Appendix A.

Disposable gloves
24 pairs of safety glasses
Bucket or 6 beakers containing 10% household bleach solution
6 spray bottles containing 10% bleach solution
Autoclave bag
Designated lancet (sharps) disposable container
6 animal plasma samples (obtained from an animal hospital or prepared by centrifuging animal blood obtained from a biological supply house)
24 test tubes and test tube racks
6 packages of wide-range pH paper
Stained smears of human blood from a biological supply house or heparinized animal blood
obtained from a biological supply house or animal hospital
2 boxes of clean microscope slides
Glass stirring rods
6–12 dropper bottles of Wright’s stain
6–12 dropper bottles of distilled water
6 boxes sterile lancets, alcohol swaps, absorbent cotton balls
Paper towels
24 compound microscopes, lens paper, lens cleaning solution
Immersion oil
3-D models and/or charts of blood cells
Assorted slides of white blood count pathologies labeled “Unknown Sample # ____”
6 timers
24 heparinized capillary tubes
Microhematocrit centrifuge and reading gauge (if reading gauge is not available, a millimeter ruler may be used)
24 millimeter rulers
Capillary tube sealer or modeling clay
Hemoglobinometer, hemolysis applicator, and lens paper; or Tallquist hemoglobin scale and test paper
24 capillary tubes (nonheparinized)
6–12 fine triangular files
6 bottles of each blood typing sera (anti-A, anti-B, and anti-Rh [anti-D])
Rh typing box
24 wax marking pencils
Toothpicks and 24 clean glass slides or 24 test cards and blood-mixing sticks
Advance Preparation

1. Set out safety glasses, lens paper, lens cleaning solution, and immersion oil. Have compound microscopes available. Set out any available models and charts of blood cells.

2. Set out prepared slides of macrocytic hypochromic anemia, microcytic hypochromic anemia, sickle-cell anemia, lymphocytic leukemia (chronic), and eosinophilia.

3. Set up the following supply areas (if all tests are to be done). Ideally there should be at least one set of solutions for each lab bench and enough of the other supplies for each student to do each test. If equipment must be shared, it should be washed in hot soapy water and rinsed in 10% bleach solution after each use.

   **General supply area:**
   a. For instructors using student blood samples, set out sterile blood lancets, designated lancet (sharps) disposal containers, alcohol wipes, and absorbent cotton balls. Set up a disposable autoclave bag for all disposable items, and a laboratory bucket or battery jar of 10% bleach solution for glassware. For each lab group, set out a 250-milliliter beaker of 10% bleach solution (for used slides), spray bottles of 10% bleach solution, clean microscope slides (two per member of the group), a dropper bottle of Wright’s stain (Carolina), a dropper bottle of distilled water, wide-range pH paper, test tube and test tube rack, nonhemolyzed plasma obtained fresh from an animal hospital or prepared by centrifuging animal (e.g., cattle or sheep) blood obtained from a biological supply house, timers, and disposable gloves.
   b. For instructors using heparinized dog blood, set out heparinized dog blood, glass rods, and all the materials listed in paragraph a, except the sterile lancets and alcohol wipes.
   c. EDTA-treated red cells (reference cells) with blood type labels obscured (available from Immucor, Inc.) could also be used.
   d. For instructors using stained smears of human blood, set out prepared slides of human blood stained with Wright’s stain.
   e. Set out slides of WBC pathologies with the labels covered and marked “Unknown sample # ___.“ Suggestions include eosinophilia, neutrophilia, and various leukemias.

   **Hematocrit supply area:**
   Set out heparinized capillary tubes, microhematocrit centrifuge and reading gauge or millimeter ruler, and BD Seal-Ease™ or capillary tube sealer (Carolina) or modeling clay.

   **Hemoglobin-determination supply area:**
   Set out hemoglobinometer and hemolysis applicator or Tallquist scales.

   **Coagulation time supply area:**
   Set out nonheparinized capillary tubes, fine triangular files, and paper towels.

   **Blood-typing supply area:**
   Set out blood-typing sera, Rh-typing boxes (if used), wax markers, toothpicks, and blood test cards or slides (Carolina). If you are using WARD’S artificial blood, set out simulated blood and antibodies provided with the kit.

   **Cholesterol-measurement supply area:**
   Set out cholesterol test cards and color scale (Craig Medical).
Comments and Pitfalls

1. If human blood samples are provided, disposable gloves and safety glasses should be worn at all times. If student samples are used, be sure students use only their own blood. Emphasize instructions for proper care or disposal of items used in the blood tests (see Anatomy and Physiology Laboratory Safety Procedures in the preface of this Instructor Guide and p. 424 of the laboratory manual). Be sure that sharp objects such as lancets are discarded only in a designated lancet or sharps disposal container.

2. If student blood samples are used, have the students plan their work so that a minimum number of pricks are necessary. Obtaining enough blood is the usual problem. Be sure that students’ hands are warm before trying to obtain blood, and that they follow the advice in the laboratory manual. Emphasize that the capillary tube should be held in a horizontal position with the tip in the drop of blood.

3. It is nearly impossible to prick your own finger to draw blood unless an automatic device is used (available in many pharmacies or online at www.walgreens.com). Students are often careless with the lancets since they are concentrating on obtaining blood for several different tests. Emphasize the importance of proper disposal. This is particularly important when using an automatic device, as it is difficult to distinguish a used lancet with a replaced cap from a new, unused one.

4. Obviously, heparinized blood samples may not be used for the coagulation time experiment.

5. Several problems may arise with the slides. Student-prepared blood smears tend to be too thick; be sure they understand the technique before starting. Warn against allowing the slide to dry with the stain on it. Avoid using old Wright stain, which may develop sediment that interferes with reading the slides.

6. A good color plate of the blood cells will help with identification. It may help to have some prepared slides available for demonstration. Also, point out the typical percentages of each cell type. Many students initially identify large numbers of cells as basophils.

7. Emphasize that the coagulation-time test must be started as soon as blood is drawn up into the capillary tube. Have students hold the tubes with paper towels when breaking them to avoid cuts.

8. Blood typing may be done here, but it may be easier to explain if it is done after the immune system has been discussed.

Answers to Pre-Lab Quiz (p. 423)

1. false
2. c, platelets
3. erythrocytes
4. c, monocyte
5. a, Basophils
6. hematocrit
7. antigens
8. true
Blood

Composition of Blood

1. What is the blood volume of an average-size adult male? ______________ liters
   An average adult female? ______________ liters

2. What determines whether blood is bright red or a dull brick-red? Its degree of oxygenation. The more oxygen it carries, the brighter red it is.

3. Use the key to identify the cell type(s) or blood elements that fit the following descriptive statements.

   Key:
   a. red blood cell
   b. megakaryocyte
   c. eosinophil
   d. basophil
   e. monocyte
   f. neutrophil
   g. lymphocyte
   h. formed elements
   i. plasma

   f; neutrophil  1. most numerous leukocyte
   c; eosinophil  d; basophil, and f; neutrophil  2. granulocytes (3)
   a; red blood cell  3. also called an erythrocyte; anucleate formed element
   e; monocyte  f; neutrophil  4. actively phagocytic leukocytes
   e; monocyte  g; lymphocyte  5. agranulocytes
   b; megakaryocyte  6. ancestral cell of platelets
   h; formed elements  7. (a) through (g) are all examples of these
   c; eosinophil  8. number rises during parasite infections
   d; basophil  9. releases histamine; promotes inflammation
   g; lymphocyte  10. many formed in lymphoid tissue
   a; red blood cell  11. transports oxygen
   i; plasma  12. primarily water, noncellular; the fluid matrix of blood
   e; monocyte  13. increases in number during prolonged infections
   c; eosinophil  d; basophil  e; monocyte.
   f; neutrophil, and g; lymphocyte  14. the five types of white blood cells
4. List four classes of nutrients normally found in plasma. **sugar (e.g., glucose)**, **amino acids** and **lipids (fatty acids)**, and **vitamins**

Name two gases. **oxygen** and **carbon dioxide (nitrogen)**

Name three ions. **Na⁺**, **Cl⁻**, and **Mg²⁺ (HCO₃⁻, K⁺, Ca²⁺)**

5. Describe the consistency and color of the plasma you observed in the laboratory. **Viscous and sticky; straw colored**

6. What is the average life span of a red blood cell? How does its anucleate condition affect this life span?

   *100–120 days. When the RBC’s ATP reserves have been exhausted, the membrane begins to fragment. Without DNA to direct mRNA (therefore protein) synthesis, needed enzymes cannot be made.*

7. From memory, describe the structural characteristics of each of the following blood cell types as accurately as possible, and note the percentage of each in the total white blood cell population.

   - **Eosinophils**: Large, red-staining cytoplasmic granules; figure 8 or bilobed nucleus; 1–4% of WBC.
   - **Neutrophils**: Pale pink cytoplasm with fine granules; nucleus is multilobed and stains deep purple; 40–70% of WBC.
   - **Lymphocytes**: Small cell with sparse pale blue cytoplasm and dark purple-staining spherical nucleus; 20–45% of WBC.
   - **Basophils**: Sparse dark blue cytoplasmic granules that may obscure the large U-shaped nucleus which stains dark blue; 0.5% or less of WBC.
   - **Monocytes**: Abundant gray-blue cytoplasm, dark blue-purple nucleus (often kidney shaped); 4–8% of WBC.

8. Correctly identify the blood pathologies described in column A by matching them with selections from column B:

<table>
<thead>
<tr>
<th>Column A</th>
<th>Column B</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>b: leukocytosis</strong></td>
<td>1. abnormal increase in the number of WBCs</td>
</tr>
<tr>
<td><strong>d: polycythemia</strong></td>
<td>2. abnormal increase in the number of RBCs</td>
</tr>
<tr>
<td><strong>a: anemia</strong></td>
<td>3. condition of too few RBCs or of RBCs with hemoglobin deficiencies</td>
</tr>
<tr>
<td><strong>c: leukopenia</strong></td>
<td>4. abnormal decrease in the number of WBCs</td>
</tr>
</tbody>
</table>
Hematologic Tests

9. Broadly speaking, why are hematologic studies of blood so important in the diagnosis of disease?

Specific changes from the normal numbers/types of formed elements and/or plasma constituents are characteristic of certain disease states.

10. In the chart below, record information from the blood tests you read about or conducted. Complete the chart by recording values for healthy male adults and indicating the significance of high or low values for each test.

<table>
<thead>
<tr>
<th>Test</th>
<th>Student test results</th>
<th>Normal values (healthy male adults)</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total WBC count</td>
<td>No data</td>
<td>4000–11,000/mm³</td>
<td>infection, metabolic disease, hemorrhage, or poisoning</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>decreased body protection or chemical toxicity, or disease</td>
</tr>
<tr>
<td>Total RBC count</td>
<td>No data</td>
<td>4–6 million/mm³</td>
<td>polycythemia due to high altitude or pulmonary disease</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>anemia or bone marrow cancer</td>
</tr>
<tr>
<td>Hematocrit</td>
<td></td>
<td>42–52 volume %</td>
<td>polycythemia, dehydration, congestive heart failure, shock, or</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>surgery</td>
</tr>
<tr>
<td>Hemoglobin determination</td>
<td></td>
<td>13–18g/100 ml blood</td>
<td>polycythemia or dehydration</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>anemia (particularly iron-deficiency anemia)</td>
</tr>
<tr>
<td>Bleeding time</td>
<td>No data</td>
<td>2–7 min (Ivy) 0–5 min (Duke)</td>
<td>deficient or abnormal platelets</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>high platelet count</td>
</tr>
<tr>
<td>Coagulation time</td>
<td></td>
<td>2–6 min</td>
<td>hemophilia, leukemia, increased clotting time</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>thromboembolic disorders</td>
</tr>
</tbody>
</table>

11. Why is a differential WBC count more valuable than a total WBC count when trying to pin down the specific source of pathology? A differential count determines the relative percent of each type of WBC. Increases or decreases in specific WBC populations are often indicative (diagnostic) of specific pathologies.
12. What name is given to the process of RBC production? **Erythropoiesis**

What hormone acts as a stimulus for this process? **Erythropoietin**

Why might patients with kidney disease suffer from anemia? *When kidneys fail, they also do not produce enough erythropoietin to sustain erythropoiesis.*

How can such patients be treated? *They can be given genetically engineered erythropoietin (EPO).*

13. Discuss the effect of each of the following factors on RBC count. Consult an appropriate reference as necessary, and explain your reasoning.

- **Long-term effect of athletic training** (for example, running 4 to 5 miles per day over a period of six to nine months): *Increases the RBC count. An athlete has relatively large muscle mass and needs an efficient oxygen delivery to the muscles when they are working.*

- **A permanent move from sea level to a high-altitude area:** *Increased RBC count. The air is thinner at high altitudes and contains less O₂. The body compensates by producing more RBCs so that the same relative amount of O₂ can be picked up and transported by the blood.*

14. Define **hematocrit.** *Packed cell volume; percentage of total blood volume occupied by RBC.*

15. If you had a high hematocrit, would you expect your hemoglobin determination to be high or low? **High**

   Why? *Assuming the RBCs have a normal hemoglobin content, the higher the RBC volume, the higher the hemoglobin determination.*

16. What is an anticoagulant? *A substance that inhibits blood clotting*

   Name two anticoagulants used in conducting the hematologic tests: **Heparin (in capillary tubes)** and **EDTA**

   What is the body’s natural anticoagulant? **Heparin**

17. If your blood clumped with both anti-A and anti-B sera, your ABO blood type would be **AB**

   To what ABO blood groups could you give blood? **AB**

   From which ABO donor types could you receive blood? **A, B, AB, O**

   Which ABO blood type is most common? **O** Least common? **AB**

18. What blood type is theoretically considered the universal donor? **O⁻**

   Why? *These RBCs have no A, B or Rh antigens on the cell membrane, reducing the chance of a transfusion reaction.*
19. Assume the blood of two patients has been typed for ABO blood type.

Typing results
Mr. Adams:

Typing results
Mr. Calhoon:

On the basis of these results, Mr. Adams has type \(O\) \(\) blood, and Mr. Calhoon has type \(A\) \(\) blood.

20. Explain why an Rh-negative person does not have a transfusion reaction on the first exposure to Rh-positive blood but \(\)\(\) has a reaction on the second exposure. \(\)\(\) There are no preformed anti-Rh antibodies in his/her blood. After the first exposure to \(\)\(\) Rh\(^+\) blood, the immune system reacts and then starts making antibodies. \(\)\(\) What happens when an ABO blood type is mismatched for the first time? \(\)\(\) A transfusion reaction occurs the first and every time. \(\)\(\)

21. Record your observations of the five demonstration slides viewed.

a. Macrocytic hypochromic anemia: \(\)\(\) RBCs are large and pale. \(\)\(\)

b. Microcytic hypochromic anemia: \(\)\(\) RBCs are small and pale. \(\)\(\)

c. Sickle-cell anemia: \(\)\(\) RBCs are crescent shaped. \(\)\(\)

d. Lymphocytic leukemia (chronic): \(\)\(\) Large number of small abnormal lymphocytes. \(\)\(\)

e. Eosinophilia: \(\)\(\) Increased number of eosinophils. \(\)\(\)

Which of the slides above (a through e) corresponds with the following conditions?

\(b\) 1. iron-deficient diet \(\)\(\) \(a\) 4. lack of vitamin \(B_{12}\) \(\)
\(d\) 2. a type of bone marrow cancer \(\)\(\) \(e\) 5. a tapeworm infestation in the body \(\)
\(c\) 3. genetic defect that causes hemoglobin to become sharp/spiky \(\)\(\) \(b\) 6. a bleeding ulcer \(\)
22. Provide the normal, or at least “desirable,” range for plasma cholesterol concentration.

130–200 mg/100 ml

23. Describe the relationship between high blood cholesterol levels and cardiovascular diseases such as hypertension, heart attacks, and strokes.

*High LDL levels favor cholesterol uptake and deposit in arteriosclerotic plaques, which, in turn: (1) narrow the vessel, reducing blood flow to more distal tissues, and (2) increase the risk of thrombus formation. Narrowing of blood vessels is one cause of hypertension. Attached thrombi or detached thrombi (emboli) are common causes of heart attack and stroke.*
Anatomy of the Heart

Time Allotment: 1½ hours.


- A.D.A.M.® Interactive Anatomy 4.0 (AIA: CD-ROM, DVD)
- The Circulatory System: Two Hearts that Beat as One (FHS: 28 minutes, VHS, DVD, 3-year streaming webcast)
- Human Cardiovascular System: The Heart Videotape (BC: 22 minutes, VHS)
- Interactive Physiology® 10-System Suite: Cardiovascular System (BC: CD-ROM, Website)
- Life Under Pressure (FHS: 26 minutes, VHS, DVD, 3-year streaming webcast)
- Practice Anatomy Lab™ 2.0 (PAL) (BC: CD-ROM, Website)

Laboratory Materials

Ordering information is based on a lab size of 24 students, working in groups of 4. A list of supply house addresses appears in Appendix A.

- X ray of human thorax
- X-ray viewing box
- 3-D model of the heart
- 3-D torso model
- Chart showing heart anatomy
- 24 red pencils
- 24 blue pencils
- 3-D models of cardiac and skeletal muscle
- 24 compound microscopes, lens paper, lens cleaning solution, immersion oil
- 24 prepared slides of cardiac muscle (longitudinal section)
- 6–12 preserved sheep hearts (with pericardial sacs intact, if possible)
- 6–12 dissecting instruments and tray sets
- 6–12 pointed glass rods for probes (or blunt probes)
- 6–12 millimeter rulers
- Disposable gloves
- Container for disposal of organic debris
- Laboratory detergent
- Spray bottle with 10% household bleach solution

Advance Preparation

1. Make arrangements for appropriate storage, disposal, and cleanup of dissection materials. Check with the Department of Health or the Department of Environmental Protection, or their counterparts, for state regulations.
2. Set out disposable gloves and safety glasses.
3. Set out dissecting kits, dissecting pans, glass or blunt probes, plastic metric rulers, and preserved sheep hearts (one for each group).
4. Set out dissectible heart and cardiac muscle models, red and blue pencils, and heart anatomy charts.
5. Set out prepared slides of cardiac muscle (longitudinal section), lens tissue, immersion oil, and lens cleaning solution. Have compound microscopes available.
6. Set out an X ray of the human thorax and an X-ray viewing box.
7. Set out dissectable heart models.
Comments and Pitfalls

1. Some sheep hearts are sold with the pericardial sac removed. If possible, order sheep hearts with intact pericardial sacs (biology supply companies).
2. Students often confuse the base and apex of the heart.
3. Be sure students have correctly identified the left ventricle of the heart as a landmark before they begin the dissection. As with all dissections, urge students to be cautious with the scalpel.
4. Many preserved hearts have the venae cavae and pulmonary veins completely removed, leaving large holes in the walls of the atria. This will make it difficult for students to answer some of the questions in the lab text. Purchase a dissected pig heart that has all the major vessels intact (biology supply companies), or refer students to models if necessary.
5. Provide students with extra blunt probes to mark vessels as they are identified.

Answers to Pre-Lab Quiz (p. 443)

1. c, pericardium
2. c, four
3. atria
4. a, aorta
5. true
6. tricuspid
7. right
8. c, coronary arteries
9. a, intercalated discs
10. left

Answers to Dissection Questions

Dissection: The Sheep Heart (pp. 449–452)

2. The pericardium is attached to the base of the heart.
3. The visceral pericardium is much thinner than the tough two-layered sero-fibrous parietal pericardium. The visceral pericardium adheres tightly to the heart, while the parietal pericardium forms the outer sac surrounding the pericardial cavity.
6. The aorta is easier to stretch. The aorta must stretch to accommodate the increased volume of blood that enters with each left ventricular contraction.
8. The lumen of the vena cava is larger. The aorta has thicker walls. The aorta is capable of stretching and elastic recoiling, which helps to maintain pressure in the vessels. This requires strength and resilience. The vena cava is a low-pressure vessel for blood return to the heart, and is not subjected to large pressure fluctuations.
9. The tricuspid valve has three flaps.
10. The pulmonary (semilunar) valve closes when fluid fills the collapsed cuplike valves, causing them to bulge out into the lumen. The atrioventricular valves are flaps that swing closed as pressure in the ventricle increases. They are prevented from opening backwards into the atria by the chordae tendineae attached to the papillary muscles.
14. The left ventricular cavity is much narrower than the right ventricular cavity. Papillary muscles and chordae tendineae are present in both cavities. The mitral valve has two cusps; the tricuspid valve has three cusps. The sheep valves are very similar to their human counterparts.
Anatomy of the Heart

Gross Anatomy of the Human Heart

1. An anterior view of the heart is shown here. Match each structure listed on the left with the correct letter in the figure.

   g □ ______ 1. right atrium           a □ ______  i. right atrium
   j □ ______ 2. right ventricle         b □ ______  j. right ventricle
   r □ ______ 3. left atrium             c □ ______  c. left atrium
   u □ ______ 4. left ventricle          d □ ______  d. left ventricle
   b □ ______ 5. superior vena cava      e □ ______  e. superior vena cava
   k □ ______ 6. inferior vena cava      f □ ______  f. inferior vena cava
   d □ ______ 7. ascending aorta         g □ ______  g. ascending aorta
   n □ ______ 8. aortic arch             h □ ______  h. aortic arch
   a □ ______ 9. brachiocephalic artery  i □ ______  i. brachiocephalic artery
   l □ ______ 10. left common carotid artery  j □ ______  j. left common carotid artery
   m □ ______ 11. left subclavian artery  k □ ______  k. left subclavian artery
   e □ ______ 12. pulmonary trunk        l □ ______  l. pulmonary trunk
   c □ ______ 13. right pulmonary artery  m □ ______  m. right pulmonary artery
   p □ ______ 14. left pulmonary artery  o □ ______  o. left pulmonary artery
   f □ ______ 16. right pulmonary veins  t □ ______  t. right pulmonary veins
   q □ ______ 17. left pulmonary veins   s □ ______  s. left pulmonary veins
   h □ ______ 18. right coronary artery  w □ ______  w. right coronary artery
   i □ ______ 19. anterior cardiac vein  x □ ______  x. anterior cardiac vein
   v □ ______ 20. left coronary artery   y □ ______  y. left coronary artery
   x □ ______ 21. circumflex artery      z □ ______  z. circumflex artery
   v □ ______ 22. anterior interventricular artery  u □ ______  u. anterior interventricular artery
   f □ ______ 23. apex of heart          v □ ______  v. apex of heart
   y □ ______ 24. great cardiac vein     w □ ______  w. great cardiac vein
2. What is the function of the fluid that fills the pericardial sac? To reduce friction during heart activity.

3. Match the terms in the key to the descriptions provided below.

   f  1. location of the heart in the thorax
   a  2. superior heart chambers
   h  3. inferior heart chambers
   e  4. visceral pericardium
   a  5. “anterooms” of the heart
   g  6. equals cardiac muscle
   b  7. provide nutrient blood to the heart muscle
   d  8. lining of the heart chambers
   h  9. actual “pumps” of the heart
   c  10. drains blood into the right atrium

   Key:
   a. atria
   b. coronary arteries
   c. coronary sinus
   d. endocardium
   e. epicardium
   f. mediastinum
   g. myocardium
   h. ventricles

4. What is the function of the valves found in the heart? They enforce a one-way flow of blood through the heart.

5. What is the role of the chordae tendineae? They anchor the AV valve flaps during ventricular systole, thus preventing backflow of blood into the atria.

**Pulmonary, Systemic, and Cardiac Circulations**

6. A simple schematic of a so-called general circulation is shown below. What part of the circulation is missing from this diagram? Pulmonary circulation is not distinct from systemic circulation. Add to the diagram as best you can to make it depict a complete systemic/pulmonary circulation. Label the systemic and pulmonary circulations.
7. Differentiate clearly between the roles of the pulmonary and systemic circulations. The pulmonary circuit provides for gas exchange only; the systemic circuit provides the functional supply of the body tissues.

8. Complete the following scheme of circulation of a red blood cell in the human body.

Right atrium through the tricuspid valve to the right ventricle, through the pulmonary semilunar valve to the pulmonary trunk, to the right and left pulmonary arteries, to the capillary beds of the lungs, to the pulmonary veins, to the left atrium of the heart, through the mitral/bicuspid valve to the left ventricle, through the aortic semilunar valve to the aorta, to the systemic arteries, to the capillary beds of the tissues, to the systemic veins, to the inferior vena cava, superior vena cava, and coronary sinus entering the right atrium of the heart.

9. If the mitral valve does not close properly, which circulation is affected? Systemic

10. Why might a thrombus (blood clot) in the anterior descending branch of the left coronary artery cause sudden death? This artery supplies blood to the interventricular septum and the anterior walls of both ventricles. Ventricular damage, particularly to the left ventricle, is very serious.

Microscopic Anatomy of Cardiac Muscle

11. How would you distinguish the structure of cardiac muscle from that of skeletal muscle? Both tissue types are striated; thus, this is not a distinguishing feature. Skeletal muscle cells are long cylindrical cells with many peripherally located nuclei per cell. Cardiac cells have one (or two) centrally located nuclei per cell; their branched ends fit together at tight junctions called intercalated discs, which are not seen in skeletal muscle.

12. Add the following terms to the photograph of cardiac muscle below.

   a. intercalated disc  b. nucleus of cardiac fiber  c. striations  d. cardiac muscle fiber

   Describe the unique anatomical features of cardiac muscle. What role does the unique structure of cardiac muscle play in its function? Cardiac muscle cells form a functional syncytium by virtue of their intercalated discs. This structural feature plus the special arrangement of cardiac muscle in the heart allows the pumping action of the heart to be carefully coordinated for maximal efficiency.
Dissection of the Sheep Heart

13. During the sheep heart dissection, you were asked initially to identify the right and left ventricles without cutting into the heart. During this procedure, what differences did you observe between the two chambers?

*The left ventricle was firmer, thicker, and less compressible; the right ventricle felt “flabby.”*

When you measured thickness of ventricular walls, was the right or left ventricle thicker? *The left ventricle*

Knowing that structure and function are related, how would you say this structural difference reflects the relative functions of these two heart chambers? *The left ventricle pumps blood through the high-resistance systemic circulation; therefore, it has to be stronger than the right ventricle, which pumps blood through the short low-resistance pulmonary circuit.*

14. Semilunar valves prevent backflow into the ventricles; mitral and tricuspid (AV) valves prevent backflow into the atria. Using your own observations, explain how the operation of the semilunar valves differs from that of the AV valves. *When the ventricle was compressed (as in systole), the AV valve flaps moved superiorly into the closed position. When water was poured (as when blood backflows) into the semilunar valves, the cusps filled and closed the valve.*

15. Compare and contrast the structure of the mitral and tricuspid valves. *Both have thin flaps secured to papillary muscles by chordae tendineae. The right valve has three cusps, the left valve has two.*

16. Two remnants of fetal structures are observable in the heart—the ligamentum arteriosum and the fossa ovalis. What were they called in the fetal heart, where was each located, and what common purpose did they serve as functioning fetal structures? *Ligamentum arteriosum—ductus arteriosus between the pulmonary trunk and the aorta. Fossa ovalis—foramen ovale, in the atrial septum. When they were open (and functional), they allowed blood to bypass the nonfunctional fetal lungs.*
Conduction System of the Heart and Electrocardiography

**Time Allotment**: about 15 minutes of lab time for each group making ECG recordings.


*Interactive Physiology® 10-System Suite: Cardiovascular System* (BC: CD-ROM, Website)

**Laboratory Materials**

*Ordering information is based on a lab size of 24 students, working in groups of 4. A list of supply house addresses appears in Appendix A.*

- Millimeter ruler
- Cot or lab table; pillow (optional)
- Apparatus A or B:
  - A: ECG recording apparatus, electrode paste, alcohol swabs, rubber straps
  - B: BIOPAC® MP36 (or MP35/30) data acquisition unit, PC or Mac computer, BIOPAC® Student Lab Software, electrode lead set, disposable vinyl electrodes

**Advance Preparation**

1. Set out ECG recording apparatus, electrode paste, alcohol swabs, and a cot (or clear a section of the lab bench). Attach the leads to the recorder.

2. If you are using an ECG recording apparatus, turn it on, and allow it to warm up. Set the paper speed at 25 millimeters per second. Test the equipment as instructed by the manufacturer. Most equipment uses heat-sensitive paper. Be sure that the stylus produces a readable tracing. Adjust temperature setting accordingly. Test to see that a 1-millivolt signal causes a 10-millimeter vertical displacement of the stylus, and make any necessary adjustments. If the equipment uses a pen and ink, make sure the ink is flowing smoothly. Be sure the base line of the pen or stylus is on a horizontal line on the paper. If there is electrical interference, use the ground wire. Water or gas pipes are handy points for attachment.

3. Be sure the electrode plates are clean.

4. Set out equipment and materials for conducting the BIOPAC® activity. Introduce your students to the basic features of the equipment prior to beginning the lab activity.

**Comments and Pitfalls**

1. If leg leads are required, select student subjects with bare legs. Nylon stockings interfere with conduction.

2. Since electrode paste can be messy, try using electrode pads.

3. Have someone in the group double-check the arrangements of the electrodes before recording begins.

4. If the ECG is not clear, check to be sure electrodes are secure, remind the subject to remain still, and check the ground wire.
5. It is difficult to obtain good results when the student is running in place and attached to the electrodes. An alternate approach is to have the student run in place for 3 minutes and then connect the electrode leads to record the ECG immediately, and 2 and 4 minutes after exercise.

6. It is helpful to use a caliper and millimeter ruler when measuring the waves, intervals, and segments. These can be measured on screen with BIOPAC®.

7. If no ECG recording equipment is available, you can give the students a selection of ECG tracings and ask them to measure the waves, intervals, and segments.

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**Answers to Pre-Lab Quiz (p. 457)**

1. true  
2. c, sinoatrial  
3. false  
4. a, electrocardiogram  
5. three  
6. a, P  
7. true  
8. tachycardia  
9. b, 4  
10. true

---

**Answers to Activity Questions**

**Activity 1A: Recording ECGs Using a Standard ECG Apparatus (pp. 460–461)**

**Recording the ECG after Running in Place**

5. The Q-T interval is shortened and the interval between adjacent QRS complexes is shortened (the strength of contraction increases and the length of diastole decreases).

**Recording the ECG for Breath Holding**

4. The heart rate increases during breath holding. As the CO₂ level in the blood increases, the blood pH decreases, causing cerebral vasodilation. This may increase sympathetic tone, thereby increasing heart rate. There may be some connection between the medullary respiratory and cardiac centers. (Depending on the text you are using, this might be difficult for the students to track down.)

**Activity 1B: Electrocardiography Using BIOPAC® (pp. 462–466)**

There is not likely to be a significant difference in deltaT between Segment 1 and Segment 3, although if there is a difference, some of the ECG components are likely to be of shorter duration in Segment 3. Postexercise heart rate should increase, so the bpm of Segment 3 should be greater than Segment 1.

There is an inverse relationship between time between R waves and heart rate. A shorter interval between R waves translates into a higher heart rate.

There is likely to be an increase in heart rate as the subject makes the transition from a lying to a sitting position.
Conduction System of the Heart and Electrocardiography

The Intrinsic Conduction System

1. List the elements of the intrinsic conduction system in order, starting from the SA node.

   SA node → AV node → AV bundle (bundle of His) → left and right bundle branches → Purkinje fibers

   At what structure in the transmission sequence is the impulse temporarily delayed? AV node

   Why? Allows completion of atrial contraction before initiation of ventricular systole.

2. Even though cardiac muscle has an inherent ability to beat, the nodal system plays a critical role in heart physiology. What is that role? Ensures that depolarization proceeds in an orderly manner from atria to ventricles; accelerates and coordinates heart activity to effectively pump blood.

Electrocardiography

3. Define ECG. Recording of electrical changes occurring during heart activity.

4. Draw an ECG wave form representing one heartbeat. Label the P, QRS, and T waves; the P-R interval; the S-T segment; and the Q–T interval.

5. Why does heart rate increase during running? Exercise raises heart rate by acting through the sympathetic nervous system.

   Sympathetic nerve fibers release norepinephrine on the heart and the pacemaker fires more rapidly.
6. Describe what happens in the cardiac cycle in the following situations.

1. immediately before the P wave: the heart is in relaxation (diastole)

2. during the P wave: depolarization of the atria

3. immediately after the P wave (P-R segment): contraction of the atria

4. during the QRS wave: depolarization of the ventricles

5. immediately after the QRS wave (S-T interval): contraction of the ventricles

6. during the T wave: repolarization of the ventricles

7. Define the following terms.

1. tachycardia: Heart rate over 100 beats/min.

2. bradycardia: Heart rate below 60 beats/min.

3. fibrillation: Very rapid uncoordinated myocardial activity.

8. Which would be more serious, atrial or ventricular fibrillation? Ventricular fibrillation

Why? The ventricles bear major responsibility for pumping blood from the heart to the lungs and all other body organs.

9. Abnormalities of heart valves can be detected more accurately by auscultation than by electrocardiography. Why is this so?

Most often serious valve problems can be detected (heard) with a stethoscope. However, since valves are not part of the depolarization pathway of the heart, their inefficiency would not be recorded on an ECG.
Anatomy of Blood Vessels

**Time Allotment:** 1 1/2 hours.

**Multimedia Resources:** See Appendix B for Guide to Multimedia Resource Distributors. See Exercise 6A for histology listings.

*A.D.A.M.® Interactive Anatomy 4.0* (AIA: CD-ROM, DVD)
*Circulation* (IM: 20 minutes, VHS, DVD)
*The Circulatory System* (IM: 23 minutes, DVD)
*Circulatory System: The Plasma Pipeline* (FHS: 25 minutes, VHS, DVD, 3-year streaming webcast)
*Human Biology* (FHS: 58 minutes, VHS, DVD)
*Human Cardiovascular System: Blood Vessels Videotape* (BC: 25 minutes, VHS)
*Interactive Physiology® 10-System Suite: Cardiovascular System* (BC: CD-ROM, Website)
*Life Under Pressure* (FHS: 26 minutes, VHS, DVD, 3-year streaming webcast)
*Practice Anatomy Lab™ 2.0* (PAL) (BC: CD-ROM, Website)
*Pumping Life—The Heart and Circulatory System Video* (WNS: 20 minutes, VHS)

**Laboratory Materials**

*Ordering information is based on a lab size of 24 students, working in groups of 4. A list of supply house addresses appears in Appendix A.*

- Anatomical charts of human arteries and veins or a 3-D model of the human circulatory system
- Anatomical charts and/or 3-D models of the following specialized circulations: pulmonary circulation, hepatic portal circulation, arterial supply to the brain and cerebral arterial circle (Circle of Willis), fetal circulation
- 24 compound microscopes, lens paper, lens cleaning solution
- 24 prepared microscope slides showing cross sections of an artery and a vein

**Advance Preparation**

1. Set out anatomical charts and/or models of human arteries and veins and the human circulatory system.
2. Set out anatomical charts of special circulations.

**Answers to Pre-Lab Quiz (p. 469)**

1. Veins
2. true
3. a, aorta
4. superior mesenteric
5. a, dorsalis pedis
6. superior
7. c, great saphenous
8. hepatic
9. b, hepatic portal circulation
10. vein
**Microscopic Structure of the Blood Vessels**

1. Cross-sectional views of an artery and of a vein are shown here. Identify each; and on the lines to the sides, note the structural details that enabled you to make these identifications:

   - **Artery**
     - open, circular lumen
     - thick tunica media

   - **Vein**
     - somewhat collapsed lumen
     - thinner tunica media

Now describe each tunic more fully by selecting its characteristics from the key below and placing the appropriate key letters on the answer lines.

- Tunica intima: a, c, f
- Tunica media: d, e
- Tunica externa: b

**Key:**
- a. innermost tunic
- b. most superficial tunic
- c. thin tunic of capillaries
- d. especially thick in elastic arteries
- e. contains smooth muscle and elastin
- f. has a smooth surface to decrease resistance to blood flow

2. Why are valves present in veins but not in arteries?

   The high blood pressure in arteries propels the blood through them. The blood pressure in veins is low and often the blood is flowing against gravity. Valves prevent backflow.

3. Name two events occurring within the body that aid in venous return.

   Skeletal muscle “milking action” and changes in thoracic cavity pressure during breathing.

4. Why are the walls of arteries proportionately thicker than those of the corresponding veins?

   Arteries must withstand high pressure and pressure fluctuations. Veins are low-pressure vessels.
Major Systemic Arteries and Veins of the Body

5. Use the key on the right to identify the arteries or veins described on the left.

   d. 1. the arterial system has one of these; the venous system has two
   i. 2. these arteries supply the myocardium
   r, z. 3. two paired arteries serving the brain
   o. 4. longest vein in the lower limb
   k. 5. artery on the dorsum of the foot checked after leg surgery
   j. 6. serves the posterior thigh
   t. 7. supplies the diaphragm
   c. 8. formed by the union of the radial and ulnar veins
   b, f. 9. two superficial veins of the arm
   w. 10. artery serving the kidney
   p. 11. veins draining the liver
   q. 12. artery that supplies the distal half of the large intestine
   s. 13. drains the pelvic organs
   m. 14. what the external iliac artery becomes on entry into the thigh
   c. 15. major artery serving the arm
   y. 16. supplies most of the small intestine
   h. 17. join to form the inferior vena cava
   e. 18. an arterial trunk that has three major branches, which run to the
   l. liver, spleen, and stomach
   a, n, u. 19. major artery serving the tissues external to the skull
   v. 20. three veins serving the leg
   21. artery generally used to take the pulse at the wrist

   Key: a. anterior tibial
   b. basilic
   c. brachial
   d. brachiocephalic
   e. celiac trunk
   f. cephalic
   g. common carotid
   h. common iliac
   i. coronary
   j. deep artery of the thigh
   k. dorsalis pedis
   l. external carotid
   m. femoral
   n. fibular
   o. great saphenous
   p. hepatic
   q. inferior mesenteric
   r. internal carotid
   s. internal iliac
   t. phrenic
   u. posterior tibial
   v. radial
   w. renal
   x. subclavian
   y. superior mesenteric
   z. vertebral

6. What is the function of the cerebral arterial circle (circle of Willis)?

   Provides an alternate set of pathways for blood to reach brain tissue in case of impaired blood flow anywhere in the system.

7. The anterior and middle cerebral arteries arise from the internal carotid artery. They serve the cerebral hemispheres of the brain.

8. Trace the pathway of a drop of blood from the aorta to the left occipital lobe of the brain, noting all structures through which it flows.

   Aorta → subclavian artery → vertebral artery → basilar artery → posterior cerebral artery → occipital brain tissue.
9. The human arterial and venous systems are diagrammed on this page and the next. Identify all indicated blood vessels.
Veins

- Dural sinuses
- External jugular vein
- Vertebral vein
- Internal jugular vein
- R. brachiocephalic vein
- Superior vena cava
- Axillary vein
- Great cardiac vein
- Hepatic veins
- Hepatic portal vein
- Superior mesenteric vein
- Inferior vena cava
- Ulnar vein
- Radial vein
- Common iliac vein
- External iliac vein
- Internal iliac vein
- Digital veins
- Femoral vein
- Great saphenous vein
- Popliteal vein
- Posterior tibial vein
- Anterior tibial vein
- Fibular vein
- Dorsal venous arch
- Superficial temporal vein
- Facial vein
- Left subclavian vein
- Left brachiocephalic veins
- Cephalic vein
- Brachial vein
- Basilic vein
- Splenic vein
- Median cubital vein
- Renal vein
- Ulnar vein
- Inferior mesenteric vein
- Median antebrachial vein
- Superficial palmar venous arch
- Metatarsal veins
10. Trace the blood flow for each of the following situations.

a. from the capillary beds of the left thumb to the capillary beds of the right thumb: Digital vein, L radial vein, L brachial vein, L axillary vein, L subclavian vein, L brachiocephalic vein, superior vena cava, R atrium, R ventricle, pulmonary trunk, pulmonary artery, lobar artery, pulmonary capillaries of the lung, lobar veins, pulmonary veins, L atrium, L ventricle, aortic arch, brachiocephalic artery, R subclavian artery, R axillary artery, R brachial artery, R radial artery, digital artery.

b. from the mitral valve to the tricuspid valve by way of the great toe: Through mitral valve into left ventricle, aorta, common iliac artery, external iliac artery, femoral artery, posterior tibial artery, medial plantar artery, digital artery, capillary beds, digital vein, plantar arch, plantar vein, posterior tibial vein, femoral vein, external iliac vein, common iliac vein, inferior vena cava, right atrium, then through tricuspid valve.

Pulmonary Circulation

11. Trace the pathway of a carbon dioxide gas molecule in the blood from the inferior vena cava until it leaves the bloodstream. Name all structures (vessels, heart chambers, and others) passed through en route.

| Inferior vena cava | right atrium | tricuspid valve | right ventricle | pulmonary (semilunar) valve | pulmonary trunk | right or left pulmonary artery | lobar artery | pulmonary capillaries in lungs | air sacs (alveoli) of lungs. |

12. Trace the pathway of oxygen gas molecules from an alveolus of the lung to the right atrium of the heart. Name all structures through which it passes. Circle the areas of gas exchange.

Alveolus \(\rightarrow\) alveolar/capillary walls \(\rightarrow\) pulmonary vein \(\rightarrow\) left atrium \(\rightarrow\) mitral valve \(\rightarrow\) left ventricle \(\rightarrow\) aortic (semilunar) valve \(\rightarrow\) aorta \(\rightarrow\) systemic arteries \(\rightarrow\) capillary beds of tissues \(\rightarrow\) systemic veins \(\rightarrow\) superior or inferior vena cava \(\rightarrow\) right atrium.

13. Most arteries of the adult body carry oxygen-rich blood, and the veins carry oxygen-depleted, carbon dioxide–rich blood. How does this differ in the pulmonary arteries and veins? The pulmonary arteries carry oxygen-poor blood to the lungs, whereas the pulmonary veins carry oxygen-rich blood from the lungs to the left heart.

14. How do the arteries of the pulmonary circulation differ structurally from the systemic arteries? What condition is indicated by this anatomical difference? The pulmonary arteries are more like veins anatomically. They have relatively thin walls, reflecting the fact that the pulmonary circulation is a low pressure bed.

Hepatic Portal Circulation

15. What is the source of blood in the hepatic portal system? Blood drained from the digestive viscera.

16. Why is this blood carried to the liver before it enters the systemic circulation? This blood is rich in nutrients. The liver is the key body organ responsible for maintaining proper blood concentrations of glucose, proteins, etc. Its phagocytes also cleanse the blood of debris.
17. The hepatic portal vein is formed by the union of (a) \textit{splenic vein}, which drains the \textit{spleen}, pancreas, \textit{greater curvature of the stomach}, and distal large intestine via the \textit{inferior mesenteric vein}, and (b) \textit{superior mesenteric vein}, which drains the \textit{small intestine} and ascending \textit{colon}. The \textit{gastric vein}, which drains the lesser curvature of the stomach, empties directly into the hepatic portal vein.

18. Trace the flow of a drop of blood from the small intestine to the right atrium of the heart, noting all structures encountered or passed through on the way. \textit{Capillaries of small intestine} $\rightarrow$ \textit{superior mesenteric vein} $\rightarrow$ \textit{hepatic portal vein} $\rightarrow$ \textit{liver sinusoids} $\rightarrow$ \textit{hepatic vein} $\rightarrow$ \textit{inferior vena cava} $\rightarrow$ \textit{right atrium of heart}.

Fetal Circulation

19. For each of the following structures, first indicate its function in the fetus; and then note its fate (what happens to it or what it is converted to after birth). Circle the blood vessel that carries the most oxygen-rich blood.

<table>
<thead>
<tr>
<th>Structure</th>
<th>Function in fetus</th>
<th>Fate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Umbilical artery</td>
<td>Carries O$_2$-poor blood from the fetus to the placenta.</td>
<td>Obliterated. Becomes the medial umbilical ligament.</td>
</tr>
<tr>
<td>Umbilical vein</td>
<td>Carries O$_2$-rich blood from the placenta to the fetus.</td>
<td>Obliterated. Becomes the round ligament of the liver (ligamentum teres).</td>
</tr>
<tr>
<td>Ductus venosus</td>
<td>Shunts blood through the fetal liver, bypassing the bulk of its tissue.</td>
<td>Becomes the fibrous ligamentum venosum.</td>
</tr>
<tr>
<td>Ductus arteriosus</td>
<td>Bypasses the fetal lungs by shunting blood from the pulmonary trunk to the aorta.</td>
<td>Occludes. Becomes the ligamentum arteriosum.</td>
</tr>
<tr>
<td>Foramen ovale</td>
<td>Bypasses the lungs by shunting blood from the right atrium to the left atrium.</td>
<td>Closes. Becomes the fossa ovalis.</td>
</tr>
</tbody>
</table>

20. What organ serves as a respiratory/digestive/excretory organ for the fetus? \textit{Placenta}
**Human Cardiovascular Physiology: Blood Pressure and Pulse Determinations**

**Time Allotment:** 2 hours (with some shared small-group data).

**Multimedia Resources:** See Appendix B for Guide to Multimedia Resource Distributors. A record, audiotape, or CD-ROM of *Interpreting Heart Sounds* (if available on free loan from the local chapters of the American Heart Association) or any suitable Web resource featuring heart sounds.

- *A.D.A.M.® Interactive Anatomy 4.0* (AIA: CD-ROM, DVD)
- *Human Biology* (FHS: 58 minutes VHS, DVD)
- *Life Under Pressure* (FHS: 26 minutes, VHS, DVD, 3-year streaming webcast)
- *The Physiology of Exercise* (FHS: 15 minutes, DVD, VHS)

**Laboratory Materials**

Ordering information is based on a lab size of 24 students, working in groups of 4. A list of supply house addresses appears in Appendix A.

- 12 stethoscopes
- 12 sphygmomanometers
- Watch (or clock) with second hand
- Alcohol swabs
- 6 felt-tipped pens
- 6 small basins or large finger bowls
- 6 laboratory thermometers
- Ice

Audio recording of *Interpreting Heart Sounds* (if available on free loan from local chapters of the American Heart Association) and appropriate player, or any suitable Web resource featuring heart sounds

BIOPAC® MP36 (or MP35/30) data acquisition unit, PC or Mac

- computer, BIOPAC® Student Lab Software, electrode lead set,
- BIOPAC® pulse plethysmograph
- Cot (if available)
- 6 meter sticks
- Step stools (0.4 m [16 in.] and 0.5 m [20 in.] in height)

**Advance Preparation**

1. Set out stethoscopes (both bell and diaphragm) and sphygmomanometers (two per group). Check the valves on the bulbs of the cuffs to be sure that air is released from the cuff when the valves are opened (replacement valves can be ordered). If electronic monitoring equipment is to be used, prepare instructions and distribute.

2. Set out or ask students to bring watches with second hands. Provide each group with a meter stick, alcohol swabs, a felt-tipped pen, a small basin or large finger bowl, and a laboratory thermometer. Have ice available.

3. Set out one 0.4 m (16-inch) high bench (for women) and one 0.5 m (20-inch) high bench (for men). You may have to compromise with a 0.45 m (18-inch) bench. Set up a cot, if available.

4. If the record or tape is used, set up a phonograph or tape deck.

5. Divide the class into small groups to collect data for Effect of Various Factors on Blood Pressure and Heart Rate. It may be hard to define *well-conditioned* and *poorly conditioned* subjects. A runner or a member of an athletic team might be compared to a more sedentary person (see Comments and Pitfalls, item 4).
6. Set out equipment and materials for conducting the BIOPAC® activity. Introduce your students to the basic features of the equipment prior to beginning the lab activity.

Comments and Pitfalls

1. Most students in the health sciences will have no trouble with this lab, and in fact enjoy bringing their own stethoscopes and sphygmomanometers to lab if they are given advance notice.

2. If students have trouble hearing the heart sounds with the bell stethoscope, have them try the diaphragm model. This will be particularly helpful when trying to hear the split sounds. The sounds are louder with the bell stethoscopes, but placement must be more precise.

3. Caution students against overtightening the valve on the sphygmomanometer. If the air in the cuff can’t be released, it is very painful to the subject. If the valve does stick, most cuffs can be undone even when filled with air. To avoid problems once the cuff is inflated, have students practice first with the bulb valve.

4. Students performing the Harvard step test should be carefully monitored to be sure that they step completely up and completely down at the prescribed rate. This can be very fatiguing. If the student population is fairly uniform it may be difficult to detect major differences between the well-conditioned and poorly conditioned individuals. Try to compare people of the same general age and sex, and do not compare a smoker to a nonsmoker. Students who are aware that they have heart problems should be discouraged from acting as subjects.

5. Many fitness tests are designed for people in their early twenties. Some tests take age and gender into account (see “The President’s Challenge, Adult Fitness Test” at www.adultfitnesstest.org).

6. If a person with Raynaud’s disease is used as the subject for the cold pressor test, he or she may experience temporary loss of feeling in the hand.

7. Students who are testing the effects of venous congestion should be reminded to keep both arms quietly on the lab bench for the full 5 minutes. Check to be sure pressure is maintained at 40 mm Hg.

Answers to Pre-Lab Quiz (pp. 491–492)

1. diastole 6. c, pulse
2. b, cardiac cycle 7. radial
3. true 8. Sphygmomanometer
4. b, 75 9. 90
5. murmurs 10. d, sounds of Korotkoff

Answers to Activity Questions

Activity 1: Auscultating Heart Sounds (pp. 492–494)

3. The interval is about 0.5 second. It is about twice as long as the interval between the first and second heart sounds.

Activity 2: Palpating Superficial Pulse Points (p. 495)

The carotid pulse point has the greatest amplitude, and the dorsalis pedis artery has the least. This is related to distance from the left ventricle of the heart.
Activity 7: Observing the Effect of Various Factors on Blood Pressure and Heart Rate (pp. 500–502)

**Exercise**

6. Greater elevation of blood pressure is generally noted just after completion of exercise. Increased cardiac output during exercise results in increased systolic pressure. A poorly conditioned individual usually has a higher systolic pressure at the end of exercise, and it usually takes a longer time for the pressure to return to normal. A well-conditioned individual usually has a larger stroke volume and thus can pump more blood with fewer beats per minute than a poorly conditioned individual. Diastolic pressure usually does not increase significantly, as it is the resting pressure of the vessels.

A *Noxious Sensory Stimulus* (Cold)

Blood pressure changes will be variable. The pulse rate will probably increase.

Activity 8: Examining the Effect of Local Chemical and Physical Factors on Skin Color (pp. 502–504)

**Vasodilation and Flushing of the Skin Due to Local Metabolites**

7. Stopping blood flow causes the hand to turn very pale. Weakness and a tingling sensation may be felt (variable). The skin flushes bright red immediately upon release of pressure and normal color is restored after several minutes or longer. There may be some lingering pain in the forearm region.

**Effects of Venous Congestion**

2. Slight pressure may be felt in the hand at the end of 5 minutes (variable). The veins are bulging and the hand has a mottled appearance, much darker in color than the control. Upon release of pressure, the veins deflate, and color and feeling return to normal.

3. Intensity of skin color (pink or blue) is related to the volume of blood in the area. The color is determined by the degree of oxygenation of the blood. In this experiment, venous blood gives a blue tint and arterial blood gives a pink tint.

**Collateral Blood Flow**

5. Results are variable. The hand usually turns intensely red and a warm tingling sensation may be felt. Redness may last for several minutes.

6. The hand does not become totally ischemic. The second test result is much less dramatic, with much less intense reactive hyperthermia.

7. With only the ulnar artery compressed, the results are intermediate between questions 5 and 6. The ulnar artery has a larger diameter than the radial artery, but they anastomose in the hand to serve the same areas.

**Effect of Mechanical Stimulation of Blood Vessels of the Skin**

Results will vary. A red streak develops with moderate pressure. With heavy pressure, a wider, darker, longer-lasting streak develops and may swell.
Human Cardiovascular Physiology: Blood Pressure and Pulse Determinations

Cardiac Cycle

1. Using the grouped sets of terms to the right of the diagram, correctly identify each trace, valve closings and openings, and each time period of the cardiac cycle.

   a. 1. aortic pressure
   b. 2. atrial pressure
   c. 3. ECG
   d. 4. first heart sound
   e. 5. second heart sound
   f. 6. ventricular pressure
   g. 7. ventricular volume
   h. 8. aortic semilunar valve closes
   i. 9. aortic semilunar valve opens
   j. 10. AV and semilunar valves closed
   k. 11. AV valve closes
   l. 12. AV valve opens
   m. 13. ventricular diastole
   n. 14. ventricular systole
2. Define the following terms.

systole: Contraction of the ventricles (general usage)

diastole: Ventricular relaxation (general usage)

cardiac cycle: One complete heartbeat including atrial and ventricular contraction

3. Answer the following questions concerning events of the cardiac cycle.

When are the AV valves closed? During ventricular systole

What event within the heart causes the AV valves to open? Ventricular pressure < atrial pressure

When are the semilunar valves closed? During the period of relaxation of the heart as a whole and during atrial contraction.

What event causes the semilunar valves to open? Ventricular pressure > pressure in great arteries

Are both sets of valves closed during any part of the cycle? Yes

If so, when? Momentarily after atrial contraction and ventricular systole.

Are both sets of valves open during any part of the cycle? No

At what point in the cardiac cycle is the pressure in the heart highest? Ventricular systole

Lowest? Ventricular diastole

What event results in the pressure deflection called the dicrotic notch? The momentary increase in aortic pressure that occurs when its semilunar valves snap shut.

4. Using the key below, indicate the time interval occupied by the following events of the cardiac cycle.

Key: a. 0.8 sec  b. 0.4 sec  c. 0.3 sec  d. 0.1 sec

a  1. the length of the normal cardiac cycle

d  2. the time interval of atrial systole

b  3. the quiescent period, or pause

c  4. the ventricular contraction period

5. If an individual’s heart rate is 80 beats/min, what is the length of the cardiac cycle? 0.75 sec

What portion of the cardiac cycle is shortened by this more rapid heart rate? Quiescent period (ventricular relaxation period).

6. What two factors promote the movement of blood through the heart? Alternate contraction and relaxation of the myocardium

and opening and closing of the heart valves (which is responsive to pressure gradients).
Heart Sounds

7. Complete the following statements.

The monosyllables describing the heart sounds are 1. The first heart sound is a result of closure of the 2 valves, whereas the second is a result of closure of the 3 valves. The heart chambers that have just been filled when you hear the first heart sound are the 4. and the chambers that have just emptied are the 5. Immediately after the second heart sound, both the 6. and 7. are filling with blood.

8. As you listened to the heart sounds during the laboratory session, what differences in pitch, length, and amplitude (loudness) of the two sounds did you observe? First heart sound is longer, louder, and lower in pitch than the second heart sound, which is short, sharp, and high-pitched.

9. In order to auscultate most accurately, indicate where you would place your stethoscope for the following sounds:

- closure of the tricuspid valve: Left or right sternal border of the 5th intercostal space.
- closure of the aortic semilunar valve: Right sternal border of the 2nd intercostal space.
- apical heartbeat: 5th intercostal space in line with the middle of the left clavicle.

Which valve is heard most clearly when the apical heartbeat is auscultated? Mitral

10. No one expects you to be a full-fledged physician on such short notice; but on the basis of what you have learned about heart sounds, how might abnormal sounds be used to diagnose heart problems?

Abnormal sounds such as swishing sounds after valvular closure or high-pitched sounds arising when blood is forced through constricted (valve) openings might indicate valvular problems.

The Pulse

11. Define pulse. Pressure surges in an artery occurring during each contraction and relaxation of the left ventricle.

12. Describe the procedure used to take the pulse. Place the first 2–3 fingertips of one hand over an arterial pressure point. Compress firmly and then release the pressure slightly to palpate the pulse.

13. Identify the artery palpated at each of the pressure points listed.

- at the wrist: Radial
- in front of the ear: Temporal
- on the dorsum of the foot: Dorsalis pedis
- at the side of the neck: Carotid
14. When you were palpating the various pulse or pressure points, which appeared to have the greatest amplitude or tension? 
   Carotid artery Why do you think this was so? The carotid artery(ies) is the major artery delivering blood to the brain (against gravity) and it is closest to the heart.

15. Assume someone has been injured in an auto accident and is hemorrhaging badly. What pressure point would you compress to help stop bleeding from each of the following areas?
   the thigh: Femoral artery the calf: Popliteal artery
   the forearm: Brachial artery the thumb: Radial artery
   If it spurts, it is arterial. It will flow evenly if it is venous blood.

16. How could you tell by simple observation whether bleeding is arterial or venous? Pulse deficit

17. You may sometimes observe a slight difference between the value obtained from an apical pulse (beats/min) and that from an arterial pulse taken elsewhere on the body. What is this difference called? Pulse deficit

Blood Pressure Determinations

18. Define blood pressure. Pressure exerted by blood against the walls of the blood vessels.

19. Identify the phase of the cardiac cycle to which each of the following apply.
   systolic pressure: Systole (ventricular contraction) diastolic pressure: Diastole (relaxation)

20. What is the name of the instrument used to compress the artery and record pressures in the auscultatory method of determining blood pressure? Sphygmomanometer Sounds that can be auscultated over a partially occluded artery.

21. What are the sounds of Korotkoff? Sound of turbulent blood flow as it first begins to move through the constricted artery.

   What causes the systolic sound? Blood is flowing freely; the artery is no longer constricted.

   What causes the disappearance of the sound? Blood is flowing freely; the artery is no longer constricted.

22. Interpret 145/85/82. 145 = systolic pressure; 85 = diastolic pressure reported as the point where the sound muffles; 82 = diastolic pressure reported as the point at which sound disappears.

23. Assume the following BP measurement was recorded for an elderly patient with severe arteriosclerosis: 170/110/-. Explain the inability to obtain the third reading.
   The patient's arteries are so narrowed by arteriosclerosis that blood flow is always partially occluded. Hence, the sound.
24. Define pulse pressure. Systolic pressure minus diastolic pressure.

Why is this measurement important? It indicates the actual working pressure (actual amount of blood forced out of the heart during systole).

25. How do venous pressures compare to arterial pressures? Venous pressures are lower.

Why? Veins are far removed (in the circuit) from the pumping action of the heart.

26. What maneuver to increase the thoracic pressure illustrates the effect of external factors on venous pressure? Valsalva maneuver

How is it performed? A person takes a deep breath, and mimics the motions of exhaling forcibly, but without actually exhaling. The glottis will close and the intrathoracic pressure will increase.

27. What might an abnormal increase in venous pressure indicate? (Think!) Heart failure. With the heart unable to adequately pump blood, it pools in the lower extremities and increases venous pressure.

Observing the Effect of Various Factors on Blood Pressure and Heart Rate

28. What effect do the following have on blood pressure? (Indicate increase by ↑ and decrease by ↓.)

| ↓ | 1. increased diameter of the arterioles | ↓ | 4. hemorrhage |
| ↑ | 2. increased blood viscosity | ↑ | 5. arteriosclerosis |
| ↑ | 3. increased cardiac output | ↑ | 6. increased pulse rate |

29. In which position (sitting, reclining, or standing) is the blood pressure normally the highest?

Standing The lowest? Reclining

What immediate changes in blood pressure did you observe when the subject stood up after being in the sitting or reclining position? It decreased initially and then increased.

What changes in the blood vessels might account for the change? Upon standing, gravitational pull caused blood pooling in the lower part of the body, but then vasoconstriction initiated by the vasomotor center caused blood pressure to rise.

After the subject stood for 3 minutes, what changes in blood pressure were observed? It decreased once again.

How do you account for this change? Decreased activity of the sympathetic nervous system.
30. What was the effect of exercise on blood pressure? __It increased the blood pressure.__

On pulse rate? __It increased the pulse rate.__

Do you think these effects reflect changes in cardiac output or in peripheral resistance? __Both; cardiac output increases, but peripheral resistance also changes (it decreases as vessels to skeletal muscle and the heart dilate, and increases as vessels to other organs, e.g., GI tract and kidneys, constrict). Overall, peripheral resistance often decreases during exercise, but it decreases less than cardiac output increases. Therefore, blood pressure rises.__

Why are there normally no significant increases in diastolic pressure after exercise? __Since diastolic pressure reflects the heart in relaxation, it would not be expected to increase in healthy individuals.__

31. What effects of the following did you observe on blood pressure in the laboratory?

cold temperature: __increased BP__

What do you think the effect of heat would be? __Decreased BP__

Why? __Vasodilation would occur.__

32. Differentiate between a hypo- and a hyperreactor relative to the cold pressor test. __Hyperreactors exhibit a rise of 23 mm Hg or more in BP during the test. Hyporeactors exhibit a smaller increase or a decrease in BP.__

Skin Color as an Indicator of Local Circulatory Dynamics

33. Describe normal skin color and the appearance of the veins in the subject’s forearm before any testing was conducted.

__Skin pink; veins flat and difficult to see.__

34. What changes occurred when the subject emptied the forearm of blood (by raising the arm and making a fist) and the flow was occluded with the cuff? __Skin becomes pale (cyanotic in some cases) and cool.__

What changes occurred during venous congestion? __Skin becomes pink (red) and warm, and veins are congested and very visible.__

35. What is the importance of collateral blood supplies? __Can maintain the blood supply to an organ (body part) in case the major nutrient artery is occluded.__

36. Explain the mechanism by which mechanical stimulation of the skin produced a flare. __Local inflammatory response produced by the chemical mediators released by injured tissue cells.__
Frog Cardiovascular Physiology: Wet Lab

**Time Allotment:** 3 hours. (Allow additional time if students must learn to use equipment.)

**Solutions:**

*Ringer’s Solution, Frog*
- 6.50 grams sodium chloride
- 0.14 gram potassium chloride
- 0.12 gram calcium chloride
- 0.20 gram sodium bicarbonate
Combine salts in flask and add distilled water to make 1 liter of solution.

**Test Solutions:**

*Atropine Sulfate in Frog Ringer’s Solution, 5%*
Weigh out 5 grams of atropine sulfate. Add frog Ringer’s solution to a final volume of 100 milliliters. **Caution! Atropine sulfate is toxic. Label TOXIC.**

*Calcium Chloride in Frog Ringer’s Solution, 2%*
Weigh out 2 grams of calcium chloride. Add frog Ringer’s solution to a final volume of 100 milliliters.

*Digitalis in Frog Ringer’s Solution, 2%*
Weigh out 2 grams of digitoxin. Add frog Ringer’s solution to a final volume of 100 milliliters.

*Epinephrine in Frog Ringer’s Solution, 1%*
Weigh out 1 gram of epinephrine (Carolina). Dissolve in 0.5 milliliter of 1 N HCl. Add frog Ringer’s solution to a final volume of 100 milliliters. **Caution! Epinephrine is toxic. Label TOXIC.**

*Histamine in Frog Ringer’s Solution, 0.01%*
Weigh out 0.01 gram histamine. Add frog Ringer’s solution to a final volume of 100 milliliters.

*Hydrochloric Acid (HCl) in Frog Ringer’s Solution, 0.01 N*
Add 0.8 milliliter concentrated HCl to 900 milliliters frog Ringer’s solution. Add distilled water to make 1 liter of solution.

*Pilocarpine in Frog Ringer’s Solution, 2.5%*
Weigh out 2.5 grams of pilocarpine chloride. Add frog Ringer’s solution to a final volume of 100 milliliters.

*Potassium Chloride in Frog Ringer’s Solution, 5%*
Weigh out 5 grams of potassium chloride. Add frog Ringer’s solution to a final volume of 100 milliliters.

*Sodium Chloride (NaCl) in Frog Ringer’s Solution, 0.7%*
Weigh out 0.7 gram of sodium chloride. Add frog Ringer’s solution to a final volume of 100 milliliters.
Laboratory Materials

Ordering information is based on a lab size of 24 students, working in groups of 4. A list of supply house addresses appears in Appendix A.

6 frogs
Disposable gloves
Apparatus A or B:
A: physiograph (polygraph), paper, ink, myograph transducer, transducer cables, stimulator output extension cable, electrodes
B: BIOPAC® MP36 (or MP35/30) data acquisition unit, PC or Mac computer, BIOPAC® BSL Pro software, BIOPAC® HDW100A tension adjuster (or equivalent), BIOPAC® SS12LA force transducer with S-hook, small hook with thread, transducer (or ring) stand
Dispersal container for organic debris
18 bottles of Ringer’s solution, frog
Water bath at 32°C and 5°C
12 petri dishes
6 medicine droppers
6 dissecting pans and dissecting kits
6 millimeter rulers
6 large rubber bands
Box of fine common pins
6 frog boards
Cotton balls
Paper towels
6 compound microscopes, lens paper, lens cleaning solution
6 dropper bottles of each of the following (using frog Ringer’s solution as the solvent):
5% atropine sulfate
2% digitalis
1% epinephrine
2.5% pilocarpine
5% potassium chloride (KCl)
2% calcium chloride (CaCl2)
0.7% sodium chloride (NaCl)
0.01% histamine
0.01 N HCl

Advance Preparation

1. Order frogs to be delivered close to the date of the lab (see the frog experiment in Exercise 16A). Each group will need one double-pithed frog. If time (or student aversion) is a problem, frogs can be pithed just before the lab begins (see Exercise 16A). Keep the frogs moist with frog Ringer’s solution.
2. Set out data acquisition equipment (one per group of four). If the equipment has not been used in an earlier experiment, acquaint students with its set-up and use (see Exercise 16A).
   a. BIOPAC®. Set out equipment and materials for the conduction of the BIOPAC® activity, including a computer with BIOPAC® BSL Pro Software installed, tension adjuster, force transducer, and transducer (or ring) stand.
   b. Physiograph. For each physiograph, set out paper, ink, transducer stand, myograph transducer, transducer cables, stimulator output extension cable, and electrodes.
3. Put bottles of frog Ringer’s solution in a water bath set at 32°C and in a refrigerator set at 5°C. Have a supply bottle of room temperature frog Ringer’s solution available.
4. Each group should be provided with disposable gloves, a dissecting pan and instruments, a 250-milliliter bottle of frog Ringer’s solution, two petri dishes, a medicine dropper, a millimeter ruler, thread, sturdy rubber bands, several fine common pins, a frog board with a hole in one end (biology supply company), cotton balls, paper towels, and 25-milliliter bottles of test solutions. Have supply bottles of the test solutions available.
5. Have microscopes, lens paper, and lens cleaning solution available.
6. Designate an appropriate disposal area for the frogs.

Comments and Pitfalls

1. Remind students to keep the tissue moist with frog Ringer’s solution at all times.
2. Be sure the students have correctly located the vagus nerve and have not invented a nerve from connective tissue.
3. Do not overstretched the heart when attaching it to the recording equipment.
4. A Stannius ligature is a simple overhand knot in a loop of thread that can be tightened by pulling on both ends of the thread.
5. See Exercise 16A for additional comments on troubleshooting the recording equipment.

Answers to Pre-Lab Quiz (pp. 511–512)

1. true 6. b, digitalis
2. b, rhythmicity 7. d, vagus
3. b, three 8. vagal escape
4. true 9. true
5. An extra beat that shows up on the ventricular contraction peak 10. c, Histamine

Answers to Activity Questions

Activity 1: Investigating the Automaticity and Rhythmicity of Heart Muscle (pp. 512–513)

4. The heart is contracting rhythmically while the gastrocnemius muscle is not contracting at all.
5. The sinus venosus will continue to beat.
6. Each atrium should continue to beat, as well as the ventricle.
7. The sinus venosus usually displays the most automaticity (contracts at the fastest rate) and the ventricle the least.

Activity 2: Recording Baseline Frog Heart Activity (pp. 514–516)

Preparation of the Frog

4. Yes. The atrium contracts before the ventricle.

Activity 3: Investigating the Refractory Period of Cardiac Muscle Using the Physiograph (p. 517)

3. Extrasystole can be induced during the first part of ventricular relaxation.
4. The heart does not go into tetanus. The heart would be of no value as a pump if it could go into tetanus as a result of rapid repeated stimulation.

Activity 4: Assessing Physical and Chemical Modifiers of Heart Rate (pp. 517–519)

Temperature

5. Cold Ringer’s solution slows it down. Warm Ringer’s solution speeds up the heart rate.

Chemical Agents: Pilocarpine
Pilocarpine slows the heart. Pilocarpine is an agonist of acetylcholine (cholinergic agonist).

Chemical Agents: Atropine Sulfate
The heart rate should increase. Atropine is antagonistic to acetylcholine (cholinergic antagonist).

Chemical Agents: Epinephrine
Epinephrine increases heart rate, imitating the sympathetic nervous system.

Chemical Agents: Digitalis
Digitalis slows and steadies heart contraction.
Various Ions
Ca\textsuperscript{2+} increases strength of contraction.
Na\textsuperscript{+} decreases strength and rate of contraction.
K\textsuperscript{+} weakens heart contractions and causes premature beats.
Yes. Students may observe arrhythmia with all three ions.

Vagus Nerve Stimulation
3. Vagal stimulation slows down and eventually stops the heart.

Intrinsic Conduction System Disturbance (Heart Block)
4. A normal AV rhythm should reestablish after removing the block.

Activity 5: Investigating the Effect of Various Factors on the Microcirculation (pp. 519–520)
5. RBCs move through capillaries in single file. They are flexible and they may appear “stacked” and slightly curved as they move through. White blood cells resembling monocytes may be seen.
6. Blood flow in the arterioles is rapid and pulsating, while it is slow and steady in the venules. Movement is very slow in the capillaries. The capillaries are much smaller in diameter than the arterioles.

Temperature
Arterioles respond most noticeably to the temperature change. Cold saline causes a reduction in diameter and warm saline an increase in diameter.

Inflammation
HCl causes vasodilation, increasing capillary blood flow. This is a local response to bring more inflammatory cells to the damaged area.

Histamine
1. Histamine also causes vasodilation and increased blood flow. The response to histamine is similar to the response to HCl.
2. Epinephrine causes vasoconstriction and reduced blood flow.
Frog Cardiovascular Physiology: Wet Lab

Special Electrical Properties of Cardiac Muscle: Automaticity and Rhythmicity

1. Define the following terms.

   automaticity: Ability to depolarize spontaneously in the absence of external stimulation.
   rhythmicity: Depolarization/repolarization events occur in a regular and continuous manner.

2. Discuss the anatomical differences between frog and human hearts. The frog heart has a single ventricle and two atria. Dorsally there is an expanded area called the sinus venosus. The human heart has two atria and two ventricles. No sinus venosus is present.

3. Which region of the dissected frog heart had the highest intrinsic rate of contraction? Sinus venosus

   The greatest automaticity? Sinus venosus

   The greatest regularity or rhythmicity? Sinus venosus How do these properties correlate with the duties of a pacemaker? The human pacemaker (SA node) has automaticity, rhythmicity, and the highest depolarization rate in the heart.

   Is this region the pacemaker of the frog heart? Yes

   Which region had the lowest intrinsic rate of contraction? Ventricle

Investigating the Refractory Period of Cardiac Muscle

4. Define extrasystole. An extra beat occurring before the time a normal contraction would occur.

5. Respond to the following questions if you used a physiograph.

   What was the effect of stimulation of the heart during ventricular contraction? No effect.

   During ventricular relaxation (first portion)? Extrasystole.

   During the pause interval? No effect.

   What does this indicate about the refractory period of cardiac muscle? Much longer than that of skeletal muscle.
Assessing Physical and Chemical Modifiers of Heart Rate

6. Describe the effect of thermal factors on the frog heart.
   cold: Decreased heart rate
   heat: increased heart rate

7. Once again refer to your recordings. Did the administration of the following produce any changes in force of contraction (shown by peaks of increasing or decreasing height)? If so, explain the mechanism.
   epinephrine: ↑ rate and force of heartbeat. Acts on the SA and AV nodes and the myocardium to ↑ membrane permeability to Na⁺ and Ca²⁺.
   acetylcholine: ↓ rate and force of heartbeat. Acts on SA and AV nodes. Increases membrane permeability to K⁺ which makes the tissue less excitable.
   calcium ions: ↑ strength of myocardial contraction. Effects as in skeletal muscle, i.e., Ca²⁺ is the “trigger” for sliding of myofilaments.

8. Excessive amounts of each of the following ions would most likely interfere with normal heart activity. Note the type of changes caused in each case.
   K⁺: heart block; cardiac arrest
   Ca²⁺: ↑ spasticity of cardiac activity
   Na⁺: ↓ strength of contraction

9. Respond to the following questions if you used a physiograph. What was the effect of vagal stimulation on heart rate?
   Decreased heart rate
   Which of the following factors cause the same (or very similar) heart rate–reducing effects: epinephrine, acetylcholine, atropine sulfate, pilocarpine, sympathetic nervous system activity, digitalis, potassium ions?
   Acetylcholine, pilocarpine, digitalis, potassium ions.
   Which of the factors listed above would reverse or antagonize vagal effects? Epinephrine, atropine sulfate, sympathetic nervous system activity.

10. What is vagal escape? Return to a normal heart rate after a period of rate depression by the vagus nerve.
    Why is vagal escape valuable in maintaining homeostasis? Continued vagal depression can completely stop the heart and lead to death; vagal escape allows the heart to begin beating again even though the vagus nerve continues to be stimulated.

11. How does the Stannius ligature used in the laboratory produce heart block? It physically blocks transmission of impulses from the atria to the ventricle.
12. Define partial heart block, and describe how it was recognized in the laboratory. *When the 1:1 ratio of atrial to ventricular contractions was replaced by different whole number ratios, e.g. 2:1, 3:1, the heart was in partial heart block.*

13. Define total heart block, and describe how it was recognized in the laboratory. *No synchrony between depolarization waves of atria and ventricle. Impulses not being transmitted from atria to the ventricle; no whole number relationship between atrial and ventricular contractions was demonstrated.*

14. What do your heart block experiment results indicate about the spread of impulses from the atria to the ventricles? *In normal heart activity, the ventricles are depolarized by the depolarization wave spreading from the atria.*

**Observing the Microcirculation Under Various Conditions**

15. In what way are the red blood cells of the frog different from those of the human? *Frog RBCs are nucleated; human RBCs are anucleate.*

On the basis of this one factor, would you expect their life spans to be longer or shorter? *Longer*

16. The following statements refer to your observation of one or more of the vessel types observed in the microcirculation in the frog’s web. Characterize each statement by choosing one or more responses from the key.

*Key: a. arteriole     b. venule     c. capillary*

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>c</td>
<td>1. smallest vessels observed</td>
</tr>
<tr>
<td>a</td>
<td>2. vessel in which blood flow is rapid, pulsating</td>
</tr>
<tr>
<td>c</td>
<td>3. vessel in which blood flow is least rapid</td>
</tr>
<tr>
<td>c</td>
<td>4. red blood cells pass through these vessels in single file</td>
</tr>
<tr>
<td>b</td>
<td>5. blood flow smooth and steady</td>
</tr>
<tr>
<td>c</td>
<td>6. most numerous vessels</td>
</tr>
<tr>
<td>a</td>
<td>7. vessels that deliver blood to the capillary bed</td>
</tr>
<tr>
<td>c</td>
<td>8. vessels that serve the needs of the tissues via exchanges</td>
</tr>
<tr>
<td>b</td>
<td>9. vessels that drain the capillary beds</td>
</tr>
</tbody>
</table>

17. Which of the vessel diameters changed most? *Arterioles*

What division of the nervous system controls the vessels? *Autonomic nervous system, sympathetic division.*
18. Discuss the effects of the following on blood vessel diameter (state specifically the blood vessels involved) and rate of blood flow. Then explain the importance of the reaction observed to the general well-being of the body.

**local application of cold:** \textit{Vasoconstriction of arterioles. Bypasses the skin capillaries and withdraws blood to deeper body tissues to prevent heat loss to the external environment.}

**local application of heat:** \textit{Vasodilation of arterioles and flushing of capillary bed with blood. Increases the local blood supply and allows heat radiation from the skin surface.}

**inflammation (or application of HCl):** \textit{Vasodilation locally bringing in WBCs, and more nutrients to help fight the inflammatory stimulus.}

**histamine:** \textit{Same reaction as with inflammation.}
The Lymphatic System and Immune Response

Time Allotment: 1 hour.


A.D.A.M.® Interactive Anatomy 4.0 (AIA: CD-ROM, DVD)
Blood and Immunity (CVB: CD-ROM)
The Human Immune System: The Fighting Edge (FHS: 44 minutes, VHS, DVD, 3-year streaming webcast)
Internal Defenses (FHS: 28 minutes, VHS, DVD, 3-year streaming webcast)
Organ Systems Working Together (WNS: 14 minutes, VHS)
Practice Anatomy Lab™ 2.0 (PAL) (BC: CD-ROM, Website)

Solutions:

Simple Saline Agar
• 2 g agar (Difco Bacto)
• 1 g sodium chloride (NaCl)
• 100 ml distilled water
• 0.1 g sodium azide (optional)
Prepare a clear solution by boiling the mixture gently. Pour while hot to a depth of 3 mm into 100-mm plastic petri dishes, which have been divided into three compartments (7 ml per compartment). Leave open until the gel cools. To store, either steam sterilize the agar before pouring or add 0.1 g sodium azide per 100 ml.

Laboratory Materials

Ordering information is based on a lab size of 24 students, working in groups of 4. A list of supply house addresses appears in Appendix A.

Anatomical chart of human lymphatic system or 3-D model of human lymphatic system
Disposable gloves
24 pairs of safety glasses
24 compound microscopes, lens paper, lens cleaning solution
24 prepared microscope slides of lymph nodes
24 prepared microscope slides of spleens
24 prepared microscope slides of tonsils
24 wax marking pencils
6 petri plates with simple saline agar
6 medicine droppers
6 dropper bottles of red food coloring
6 dropper bottles of green food coloring
6 dropper bottles of goat antibody to horse serum albumin
6 dropper bottles of goat antibody to bovine serum albumin
6 dropper bottles of goat antibody to swine serum albumin
6 dropper bottles of horse serum albumin diluted to 20% with physiological saline
6 dropper bottles of unknown albumin samples diluted to 20% (prepared from horse, swine, and/or bovine albumin)
Colored pencils
Advance Preparation

1. Set out anatomical charts of the lymphatic system; prepared slides of lymph nodes, spleen, and tonsil; lens paper; and lens cleaning solution. Have microscopes available.

2. Prepare saline agar petri dishes in advance.

3. Set out petri dishes with saline agar (one per group), dropper bottles of red and green food coloring, dropper bottles of goat antibody to bovine serum albumin, horse serum albumin and swine serum albumin, dropper bottles of horse serum albumin, dropper bottles of unknown serum albumin samples diluted to 20%, medicine droppers, and wax marking pencils.

Answers to Pre-Lab Quiz (p. 525)

1. true 6. b, specificity
2. b, excess tissue fluid that has leaked out of capillaries 7. T cells
3. true 8. cellular
4. b, Lymph nodes 9. true
5. true

Answers to Activity Questions

Activity 3: Using the Ouchterlony Technique to Identify Antigens (pp. 531–532)

Results

4. A color change occurred where the two colors met.
5. No evidence of a precipitate.
6. Horse serum albumin functioned as the antigen.
7. Goat anti-horse serum (goat antibody) reacts with the antigen in section II.
   A white precipitin line formed between wells 1 and 2.
8. The swine albumin in well 1 would have reacted with the anti-swine antibody in well 4.
9. No reaction. The antibodies are specific to horse, bovine, and swine albumins.
The Lymphatic System and Immune Response

The Lymphatic System

1. Match the terms below with the correct letters on the diagram.

   1. axillary lymph nodes
   2. bone marrow
   3. cervical lymph nodes
   4. cisterna chyli
   5. inguinal lymph nodes
   6. lymphatic vessels
   7. Peyer’s patches (in intestine)
   8. right lymphatic duct
   9. spleen
   10. thoracic duct
   11. thymus
   12. tonsils

2. Explain why the lymphatic system is a one-way system, whereas the blood vascular system is a two-way system.

   Blood vessels form a complete circuit from and to the heart. The lymphatic system lacks arteries and begins with blind-ended lymph capillaries. Thus, it is a “return” system only.

3. How do lymphatic vessels resemble veins? They are thin walled and have valves.

   How do lymphatic capillaries differ from blood capillaries? Lymph capillaries are more permeable and are blind ended; they have no “feeder” arterioles.
4. What is the function of the lymphatic vessels? **To pick up and return excess tissue fluid (and leaked proteins) to the blood vascular system.**

5. What is lymph? **Leaked plasma (but contains fewer proteins). Tissue fluid that has entered lymphatic vessels.**

6. What factors are involved in the flow of lymphatic fluid? **"Milking" action of skeletal muscles; pressure changes in the thorax.**

7. What name is given to the terminal duct draining most of the body? **Thoracic duct.**

8. What is the cisterna chyli? **Enlarged terminus of the thoracic duct, which receives lymph from the digestive viscera.**

   How does the composition of lymph in the cisterna chyli differ from that in the general lymphatic stream?

   **Same, except that the lymph in the cisterna chyli is very fat-rich.**

9. Which portion of the body is drained by the right lymphatic duct? **Right half of upper torso and head; right arm.**

10. Note three areas where lymph nodes are densely clustered: **axillary region, cervical region, and inguinal region (groin).**

11. What are the two major functions of the lymph nodes? **To remove debris from the lymph and to provide a site for cloning and multiplication of lymphocytes.**

12. The radical mastectomy is an operation in which a cancerous breast, surrounding tissues, and the underlying muscles of the anterior thoracic wall, plus the axillary lymph nodes, are removed. After such an operation, the arm usually swells, or becomes edematous, and is very uncomfortable—sometimes for months. Why?

   **The lymphatic fluid is not being drained from the area due to a disruption of lymphatic vessels and nodes.**

**The Immune Response**

13. What is the function of B cells in the immune response? **Upon antigen challenge, they clone to produce daughter cells, most of which are plasma cells that release antibodies to the blood. (Humoral response.)**

14. What is the role of T cells? **Mount cell-mediated immunity. Attack virus-infected cells, tumor cells, bacteria, etc. Also activate B cells and enhance the migration of other WBCs into the area to help destroy antigens.**
15. Define the following terms related to the operation of the immune system.

**immunological memory:** Response that recognizes and mounts an attack on antigens previously encountered

**specificity:** Ability to distinguish between closely related antigens.

**recognition of self from nonself:** Ability to recognize proteins on own tissue cells as “self” and not attack them.

**autoimmune disease:** An inability of the immune system to recognize self, resulting in attack of self cells by the immune system.

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**Studying the Microscopic Anatomy of a Lymph Node, the Spleen, and a Tonsil**

16. In the space below, make a rough drawing of the structure of a lymph node. Identify the cortex area, germinal centers, and medulla. For each identified area, note the cell type (T cell, B cell, or macrophage) most likely to be found there.

[Diagram of lymph node with labeled areas: Medulla (macrophages), Cortex (other than germinal centers-T cells), Germinal centers (B cells)]

17. What structural characteristic ensures a slow flow of lymph through a lymph node? There are more afferent than efferent vessels.

Why is this desirable? Allows time for the macrophages in the node to remove antigens and other debris, and for activation of immune cells.

18. What similarities in structure and function are found in the lymph nodes, spleen, and tonsils? All are lymphoid tissue containing macrophages and lymphocytes. They are all areas where exposure to antigen causes lymphocytes to proliferate and form clones.
Antibodies and Tests for Their Presence

19. Distinguish between antigen and antibody. *An antigen is a molecule capable of provoking an immune response. An antibody is a protein produced by plasma cells that interacts with a particular antigen to form a complex.*

20. Describe the structure of the immunoglobulin monomer, and label the diagram with the choices given in the key._Four_ polypeptide chains, two “heavy” and two “light,” held together by disulfide bonds to form a Y-shaped molecule. Each chain has constant (c) and variable (v) regions.

![Diagram of immunoglobulin monomer with labels](image)

Key:
- a. antigen-binding site
- b. heavy chain
- c. hinge region
- d. light chain
- e. stem region
- f. macrophage binding site

21. Are the genes coding for one antibody entirely different from those coding for a different antibody? *No*.

Explain your answer._Only a few genes exist for coding antibody-constant regions; therefore many antibodies have identical e regions. The variable (antigen-binding) regions differ for each antibody responding to a different antigen._

22. In the Ouchterlony test, what happened when the antibody to horse serum albumin mixed with horse serum albumin? _A white precipitate formed (between wells 1 and 2)._ 

23. If the unknown antigen contained bovine and swine serum albumin, what would you expect to happen in the Ouchterlony test, and why? _Antigen-antibody complexes would form a white precipitate between bovine serum albumin and the antibody to bovine serum albumin (between wells 1 and 3), and between swine serum albumin and antibody to swine serum albumin (between wells 1 and 4)._
Anatomy of the Respiratory System

**Time Allotment**: 1 hour.


- **A.D.A.M.® Interactive Anatomy 4.0 (AIA: CD-ROM, DVD)**
- **Breath of Life (FHS: 26 minutes, VHS, DVD, 3-year streaming webcast)**
- **Human Respiratory System Videotape (BC: 25 minutes, VHS)**
- **Practice Anatomy Lab™ 2.0 (PAL) (BC: CD-ROM, Website)**
- **Respiratory System: Intake and Exhaust (FHS: 25 minutes, VHS, DVD)**

**Laboratory Materials**

*Ordering information is based on a lab size of 24 students, working in groups of 4. A list of supply house addresses appears in Appendix A.*

- Human torso models
- Respiratory system model and/or anatomical chart of the respiratory system
- Larynx model (if available)
- Resin cast of the respiratory tree (if available)
- Preserved inflatable lung preparation (obtained from a biological supply house) or sheep pluck fresh from the slaughterhouse
- Source of compressed air
- 24 prepared microscope slides of each of the following (if available):
  - trachea (cross section), normal lung tissue, pathological lung tissues (e.g., with bronchitis, pneumonia, emphysema, or lung cancer)
- 24 compound and stereomicroscopes, lens paper, lens cleaning solution
- 6 dissecting trays
- Disposable gloves
- Disposable autoclave bags

**Advance Preparation**

1. Set out human torso models, respiratory organ system model, larynx model, and/or charts of the respiratory system.
2. Set out a sheep pluck (fresh if possible), or set up an inflatable swine lungs kit (Nasco), and disposable gloves.
3. Arrange for a source of compressed air.
4. Set out prepared slides of the trachea, normal lung tissue, and pathological lung tissue exhibiting conditions such as bronchitis, pneumonia, emphysema, or lung cancer; lens paper; and lens cleaning solution. Have compound microscopes and stereomicroscopes available.
Comments and Pitfalls

1. Many prepared slides of the trachea also include the esophagus. Remind the students that the trachea is held open by cartilaginous rings, while the esophagus is not. Showing an appropriate image of the microscopic section might be useful.

2. When using a preserved sheep pluck with a compressed air supply, be careful to avoid overinflation (leading to an explosion of preserved tissue!)

3. The inflatable swine lungs kit includes an inflation rack and tray, inflatable swine lungs, and a section of dried swine lung. The inflatable lungs will last for several years and give a much more dramatic response than that usually seen with the preserved lungs of the sheep pluck. An inflatable diseased lung is also available from Nasco and is excellent for comparison to a healthy lung.

Answers to Pre-Lab Quiz (p. 537)

1. d, supply the body with oxygen and dispose of carbon dioxide
2. true
3. c, pharynx
4. thyroid cartilage
5. true
6. b, left and right main bronchi
7. columnar epithelium
8. true
9. Alveoli
10. two
Anatomy of the Respiratory System

Upper and Lower Respiratory System Structures

1. Complete the labeling of the diagram of the upper respiratory structures (sagittal section).

2. Two pairs of vocal folds are found in the larynx. Which pair are the true vocal cords (superior or inferior)?

   Inferior

3. Name the specific cartilages in the larynx that correspond to the following descriptions.

   forms the Adam’s apple: thyroid

   shaped like a signet ring: cricoid

   a “lid” for the larynx: epiglottis

   vocal cord attachment: arytenoid
4. What is the significance of the fact that the human trachea is reinforced with cartilaginous rings?  

Prevents its collapse during pressure changes occurring during breathing.

Of the fact that the rings are incomplete posteriorly?  Allows a food bolus traveling down the posterior esophagus to bulge anteriorly.

5. What is the function of the pleural membranes?  Produce a serous fluid that reduces friction during breathing movements and helps to hold the lungs tightly to the thorax wall which keeps the lungs inflated.

6. Name two functions of the nasal cavity mucosa.  

Warms and moistens incoming air.

7. The following questions refer to the primary bronchi.

Which is longer?  Left  

Larger in diameter?  Right  

More horizontal?  Left  

Which more commonly traps a foreign object that has entered the respiratory passageways?  Right  

8. Appropriately label all structures provided with leader lines on the diagrams below.
9. Trace a molecule of oxygen from the nostrils to the pulmonary capillaries of the lungs: Nostrils →

\[ \text{nasal cavity} \rightarrow \text{pharynx} \rightarrow \text{larynx} \rightarrow \text{trachea} \rightarrow \text{primary bronchus} \rightarrow \text{lobar/segmental bronchi (etc.)} \rightarrow \text{bronchiole} \rightarrow \text{respiratory bronchiole} \rightarrow \text{alveolar duct} \rightarrow \text{alveolar sac} \rightarrow \text{across alveolar/capillary walls} \rightarrow \text{pulmonary blood} \]

10. Match the terms in column B to the descriptions in column A.

<table>
<thead>
<tr>
<th>Column A</th>
<th>Column B</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. connects the larynx to the primary bronchi</td>
<td>a. alveolus</td>
</tr>
<tr>
<td>2. site of tonsils</td>
<td>b. bronchiole</td>
</tr>
<tr>
<td>3. food passageway posterior to the trachea</td>
<td>c. conchae</td>
</tr>
<tr>
<td>4. covers the glottis during swallowing of food</td>
<td>d. epiglottis</td>
</tr>
<tr>
<td>5. contains the vocal cords</td>
<td>e. esophagus</td>
</tr>
<tr>
<td>6. nerve that activates the diaphragm during inspiration</td>
<td>f. glottis</td>
</tr>
<tr>
<td>7. pleural layer lining the walls of the thorax</td>
<td>g. larynx</td>
</tr>
<tr>
<td>8. site from which oxygen enters the pulmonary blood</td>
<td>h. palate</td>
</tr>
<tr>
<td>9. connects the middle ear to the nasopharynx</td>
<td>i. pharyngotympanic tube</td>
</tr>
<tr>
<td>10. opening between the vocal folds</td>
<td>j. parietal pleura</td>
</tr>
<tr>
<td>11. increases air turbulence in the nasal cavity</td>
<td>k. pharynx</td>
</tr>
<tr>
<td>12. separates the oral cavity from the nasal cavity</td>
<td>l. phrenic nerve</td>
</tr>
<tr>
<td></td>
<td>m. primary (main) bronchi</td>
</tr>
<tr>
<td></td>
<td>n. trachea</td>
</tr>
<tr>
<td></td>
<td>o. vagus nerve</td>
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<td></td>
<td>p. visceral pleura</td>
</tr>
</tbody>
</table>

11. What portions of the respiratory system are referred to as anatomical dead space? All but the respiratory zone structures (respiratory bronchioles, alveolar ducts and sacs, and alveoli).

Why? Because no gas exchange occurs except in the respiratory zone, particularly in the alveoli.

12. Define the following terms.

- **external respiration**: Exchange of gases across the respiratory membrane in the lungs.

- **internal respiration**: Exchange of respiratory gases between the blood of the systemic capillaries and the tissue cells of the body.

- **cellular respiration**: Oxygen-using cellular processes (that produce energy) with tissue cells.
**Demonstrating Lung Inflation in a Sheep Pluck**

13. Does the lung inflate part by part or as a whole, like a balloon? *Part by part.*

14. What happened when the pressure was released? *The lung deflated.*

15. What type of tissue ensures this phenomenon? *Elastic connective tissue.*

**Examining Prepared Slides of Trachea and Lung Tissue**

16. What structural characteristics of the alveoli make them an ideal site for the diffusion of gases?

> *Thin walls, extremely large surface area.*

Why does oxygen move from the alveoli into the pulmonary capillary blood? *Because the partial pressure of oxygen is greater in the alveoli; therefore, it moves according to the laws of diffusion into the pulmonary blood.*

17. If you observed pathological lung sections, record your observations. Also record how the tissue differed from normal lung tissue. Complete the table below using your answers.

<table>
<thead>
<tr>
<th>Slide type</th>
<th>Observations</th>
<th>Comparison to normal lung tissue</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Student data.</em></td>
<td><em>Student data.</em></td>
<td></td>
</tr>
</tbody>
</table>
Respiratory System Physiology

Time Allotment: 2 hours (allow an additional half hour if students are unfamiliar with the recording apparatus).


Breath of Life (FHS: 26 minutes, VHS, DVD, 3-year streaming webcast)
Breathing (FHS: 20 minutes, VHS, DVD, 3-year streaming webcast)
Interactive Physiology® 10-System Suite: Respiratory System (BC: CD-ROM, Website)
The Physiology of Exercise (FHS: 15 minutes, VHS, DVD)
Respiration (FHS: 15 minutes, VHS, DVD)
Respiratory System: Intake and Exhaust (FHS: 25 minutes, VHS, DVD)

Solutions:

Hydrochloric Acid (HCl), 0.01 M
Add 0.8 milliliter concentrated HCl to 900 milliliters distilled water. Add distilled water to make 1 liter of solution; or add 10 milliliters of 1 N HCl to 900 milliliters of distilled water. Add distilled water to a final volume of 1 liter.

Sodium Hydroxide (NaOH), 0.05 M
Weigh out 2 g of NaOH and add to distilled water to make 1 liter of solution.

Laboratory Materials

Ordering information is based on a lab size of 24 students, working in groups of 4. A list of supply house addresses appears in Appendix A.

Model of lung (bell jar demonstrator) 6 tape measures
6 100-ml beakers
6 dropper bottles of phenol red
50 milliliters of 0.05 M NaOH
Alcohol swabs
6 paper bags
6 stethoscopes
30 250-milliliter beakers
12 50-milliliter beakers
6 100-milliliter graduated cylinders
6 dropper bottles of concentrated HCl
6 dropper bottles of concentrated NaOH
6 pH meters standardized with buffer of pH 7
2 liters standard buffer solution (pH 7)
Animal plasma
6 wash bottles of distilled water
6 glass stirring rods
6 dropper bottles of 0.01 M HCl
Straws
Physiograph, pneumograph, and recording attachments for physiograph
Apparatus A or B:
A: Spirometer, disposable cardboard mouthpieces, nose clips, table (on chalkboard/whiteboard) for recording class data, disposable autoclave bag, battery jar containing 70% ethanol solution
B: BIOPAC® MP36 (or MP35/30) data acquisition unit, PC or Mac computer, BIOPAC® Student Lab Software, BIOPAC® airflow transducer, BIOPAC® calibration syringe, disposable mouthpiece, nose clip, bacteriological filter
Advance Preparation

1. Set out the model lung (bell jar demonstrator).
2. For each group set out a tape measure, nose clips, spirometer, disposable mouthpieces (enough for each member of the group), alcohol swabs, a paper bag, a physiograph with a pneumograph and recording attachments, respiratory belt transducer and cable, paper, and a stethoscope. See the frog experiment in Exercise 16a for further directions for the physiograph. If a wet spirometer is used, be sure it is filled with distilled water according to the manufacturer’s instructions. Set out a battery jar of 70% ethanol.
3. Set out equipment and materials for the conduction of the BIOPAC® activity. Introduce your students to the basic features of the equipment prior to beginning the lab activity.
4. For each group set out a pH meter standardized with a buffer of pH 7, five 250-milliliter beakers, two 50-milliliter beakers, a 100-milliliter graduated cylinder, a dropper bottle of concentrated HCl, a dropper bottle of concentrated NaOH, 300 milliliters of standard buffer solution (pH 7), 500 milliliters of distilled water, a wash bottle of distilled water, a dropper bottle of 0.01 M HCl, a glass stirring rod, and animal plasma.
5. Set up a disposable autoclave bag.
6. Draw a class data chart on the chalkboard or whiteboard to record TV (Vt), IRV, ERV, and VC.
7. Set out bottles of 0.05 M NaOH, dropper bottles of phenol red, distilled water, 100-ml beakers, and straws for each group.

Comments and Pitfalls

1. If a dry spirometer is used, the tidal volume readings are not very accurate. Somewhat better readings are obtained if the student exhales three times into the spirometer and divides the result by three.
2. Students will have to adjust the pneumograph until a good recording can be made. Be sure that it fits comfortably around the chest. Check all connections for a good fit, and if a tambour is used, be sure the rubber is intact. (This can be easily replaced using rubber sheeting. Use a good adhesive to reattach the clip.)
3. When using the pneumograph, be sure that students can correctly interpret the tracings. On some equipment, inspiration results in a downward deflection of the pointer (opposite the direction noted on the spirometer tracing in Figure 37A.2).
4. Students may be confused about hyperventilation. The forced hyperventilation here results in a decreased breathing rate. Hyperventilation during psychological stress can produce a positive feedback situation, resulting in further hyperventilation. As hypocapnia increases, cerebral vessels constrict and increasingly acidotic conditions in the brain stimulate the medullary respiratory centers. Rebreathing air in the latter case raises blood PCO₂, reverses the cerebral vessel constriction, and stops the hyperventilation.
5. For the experiment in Observing the Operation of Standard Buffers, Activity 8, if you wish to avoid using concentrated acid and base and conserve pH buffer, you can scale down the experiment by using 1 M NaOH, 1 M HCl, and 50 milliliters of pH 7 buffer.

Answers to Pre-Lab Quiz (pp. 549–550)

1. Expiration
2. c, inspiratory muscles relax
3. false
4. b, 500
5. Vital capacity
6. false
7. aortic and carotid bodies
8. c, 7.4 ± 0.02
9. Acids
10. false
Answers to Activity Questions

Activity 1: Operating the Model Lung (pp. 550–551)

3. They deflate.

4. The walls of the human thorax expand and collapse, bringing about changes in thoracic volume. In the model, the bottle walls are rigid. All changes in thoracic volume are realized only by the diaphragm. In real lungs, the intrapleural cavity is a fluid-filled space with pleural fluid maintaining the lungs expanded against the rib cage. In the model, this cavity is air filled though sealed. Consequently, the simulation of a pneumothorax is not as significant as would occur in the biologic system.

Activity 5: Measuring Respiratory Volumes Using BIOPAC® (pp. 559–564)

Data Analysis

11. Generally, the taller and larger a subject is, the larger will be the vital capacity. This is because a larger person requires more oxygen for cellular respiration. Other factors that can affect vital capacity include: aerobic conditioning of the subject, chronic obstructive pulmonary diseases, smoking, etc.

Activity 6: Visualizing Respiratory Variations Using the Physiograph-Pneumograph Apparatus (pp. 565–566)

Using the Physiograph-Pneumograph Apparatus

4. During breath holding, the subject has the desire to expire. After a deep and forceful exhalation, the urge is to inspire. This may be explained by the Hering-Breuer reflex. Stretch receptors in the lungs are sensitive to extreme inflation and extreme deflation of the lungs. Impulses to the medulla oblongata initiate expiration or inspiration, respectively.

5. The hyperventilation tracing should be similar in height and depth to the vital capacity tracing, but with an increased rate. After hyperventilation, the breathing rate slows down.


7. After 3 minutes of rebreathing breathed air, the ventilation rate increases. It is much faster than the breathing rate after hyperventilating.

9. Forced expiration results in dilation of the neck and face veins. Increased intrathoracic pressure reduces blood flow back to the heart, decreasing cardiac output. This results in increased cardiac rate (seen here as increased pulse rate).

Activity 7: Demonstrating the Reaction Between Carbon Dioxide (in Exhaled Air) and Water (p. 567)

3. Carbon dioxide in the exhaled air combines with water to form carbonic acid, lowering the pH of the solution. The phenol red in the water changes from red to yellow.

Activity 8: Observing the Operation of Standard Buffers (p. 567)

4. The buffer system should resist change in pH. The contrast between the pH change with water alone and the pH change with buffer should be clear.

Activity 9: Exploring the Operation of the Carbonic Acid–Bicarbonate Buffer System (p. 568)

4. When testing the plasma carbonic acid–bicarbonate buffer system, it is the bicarbonate that counteracts the change in pH.
Mechanics of Respiration

1. For each of the following cases, check the column appropriate to your observations on the operation of the model lung.

<table>
<thead>
<tr>
<th>Change</th>
<th>Diaphragm pushed up</th>
<th>Diaphragm pulled down</th>
</tr>
</thead>
<tbody>
<tr>
<td>In internal volume of the bell jar</td>
<td>Increased</td>
<td>Decreased</td>
</tr>
<tr>
<td>(thoracic cage)</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>In internal pressure</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>In the size of the balloons (lungs)</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>In direction of air flow</td>
<td>Into lungs</td>
<td>Out of lungs ✓</td>
</tr>
<tr>
<td></td>
<td>Into lungs ✓</td>
<td>Out of lungs</td>
</tr>
</tbody>
</table>

2. Base your answers to the following on your observations in question 1.

Under what internal conditions does air tend to flow into the lungs? ✓ thoracic volume, and ✓ pressure.

Under what internal conditions does air tend to flow out of the lungs? Explain why this is so. ✓ thoracic volume, ✓ pressure. Gases move in the direction that tends to equalize pressure inside and outside the “container.”

3. Activation of the diaphragm and the external intercostal muscles begins the inspiratory process. What effect does contraction of these muscles have on thoracic volume, and how is this accomplished? ✓ thoracic volume. The diaphragm moves inferiorly, increasing the superior/inferior dimension; the ribs swing up and out, increasing the lateral and anterior/posterior dimensions.

4. What was the approximate increase in diameter of chest circumference during a quiet inspiration? (student data) inches
   During forced inspiration? (student data) inches
What temporary physiological advantage is created by the substantial increase in chest circumference during forced inspiration? *Increases the thoracic volume more; therefore, creates a greater negative internal pressure, causing the gases to rush in quickly. Also, more “fresh” air reaches the alveoli.*

5. The presence of a partial vacuum between the pleural membranes is integral to normal breathing movements. What would happen if an opening were made into the chest cavity, as with a puncture wound?  
*Destroys the partial vacuum in the pleural space and the lung on the affected side collapses.*

How is this condition treated medically? *Air is withdrawn (chest tube) and the chest is closed.*

Respiratory Sounds

6. Which of the respiratory sounds is heard during both inspiration and expiration? *Bronchial*  
Which is heard primarily during inspiration? *Vesicular*

7. Where did you best hear the vesicular respiratory sounds? *Heard over most of the lung area.*

Respiratory Volumes and Capacities—Spirometry or BIOPAC®

8. Write the respiratory volume term and the normal value that is described by the following statements.

Volume of air present in the lungs after a forceful expiration: *residual volume (~1100 ml)*

Volume of air that can be expired forcibly after a normal expiration: *expiratory reserve (~1200 ml)*

Volume of air that is breathed in and out during a normal respiration: *tidal volume (~500 ml)*

Volume of air that can be inspired forcibly after a normal inspiration: *inspiratory reserve (~2700–2800 ml)*

Volume of air corresponding to TV + IRV + ERV: *vital capacity (~4800 ml)*

9. Record experimental respiratory volumes as determined in the laboratory. (Corrected values are for the recording spirometer only.)

Average TV: *(student data) ml*  
Corrected value for TV: *(student data) ml*  
Average IRV: *(student data) ml*  
Corrected value for IRV: *(student data) ml*  
MRV: *(student data) ml/min*  
Average ERV: *(student data) ml*  
Corrected value for ERV: *(student data) ml*  
Average VC: *(student data) ml*  
Corrected value for VC: *(student data) ml*  
% predicted VC: *(student data) %*  
FEV₁: *(student data) %*  
FVC
10. Would your vital capacity measurement differ if you performed the test while standing? Yes ______ While lying down? Yes ______ Explain. When lying down or sitting, the abdominal organs press against the diaphragm, making it more difficult for the diaphragm to move inferiorly.

11. Which respiratory ailments can respiratory volume tests be used to detect?

Chronic bronchitis and emphysema (often associated). Chronic bronchitis ↓ the volume of air that can be inhaled due to excessive mucus production; emphysema ↓ the amount of air that can be exhaled (check-valve effect).

12. Using an appropriate reference, complete the chart below.

<table>
<thead>
<tr>
<th>% of composition of air</th>
<th>O₂</th>
<th>CO₂</th>
<th>N₂</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inspired</td>
<td>~21%</td>
<td>~0.04%</td>
<td>~78%</td>
</tr>
<tr>
<td>Expired</td>
<td>~16%</td>
<td>~4%</td>
<td>~78%</td>
</tr>
</tbody>
</table>

Factors Influencing Rate and Depth of Respiration

13. Where are the neural control centers of respiratory rhythm? medulla oblongata and pons

For questions 14–21, use your Activity 6 data (the pneumograph-physiograph recording or visual count).

14. In your data, what was the rate of quiet breathing?

Initial testing (student data) ______ breaths/min

Record observations of how the initial pneumograph recording was modified during the various testing procedures described below. Indicate the respiratory rate, and include comments on the relative depth of the respiratory peaks observed.

<table>
<thead>
<tr>
<th>Test performed</th>
<th>Observations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Talking</td>
<td>Respiratory rate becomes irregular during talking.</td>
</tr>
<tr>
<td>Yawning</td>
<td>Yawning is reflected by extremely deep prolonged inspiration.</td>
</tr>
<tr>
<td>Laughing</td>
<td>Respiratory rate becomes irregular. Respiratory depth may be ↑ or ↓ depending on the nature of the laugh.</td>
</tr>
<tr>
<td>Standing</td>
<td>Regular rhythm and rate.</td>
</tr>
<tr>
<td>Concentrating</td>
<td>Respiratory rate is regular unless punctuated by intervals of apnea in individuals who hold their breath when concentrating.</td>
</tr>
<tr>
<td>Swallowing water</td>
<td>Respiration ceases during the period of swallowing.</td>
</tr>
<tr>
<td>Coughing</td>
<td>Respiration rate becomes irregular and marked by ↑ depth of expirations during coughing.</td>
</tr>
<tr>
<td>Lying down</td>
<td>Regular rhythm and regular (or slightly depressed) rate. Depth decreases.</td>
</tr>
<tr>
<td>Running in place</td>
<td>Increased rate and depth of breathing.</td>
</tr>
</tbody>
</table>
15. Record student data below.

- Breath-holding interval after a deep inhalation: (s.d.) sec length of recovery period: (s.d.) sec
- Breath-holding interval after a forceful expiration: (s.d.) sec length of recovery period: (s.d.) sec

After breathing quietly and taking a deep breath (which you held), was your urge to inspire or expire? expire

After exhaling and then holding one’s breath, was the desire for inspiration or expiration? inspiration

Explain these results. (Hint: What reflex is involved here?) Hering-Breuer reflex. Both extreme deflation and inflation of the lungs excites receptors there. Impulses are transmitted to the medulla oblongata, which then initiates inspiration or expiration (respectively).

16. Observations after hyperventilation: (student data)

17. Length of breath holding after hyperventilation: (s.d.) sec

Why does hyperventilation produce apnea or a reduced respiratory rate? Hyperventilation washes CO₂ out of the blood. Since CO₂ is the major chemical stimulus for inspiration, the desire or drive to breathe is decreased.

18. Observations for rebreathing air: (student data)

Why does rebreathing air produce an increased respiratory rate? CO₂ (exhaled) accumulates in the bag; this stimulates increased force/rate of respiration.

19. What was the effect of running in place (exercise) on the duration of breath holding? ↓ the duration.

Explain this effect. The body’s need to get rid of CO₂ and obtain oxygen is increased by exercise.

20. Record student data from the test illustrating the effect of respiration on circulation.

- Radial pulse before beginning test: _______/min Radial pulse after testing: _______/min
- Relative pulse force before beginning test: _______ Relative force of radial pulse after testing: _______
- Condition of neck and facial veins after testing: __________________________________________

Explain these data. Forced expiration increases intrathoracic pressure, reducing blood flow back to the heart, resulting in dilation of the neck and facial veins. Decreased cardiac output results in increased cardiac rate (seen here as increased pulse rate).
21. Do the following factors generally increase (indicate with I) or decrease (indicate with D) the respiratory rate and depth?

- Increase in blood CO$_2$: I
- Increase in blood pH: D
- Decrease in blood O$_2$: I
- Decrease in blood pH: I

Did it appear that CO$_2$ or O$_2$ had a more marked effect on modifying the respiratory rate? CO$_2$

22. Where are sensory receptors sensitive to changes in blood pressure located? Aortic arch and carotid sinus.

23. Where are sensory receptors sensitive to changes in O$_2$ levels in the blood located? Aortic bodies in the aortic arch and carotid bodies at the bifurcation of the common carotid artery.

24. What is the primary factor that initiates breathing in a newborn infant? ↑ levels of CO$_2$ in the blood.

25. Blood CO$_2$ levels and blood pH are related. When blood CO$_2$ levels increase, does the pH increase or decrease?

Decrease Explain why. CO$_2$ combines with water (H$_2$O) to produce carbonic acid (H$_2$CO$_3$), which dissociates and liberates a hydrogen ion (H$^+$).

26. Which, if any, of the measurable respiratory volumes would likely be exaggerated in a person who is cardiovascularly fit, such as a runner or a swimmer?

VC, IRV, ERV, FEV would all be increased.

Which, if any, of the measurable respiratory volumes would likely be exaggerated in a person who has smoked a lot for over twenty years?

VC, IRV, ERV, FEV would all be reduced.

27. Define buffer. A molecule or molecular system that acts to resist changes in pH.

28. How successful was the laboratory buffer (pH 7) in resisting changes in pH when the acid was added? (student data) (Anticipated response: very successful.)

When the base was added? (student data) (Anticipated response: very successful.)

How successful was the buffer in resisting changes in pH when the additional aliquots (3 more drops) of the acid and base were added to the original samples? Successful; only slight pH changes are seen.
29. What buffer system operates in blood plasma? **Carbonic acid–bicarbonate system.**

Which member of the buffer system resists a drop in pH? **HCO₃⁻** Which resists a rise in pH? **H₂CO₃**

30. Explain how the carbonic acid–bicarbonate buffer system of the blood operates. **H₂CO₃**, a weak acid, remains undissociated at physiologic pH or acid pH. However, if the pH starts to rise, H₂CO₃ dissociates and liberates H⁺, which acts to ↓ the pH. HCO₃⁻ (bicarbonate ion) is the “alkaline reserve”; it acts to tie up excess H⁺ into H₂CO₃ when the environment becomes too acidic. Since it is a weak base, it does not function under physiologic or alkaline conditions.

31. What happened when the carbon dioxide in exhaled air mixed with water? **Phenol red turned yellow as CO₂ mixed with water to form carbonic acid.**

What role does exhalation of carbon dioxide play in maintaining relatively constant blood pH? **CO₂ leaves the blood during exhalation. This prevents an accumulation of carbonic acid.**
Time Allotment: 2 hours.


- *A.D.A.M.® Interactive Anatomy 4.0* (AIA: CD-ROM, DVD)
- *Digestive System: Your Personal Power Plant* (FHS: 34 minutes, VHS, DVD, 3-year streaming webcast)
- *The Food Machine* (NIMCO: 30 minutes, VHS)
- *The Human Digestive System* (DE: 18 minutes, DVD)
- *Human Digestive System Videotape* (BC: 33 minutes, VHS)
- *Practice Anatomy Lab™ 2.0* (PAL) (BC: CD-ROM, Website)

Laboratory Materials

Ordering information is based on a lab size of 24 students, working in groups of 4. A list of supply house addresses appears in Appendix A.

- 24 prepared microscope slides of each of the following: mixed salivary glands, liver, pancreas, longitudinal sections of the gastroesophageal junction and a tooth, and cross sections of the stomach, duodenum, and ileum
- 24 compound microscopes and/or hand lenses, lens paper, lens cleaning solution
- Anatomical charts of the human digestive system
- Jaw model and/or human skull
- Dissectible torso model
- 3-D model of a villus (if available)
- 3-D model of liver lobules (if available)

Advance Preparation

1. Set out the dissectible torso model and anatomical charts of the human digestive system.
2. Set out models of a villus and the liver, if available; a jaw model; and/or a human skull.
3. Set out slides of liver, mixed salivary glands, pancreas; longitudinal sections of the gastroesophageal junction and a tooth; cross sections of the stomach, duodenum, and ileum; lens paper and lens cleaning solution. Have compound microscopes and/or hand lenses available.

Answers to Pre-Lab Quiz (pp. 575–576)

1. d, all of the above
2. Absorption
3. a, mucosa
4. esophagus
5. d, peristalsis
6. d, stomach
7. true
8. descending colon
9. d, root
10. b, liver
Answers to Activity Questions

Activity 2: Studying the Histological Structure of Selected Digestive System Organs (p. 581)

Stomach
The extra layer of smooth muscle produces the churning movement because of the additional planes in which contraction can take place.

Gastroesophageal Junction
The esophagus is lined with stratified squamous epithelium, while the stomach is lined with simple columnar epithelium. The esophagus is designed to handle abrasion. The stomach lining has secretory and some absorptive functions. The stomach is designed to resist acid and the esophagus is not.

Activity 3: Observing the Histological Structure of the Small Intestine (pp. 584–585)

Duodenum
Simple columnar epithelium lines the duodenum.

Ileum
Peyer’s patches are lymphatic tissue.
Anatomy of the Digestive System

General Histological Plan of the Alimentary Canal

1. The general anatomical features of the alimentary canal are listed below. Fill in the table to complete the information.

<table>
<thead>
<tr>
<th>Wall layer</th>
<th>Subdivisions of the layer (if applicable)</th>
<th>Major functions</th>
</tr>
</thead>
<tbody>
<tr>
<td>mucosa</td>
<td>1) epithelium; 2) lamina propria; 3) muscularis mucosa</td>
<td>absorption secretion</td>
</tr>
<tr>
<td>submucosa</td>
<td>(not applicable)</td>
<td>vascular supply for mucosa; protection</td>
</tr>
<tr>
<td>muscularis externa</td>
<td>1) circular layer 2) longitudinal layer</td>
<td>churning; mixing; propulsion of food along the tract</td>
</tr>
<tr>
<td>serosa or adventitia</td>
<td>(not applicable)</td>
<td>protection and anchoring for adventitia; reduction of friction for abdominal organs by serosa</td>
</tr>
</tbody>
</table>

Organs of the Alimentary Canal

2. The tubelike digestive system canal that extends from the mouth to the anus is known as the **alimentary canal or the gastrointestinal (GI) tract.**

3. How is the muscularis externa of the stomach modified? **It has a third (obliquely oriented) muscle layer.**

   **How does this modification relate to the function of the stomach?** **Vigorous churning activity occurs here.**

4. What transition in epithelial type exists at the gastroesophageal junction? **Changes from stratified squamous (esophagus) to simple columnar (stomach).**

   **How do the epithelia of these two organs relate to their specific functions?** **The esophagus is subjected to constant abrasion (stratified squamous is well adapted for this). The stomach has secretory (and some absorptive) functions and is better protected from acid.**

5. Differentiate between the colon and the large intestine. **The large intestine includes the colon, but also includes the cecum, vermiform appendix, rectum, and anal canal.**
6. Match the items in column B with the descriptive statements in column A.

<table>
<thead>
<tr>
<th>Column A</th>
<th>Column B</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. structure that suspends the small intestine from the posterior body</td>
<td>a. anus</td>
</tr>
<tr>
<td>wall</td>
<td></td>
</tr>
<tr>
<td>2. fingerlike extensions of the intestinal mucosa that increase the</td>
<td>b. appendix</td>
</tr>
<tr>
<td>surface area for absorption</td>
<td></td>
</tr>
<tr>
<td>3. large collections of lymphoid tissue found in the submucosa of the</td>
<td>c. circular folds</td>
</tr>
<tr>
<td>small intestine</td>
<td></td>
</tr>
<tr>
<td>4. deep folds of the mucosa and submucosa that extend completely or</td>
<td>d. esophagus</td>
</tr>
<tr>
<td>partially around the circumference of the small intestine</td>
<td></td>
</tr>
<tr>
<td>5. regions that break down foodstuffs mechanically</td>
<td>e. frenulum</td>
</tr>
<tr>
<td>6. mobile organ that manipulates food in the mouth and initiates</td>
<td>f. greater omentum</td>
</tr>
<tr>
<td>swallowing</td>
<td></td>
</tr>
<tr>
<td>7. conduit for both air and food</td>
<td>g. hard palate</td>
</tr>
<tr>
<td>8. three structures continuous with and representing modifications of</td>
<td>h. haustra</td>
</tr>
<tr>
<td>the peritoneum</td>
<td></td>
</tr>
<tr>
<td>9. the “gullet”; no digestive/absorptive function</td>
<td>i. ileocecal valve</td>
</tr>
<tr>
<td>10. folds of the gastric mucosa</td>
<td>j. large intestine</td>
</tr>
<tr>
<td>11. sacculations of the large intestine</td>
<td>k. lesser omentum</td>
</tr>
<tr>
<td>12. projections of the plasma membrane of a mucosal epithelial cell</td>
<td>l. mesentery</td>
</tr>
<tr>
<td>13. valve at the junction of the small and large intestines</td>
<td>m. microvilli</td>
</tr>
<tr>
<td>14. primary region of food and water absorption</td>
<td>n. oral cavity</td>
</tr>
<tr>
<td>15. membrane securing the tongue to the floor of the mouth</td>
<td>o. parietal peritoneum</td>
</tr>
<tr>
<td>16. absorbs water and forms feces</td>
<td>p. Peyer’s patches</td>
</tr>
<tr>
<td>17. area between the teeth and lips/cheeks</td>
<td>q. pharynx</td>
</tr>
<tr>
<td>18. wormlike sac that outpockets from the cecum</td>
<td>r. pyloric valve</td>
</tr>
<tr>
<td>19. initiates protein digestion</td>
<td>s. rugae</td>
</tr>
<tr>
<td>20. structure attached to the lesser curvature of the stomach</td>
<td>t. small intestine</td>
</tr>
<tr>
<td>21. organ distal to the stomach</td>
<td>u. soft palate</td>
</tr>
<tr>
<td>22. valve controlling food movement from the stomach into the duodenum</td>
<td>v. stomach</td>
</tr>
<tr>
<td>23. posterosuperior boundary of the oral cavity</td>
<td>w. tongue</td>
</tr>
<tr>
<td>24. location of the hepatopancreatic sphincter through which pancreatic</td>
<td>x. vestibule</td>
</tr>
<tr>
<td>secretions and bile pass</td>
<td>y. villi</td>
</tr>
<tr>
<td>25. serous lining of the abdominal cavity wall</td>
<td>z. visceral peritoneum</td>
</tr>
<tr>
<td>26. principal site for the synthesis of vitamin K by microorganisms</td>
<td></td>
</tr>
<tr>
<td>27. region containing two sphincters through which feces are expelled</td>
<td></td>
</tr>
<tr>
<td>from the body</td>
<td></td>
</tr>
<tr>
<td>28. bone-supported anterosuperior boundary of the oral cavity</td>
<td></td>
</tr>
</tbody>
</table>
7. Correctly identify all organs depicted in the diagram below.
8. You have studied the histological structure of a number of organs in this laboratory. Three of these are diagrammed below. Identify and correctly label each.

![Histological diagrams of organs](image)

**Accessory Digestive Organs**

9. Correctly label all structures provided with leader lines in the diagram of a molar below. (Note: Some of the terms in the key for question 10 may be helpful in this task.)

![Diagram of molar](image)
10. Use the key to identify each tooth area described below.

Key: a. anatomical crown
   b. cementum
   c. clinical crown
   d. dentin
   e. enamel
   f. gingiva
   g. odontoblast
   h. periodontal ligament
   i. pulp
   j. root

c_____ 1. visible portion of the tooth in situ

b_____ 2. material covering the tooth root

c_____ 3. hardest substance in the body

h_____ 4. attaches the tooth to bone and surrounding alveolar structures

j_____ 5. portion of the tooth embedded in bone

d_____ 6. forms the major portion of tooth structure; similar to bone

g_____ 7. produces the dentin

i_____ 8. site of blood vessels, nerves, and lymphatics

a_____ 9. entire portion of the tooth covered with enamel

11. In the human, the number of deciduous teeth is ___________________; the number of permanent teeth is ___________________.

12. The dental formula for permanent teeth is \( \frac{2,1,2,3}{2,1,2,3} \times 2 \)

   Explain what this means. There are 2 incisors, 1 canine, 2 premolars, and 3 molars in each jaw (upper and lower) from the median line posteriorly.

   What is the dental formula for the deciduous teeth? \( \frac{2,1,0,2}{2,1,0,2} \times 2 \) = 20

13. What teeth are the “wisdom teeth”? The number 3 (most posterior) molars.

14. Various types of glands form a part of the alimentary tube wall or duct their secretions into it. Match the glands listed in column B with the function/locations described in column A.

<table>
<thead>
<tr>
<th>Column A</th>
<th>Column B</th>
</tr>
</thead>
<tbody>
<tr>
<td>a _____ 1. produce(s) mucus; found in the submucosa of the small intestine</td>
<td>a. duodenal glands</td>
</tr>
<tr>
<td>f _____ 2. produce(s) a product containing amylase that begins starch breakdown in the mouth</td>
<td>b. gastric glands</td>
</tr>
<tr>
<td>e _____ 3. produce(s) a whole spectrum of enzymes and an alkaline fluid that is secreted into the duodenum</td>
<td>c. intestinal crypts</td>
</tr>
<tr>
<td>d _____ 4. produce(s) bile that it secretes into the duodenum via the bile duct</td>
<td>d. liver</td>
</tr>
<tr>
<td>b _____ 5. produce(s) HCl and pepsinogen</td>
<td>e. pancreas</td>
</tr>
<tr>
<td>c _____ 6. found in the mucosa of the small intestine; produce(s) intestinal juice</td>
<td>f. salivary glands</td>
</tr>
</tbody>
</table>

15. Which of the salivary glands produces a secretion that is mainly serous? Parotid.
16. What is the role of the gallbladder? To store and concentrate bile made by the liver.

17. Name three structures always found in the portal triad regions of the liver. Branch of the bile duct, branch of hepatic artery, and branch of hepatic portal vein.

18. Where would you expect to find the Kupffer cells of the liver? Lining the sinusoids.

What is their function? Phagocytosis of debris and worn-out blood cells.

19. Why is the liver so dark red in the living animal? Because it is a blood reservoir.

20. The pancreas has two major populations of secretory cells—those in the islets and the acinar cells. Which population serves the digestive process? Acinar cells.
Time Allotment: 3 hours. (Two parts of the exercise require 2-hour incubations.)


Breakdown (FHS: 28 minutes, VHS, DVD, 3-year streaming webcast)
Digestion: Eating to Live (FHS: 27 minutes, VHS, DVD, 3-year streaming webcast)
Digestive System (WNS: 14 minutes, VHS)
The Human Digestive System (DE: 18 minutes, DVD, CD-ROM)
Interactive Physiology® 10-System Suite: Digestive System (BC: CD-ROM, Website)

Solutions:

Alpha-Amylase, 1%
Weigh out 1 gram of alpha-amylase. Add distilled water to a final volume of 100 milliliters. For best results, be sure that the enzyme is not standardized with maltose.

BAPNA, 0.01%
Weigh out 0.01 gram BAPNA. Add distilled water to a final volume of 100 milliliters.

Benedict’s Solution
• 173.0 grams sodium citrate
• 100.0 grams sodium carbonate, anhydrous
• 17.3 grams cupric sulfate (pure crystalline)
Add the citrate and carbonate salts to 700–800 milliliters distilled water. Heat to dissolve. Add the cupric sulfate to 100 milliliters distilled water and heat to dissolve. Cool the solutions and then combine. Add distilled water to make 1 liter of solution.

Hydrochloric Acid (HCl), 0.1 N
Add 8 milliliters concentrated HCl to 900 milliliters distilled water. Add distilled water to a final volume of 1 liter; or add 100 milliliters of 1 N HCl to 850 milliliters of distilled water. Add distilled water to a final volume of 1 liter.

Litmus Cream
Add powdered litmus to fresh cream to achieve a blue color.

Lugol’s Iodine (IKI)
• 20 grams potassium iodide
• 4 grams iodine crystals
Dissolve potassium iodide in 1 liter distilled water. Add the iodine crystals and stir to dissolve. Store in dark bottles.

Maltose, 1%
Weigh out 1 gram maltose. Add distilled water to a final volume of 100 milliliters.

Pancreatin, 1%
Weigh out 1 gram pancreatin. Dissolve in distilled water to a final volume of 100 milliliters.
**Starch Solution, Boiled, 1%**
Add 1 gram of starch to 100 milliliters distilled water. Boil just until it changes from cloudy to translucent. Cool and filter. Add a pinch of NaCl. Prepare fresh daily. For best results, use potato starch from a biological supply house.

**Trypsin, 1%**
Weigh out 1 gram trypsin. Add distilled water to a final volume of 100 milliliters.

---

**Laboratory Materials**

*Ordering information is based on a lab size of 24 students, working in groups of 4. A list of supply house addresses appears in Appendix A.*

### Part I: Enzyme Action

**General Supply Area**
- 144 test tubes
- 6 test tube racks
- 6 wax markers
- 6 test tube holders
- 6 250-milliliter beakers
- Ice water bath
- Water bath at 37°C
- Boiling chips
- 6 hot plates
- Chart (or chalkboard/whiteboard) for recording class data

**Activity 1: Starch Digestion**
- 6 dropper bottles of distilled water
- 6 dropper bottles of 1% boiled starch solution, freshly prepared
- 6 dropper bottles of 1% alpha-amylase solution
- 6 dropper bottles of 1% maltose solution
- 6 dropper bottles of Benedict’s solution
- 6 dropper bottles of Lugol’s solution (IKI)
- 6 spot plates

**Activity 2: Protein Digestion**
- 6 dropper bottles of 1% trypsin
- 6 dropper bottles of 0.01% BAPNA

**Activity 3: Bile Action and Fat Digestion**
- 6 dropper bottles of 1% pancreatin
- 6 dropper bottles of 0.1 N HCl
- 6 dropper bottles of vegetable oil
- 6 dropper bottles of litmus cream
- Bile salts (sodium taurocholate)
- Parafilm (small squares to cover test tubes)

### Part II: Physical Processes

**Activity 5: Observing Digestion**
- Water pitcher
- 24 paper cups
- 12 stethoscopes
- Alcohol swabs
- Disposable autoclave bag
- Watch, clock, or timer

**Activity 6: Videotape**
- Television and VHS or DVD player for independent viewing

---

**Advance Preparation**

1. Put a chart on the board for recording class results.
2. Decide how to divide the class into groups to do the experiments.
3. Set up five supply areas.

*General supply area* (for a class of 24, divided into six groups of four each):
- 144 test tubes, 6 test tube racks, 6 test tube holders, and 6 wax marking pencils, hot plates, 250-milliliter beakers, ice water bath, 37°C water bath, boiling chips (biological supply company), and dropper bottles of distilled water.

*Supply area 1* (for each group of four students):
- Dropper bottles of distilled water, 1% boiled starch solution, freshly prepared, 1% amylase solution, 1% maltose solution, Lugol’s solution (biological supply company), Benedict’s solution (biological supply company), and spot plates.

*Supply area 2* (for each group of four students):
- Dropper bottles of 1% trypsin (Sigma) and 0.01% BAPNA (Sigma).
Supply area 3 (for each group of four students):
Bile salts, parafilm, and dropper bottles of 1% pancreatin solution, 0.1 N HCl, vegetable oil, and litmus
cream (litmus powder—biological supply company).

Supply area 4 (for each group of four students):
Pitcher of water, four paper cups, a stethoscope, disposable autoclave bag, and alcohol swabs.

4. Set up a viewing area with a videotape or DVD on the digestive system.

Comments and Pitfalls
1. This lab requires a great deal of organization and coordination on the part of the students. Emphasize the
need for careful labeling and record keeping.
2. If a 37°C water bath is not available, incubate the tubes at room temperature and double the incubation
time.
3. Enzyme activity can vary. Enzyme solutions should be prepared just before the lab and adjusted for
appropriate activity.
4. An alternative to having each group perform each activity is to assign each activity to a different group.
   At the end of the lab period, have each group present their data along with an explanation of their activity
to all of the students.

Answers to Pre-Lab Quiz (p. 597)
1. catalysts 4. true 7. pancreatic lipase
2. b, control 5. b, green to orange 8. true
3. salivary amylase 6. d, trypsin 9. d, Segmental

Answers to Activity Questions
Activity 3: Demonstrating the Emulsification Action of Bile
and Assessing Fat Digestion by Lipase (pp. 601–602)
2. Emulsification occurs in the tubes containing bile salts.

Activity 5: Observing Movements and Sounds of Digestion (pp. 603–604)
2. Before swallowing, the tongue raises to touch the hard palate, remains raised during swallowing, then
relaxes after swallowing.
3. Superior movement of the larynx ensures that its passageway is covered by the epiglottis.
Chemical and Physical Processes of Digestion: Wet Lab

Chemical Digestion of Foodstuffs: Enzymatic Action

1. Match the following definitions with the proper choices from the key.

   Key: a. catalyst  
   b. control  
   c. enzyme  
   d. substrate

   d: substrate  
   1. substance on which a catalyst works

   c: enzyme  
   2. biologic catalyst; protein in nature

   a: catalyst  
   3. increases the rate of a chemical reaction without becoming part of the product

   b: control  
   4. provides a standard of comparison for test results

2. List the three characteristics of enzymes. Specificity (act on one or a small number of substrates); temperature specific; pH specific.

3. The enzymes of the digestive system are classified as hydrolases. What does this mean?

   Hydrolases break down organic food molecules by adding water to the molecular bonds, thus cleaving the bonds between the subunits or monomers.

4. Fill in the following chart about the various digestive system enzymes encountered in this exercise.

<table>
<thead>
<tr>
<th>Enzyme</th>
<th>Organ producing it</th>
<th>Site of action</th>
<th>Substrate(s)</th>
<th>Optimal pH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Salivary amylase</td>
<td>salivary glands</td>
<td>oral cavity</td>
<td>starch</td>
<td>6.7–7.0</td>
</tr>
<tr>
<td>Trypsin</td>
<td>pancreas</td>
<td>small intestine</td>
<td>proteins</td>
<td>8.0</td>
</tr>
<tr>
<td>Lipase (pancreatic)</td>
<td>pancreas</td>
<td>small intestine</td>
<td>fats</td>
<td>7.4–8.0</td>
</tr>
</tbody>
</table>

5. Name the end products of digestion for the following types of foods.

   proteins: amino acids  
   carbohydrates: simple sugars
   fats: fatty acids  
   and glycerol (monoglycerides)
6. You used several indicators or tests in the laboratory to determine the presence or absence of certain substances. Choose the correct test or indicator from the key to correspond to the condition described below.

Key: a. Lugol’s iodine (IKI) b. Benedict’s solution c. litmus d. BAPNA

1. used to test for protein hydrolysis, which was indicated by a yellow color
   d
2. used to test for the presence of starch, which was indicated by a blue-black color
   a
3. used to test for the presence of fatty acids, which was evidenced by a color change from blue to pink
   c
4. used to test for the presence of reducing sugars (maltose, sucrose, glucose) as indicated by a blue to green or orange color change
   b

7. What conclusions can you draw when an experimental sample gives both a positive starch test and a positive maltose test after incubation? Starch digestion is partial (incomplete).

   Why was 37°C the optimal incubation temperature? It is body temperature.

   Why did very little, if any, starch digestion occur in test tube 4A? The enzyme was destroyed by boiling.

   When starch was incubated with amylase at 0°C, did you see any starch digestion? No

   Why or why not? Amylase has an optimal temperature closer to that of the human body. At 0°C, the rate of enzyme activity and diffusion of enzymes and substrate has slowed to near zero.

   Assume you have made the statement to a group of your peers that amylase is capable of starch hydrolysis to maltose. If you had not done control tube 1A, what objection to your statement could be raised? A positive maltose test could also result from maltose contamination of the starting amylase solution.

   What if you had not done tube 2A? A negative Benedict’s test indicates starch was not contaminated with maltose. (And that starch did not break down in the absence of amylase.)

8. In the exercise concerning trypsin function, why was an enzyme assay like Benedict’s or Lugol’s IKI (which test for the presence of a reaction product) not necessary? The enzyme assay is “built in” to the substrate BAPNA. Peptide bond cleavage results in a yellow color.

   Why was tube 1T necessary? Tube 1T was a control to prove that trypsin did not turn yellow by itself.

   Why was tube 2T necessary? Tube 2T proved that BAPNA did not turn yellow by itself.

   Trypsin is a protease similar to pepsin, the protein-digesting enzyme in the stomach. Would trypsin work well in the stomach? No Why? The pH optimum for trypsin is slightly basic; the pH optimum for pepsin is acidic (stomach is acidic).

9. In the procedure concerning pancreatic lipase digestion of fats and the action of bile salts, how did the appearance of tubes 1E and 2E differ? 1E—2 layers; oil over water. 2E—fat droplets dispersed.

   Explain the reason for the difference. Bile, present in tube 2E, acted to emulsify the fat.
Why did the litmus indicator change from blue to pink during fat hydrolysis? **Fatty acids decreased the pH. Litmus in the cream is an indicator that changes from blue to red as the pH changes from alkaline to acidic conditions.**

Why is bile not considered an enzyme? **Bile only physically separates the fat droplets. It does not break the molecular bonds as do the digestive enzymes.**

How did the tubes containing bile compare with those not containing bile? **The tubes containing bile showed more hydrolysis than those not containing bile.**

What role does bile play in fat digestion? **Emulsification of fat by bile increases the surface area for lipase activity.**

10. The three-dimensional structure of a functional protein is altered by intense heat or nonphysiological pH even though peptide bonds may not break. Such inactivation is called denaturation, and denatured enzymes are nonfunctional. Explain why. **Their three-dimensional structures and active sites are necessary for their activity. If their structures are changed, the active sites change, thus inactivating the enzyme.**

What specific experimental conditions resulted in denatured enzymes? **Boiling the enzyme solution in all experiments denatured the enzymes.**

11. Pancreatic and intestinal enzymes operate optimally at a pH that is slightly alkaline, yet the chyme entering the duodenum from the stomach is very acid. How is the proper pH for the functioning of the pancreatic-intestinal enzymes ensured? **The pancreas delivers its enzymes to the small intestine in an alkaline-rich \( \text{HCO}_3^- \) fluid.**

12. Assume you have been chewing a piece of bread for 5 or 6 minutes. How would you expect its taste to change during this interval? **The bread would begin to taste sweet.**

Why? **Starch is broken down to maltose by amylase.**

13. Note the mechanism of absorption (passive or active transport) of the following food breakdown products, and indicate by a check mark (✓) whether the absorption would result in their movement into the blood capillaries or the lymph capillaries (lacteals).

<table>
<thead>
<tr>
<th>Substance</th>
<th>Mechanism of absorption</th>
<th>Blood</th>
<th>Lymph</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monosaccharides</td>
<td>Most by active transport</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Fatty acids and glycerol</td>
<td>Diffusion</td>
<td>Some</td>
<td>Most</td>
</tr>
<tr>
<td>Amino acids</td>
<td>Active transport</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Water</td>
<td>Osmosis</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>( \text{Na}^+, \text{Cl}^-, \text{Ca}^{2+} )</td>
<td>( \text{Na}^+, \text{Ca}^{2+} ) active transport; ( \text{Cl}^- ) diffusion</td>
<td>✓</td>
<td></td>
</tr>
</tbody>
</table>

14. People on a strict diet to lose weight begin to metabolize stored fats at an accelerated rate. How does this condition affect blood pH? **It would become acidic (decreased pH).**
15. Using a flowchart, trace the pathway of a ham sandwich (ham = protein and fat; bread = starch) from the mouth to the site of absorption of its breakdown products, noting where digestion occurs and what specific enzymes are involved.

<table>
<thead>
<tr>
<th>Site of digestion</th>
<th>ham</th>
<th>fat</th>
<th>bread (starch)</th>
</tr>
</thead>
<tbody>
<tr>
<td>mouth</td>
<td>pepsin</td>
<td>lipases (pancreatic)</td>
<td>salivary amylase</td>
</tr>
<tr>
<td>stomach</td>
<td>trypsin, etc. (from pancreas)</td>
<td>pancreatic amylase</td>
<td>oligosaccharides, maltose</td>
</tr>
<tr>
<td>small intestine</td>
<td>trypsin</td>
<td>lipases</td>
<td>brush border enzymes</td>
</tr>
<tr>
<td></td>
<td>chymotrypsin, etc. (from pancreas)</td>
<td>pancreatic amylase</td>
<td>brush border enzymes</td>
</tr>
<tr>
<td></td>
<td>small peptides</td>
<td>oligosaccharides, maltose</td>
<td>brush border enzymes</td>
</tr>
<tr>
<td></td>
<td>amino acids (some dipeptides and tripeptides)</td>
<td>monoglycerides, fatty acids, and glycerol</td>
<td>glucose</td>
</tr>
</tbody>
</table>

16. Some of the digestive organs have groups of secretory cells that liberate hormones into the blood. These exert an effect on the digestive process by acting on other cells or structures and causing them to release digestive enzymes, expel bile, or increase the motility of the digestive tract. For each hormone below, note the organ producing the hormone and its effects on the digestive process. Include the target organs affected.

<table>
<thead>
<tr>
<th>Hormone</th>
<th>Produced by</th>
<th>Target organ(s) and effects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Secretin</td>
<td>intestinal mucosa</td>
<td>It stimulates (1) the pancreas and liver to release bicarbonate-rich fluid, and (2) the liver to secrete bile. Inhibits gastric activity.</td>
</tr>
<tr>
<td>Gastrin</td>
<td>stomach mucosa</td>
<td>Gastrin acts on the stomach glands to increase their secretory activity (particularly of HCl).</td>
</tr>
<tr>
<td>Cholecystokinin</td>
<td>intestinal mucosa</td>
<td>It stimulates release of enzymes from the pancreas, and causes gallbladder contraction.</td>
</tr>
</tbody>
</table>

**Physical Processes: Mechanisms of Food Propulsion and Mixing**

17. Complete the following statements.

Swallowing, or _1_, occurs in two phases—the _2_ and _3_. One of these phases, the _4_ phase, is voluntary. During the voluntary phase, the _5_ is used to push the food into the back of the throat. During swallowing, the _6_ rises to ensure that its passageway is covered by the epiglottis so that the ingested substances don’t enter the respiratory passageways. It is possible to swallow water while standing on your head because the water is carried along the esophagus involuntarily by the process of _7_. The pressure exerted by the foodstuffs on the _8_ sphincter causes it to open, allowing the foodstuffs to enter the stomach.

The two major types of propulsive movements that occur in the small intestine are _9_ and _10_. One of these movements, _11_, acts to continually mix the foods and to increase the absorption rate by moving different parts of the chyme mass over the intestinal mucosa, but it has less of a role in moving foods along the digestive tract.

1. _deglutition_ 7. _peristalsis_
2. _buccal_ 8. _gastroesophageal_
3. _pharyngeal-esophageal_ 9. _peristalsis_
4. _buccal_ 10. _segmentation_
5. _tongue_ 11. _segmentation_
6. _larynx_
Anatomy of the Urinary System

**Time Allotment:** 1 hour.

**Multimedia Resources:** See Appendix B for Guide to Multimedia Resource Distributors. See Exercise 6A for histology listings.

* A.D.A.M.® Interactive Anatomy 4.0 (AIA: CD-ROM, DVD)
* Human Urinary System Videotape (BC: 23 minutes, VHS)
* The Kidney (FHS: 15 minutes, VHS, DVD, 3-year streaming webcast)
* Practice Anatomy Lab™ 2.0 (PAL) (BC: CD-ROM, Website)
* The Urinary Tract: Water! (FHS: 28 minutes, VHS, DVD, 3-year streaming webcast)

**Laboratory Materials**

* Ordering information is based on a lab size of 24 students, working in groups of 4. A list of supply house addresses appears in Appendix A.

- 6–12 pig or sheep kidneys (doubly or triply injected)
- 24 prepared microscope slides of each of the following: kidney (longitudinal section), bladder (cross section)
- 24 compound microscopes, lens paper, lens cleaning solution
- Dissectible human torso model
- 3-D model or anatomical chart of the human urinary system
- 3-D models of the kidney and nephron (if available)
- 6–12 dissecting pans
- 6–12 dissecting kits
- Disposable gloves
- 24 pairs of safety glasses
- Soap, sponges, disinfectant

**Advance Preparation**

1. Make arrangements for appropriate storage, disposal, and cleanup of dissection materials. Check with the Department of Health, the Department of Environmental Protection, or their counterparts for state regulations.
2. Set out disposable gloves and safety glasses.
3. Set out dissecting kits, dissecting pans, and pig or sheep kidneys.
4. Set out slides of longitudinal sections of the kidney and cross sections of the bladder; lens paper; and lens cleaning solution. Have compound microscopes available.
5. Set out the dissectible human torso and/or any anatomical charts and models of the urinary system, kidney, and nephron.
Answers to Pre-Lab Quiz (p. 609)

1. nitrogenous
2. a, kidneys
3. medulla
4. segmental arteries
5. Nephrons
6. b, glomerulus
7. d, proximal convoluted tubule
8. efferent
9. false
10. external

Answers to Questions

Activity 3: Studying Bladder Structure (p. 616)

5. Both organs have an internal mucosa, a layer of smooth muscle, and an external adventitia. The ureter has only two layers of smooth muscle.
Gross Anatomy of the Human Urinary System

1. Complete the following statements.

   The kidney is referred to as an excretory organ because it excretes __1__ wastes. It is also a major homeostatic organ because it maintains the electrolyte, __2__, and __3__ balance of the blood.

   Urine is continuously formed by the __4__ and is routed down the __5__ by the mechanism of __6__ to a storage organ called the __7__. Eventually, the urine is conducted to the body __8__ by the urethra. In the male, the urethra is __9__ centimeters long and transports both urine and __10__. The female urethra is __11__ centimeters long and transports only urine.

   Voiding or emptying the bladder is called __12__. Voiding has both voluntary and involuntary components. The voluntary sphincter is the __13__ sphincter. An inability to control this sphincter is referred to as __14__.

2. What is the function of the fat cushion that surrounds the kidneys in life?
   __Helps to anchor the kidneys to the dorsal body wall and cushions them against blows__.

3. Define ptosis. __Dropping of the kidney(s) to a more inferior position in the abdominal cavity__.

4. Why is incontinence a normal phenomenon in the child under 1 ½ to 2 years old?
   __Muscular control over the voluntary sphincter has not yet been achieved__.

   What events may lead to its occurrence in the adult? __Emotional problems; bladder irritability (as in infection); increased pressure on the bladder (as in pregnancy); nerve or spinal cord injury; and others__.

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5. Complete the labeling of the diagram to correctly identify the urinary system organs.

![Diagram of the urinary system](image)

**Gross Internal Anatomy of the Pig or Sheep Kidney**

6. Match the appropriate structure in column B to its description in column A.

<table>
<thead>
<tr>
<th>Column A</th>
<th>Column B</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. smooth membrane, tightly adherent to the kidney surface</td>
<td>a. cortex</td>
</tr>
<tr>
<td>2. portion of the kidney containing mostly collecting ducts</td>
<td>b. medulla</td>
</tr>
<tr>
<td>3. portion of the kidney containing the bulk of the nephron structures</td>
<td>c. minor calyx</td>
</tr>
<tr>
<td>4. superficial region of kidney tissue</td>
<td>d. fibrous capsule</td>
</tr>
<tr>
<td>5. basinlike area of the kidney, continuous with the ureter</td>
<td>e. renal column</td>
</tr>
<tr>
<td>6. a cup-shaped extension of the pelvis that encircles the apex of a pyramid</td>
<td>f. renal pelvis</td>
</tr>
</tbody>
</table>
7. Match each lettered structure in the diagram of the nephron (and associated renal blood supply) with the correct name in the numbered list.

| a | 1. afferent arteriole |
| e | 2. arcuate artery     |
| f | 3. arcuate vein       |
| i | 4. collecting duct    |
| c | 5. cortical radiate artery |
| d | 6. cortical radiate vein |
| l | 7. distal convoluted tubule |
| b | 8. efferent arteriole  |
| o | 9. glomerular capsule  |
| n | 10. glomerulus         |
| g | 11. interlobar artery  |
| h | 12. interlobar vein    |
| j | 13. loop of Henle      |
| k | 14. peritubular capillaries |
| m | 15. proximal convoluted tubule |

8. Use the terms provided in question 7 to identify the following descriptions.

- *glomerulus (n)* 1. site of filtrate formation
- *proximal convoluted tubule (m)* 2. primary site of tubular reabsorption
- *distal convoluted tubule (l)* 3. secondarily important site of tubular reabsorption
- *collecting duct (i)* 4. structure that conveys the processed filtrate (urine) to the renal pelvis
- *peritubular capillaries (k)* 5. blood supply that directly receives substances from the tubular cells
- *glomerular capsule (o)* 6. its inner (visceral) membrane forms part of the filtration membrane

9. Explain why the glomerulus is such a high-pressure capillary bed. *It is both fed and drained by arterioles (which are high-pressure vessels compared to venules), and the afferent arteriole has a larger diameter than the efferent arteriole.*

How does its high-pressure condition aid its function of filtrate formation? *The higher the capillary pressure, the more filtrate will be formed.*
10. What structural modification of certain tubule cells enhances their ability to reabsorb substances from the filtrate?

Their possession of dense microvilli (especially the PCT cells).

11. Explain the mechanism of tubular secretion, and explain its importance in the urine formation process. Tubular secretion is the process of moving substances from the tubule cells or from the peritubular capillary blood into the tubule filtrate. It is important for adjusting pH and eliminating substances not already in the filtrate.

12. Compare and contrast the composition of blood plasma and glomerular filtrate. Glomerular filtrate = blood plasma without most of the blood proteins.

13. Trace a drop of blood from the time it enters the kidney via the renal artery until it leaves the kidney through the renal vein.

Renal artery → segmental A. → interlobar A. → arcuate A. → cortical radiate A. → afferent arteriole → glomerulus → efferent arteriole → peritubular capillary bed → cortical radiate V. → arcuate V. → interlobar V. → renal vein

14. Define juxtaglomerular apparatus. Macula densa cells of the ascending limb of loop of Henle and granular (juxtaglomerular) cells of the afferent arteriole that play a role in regulating the rate of filtrate formation and systemic blood pressure.

15. Label the figure using the key letters of the correct terms.

Key:  
   a. juxtaglomerular cells  
   b. cuboidal epithelium  
   c. macula densa  
   d. glomerular capsule (parietal layer)  
   e. distal convoluted tubule

16. Trace the anatomical pathway of a molecule of creatinine (metabolic waste) from the glomerular capsule to the urethra. Note each microscopic and/or gross structure it passes through in its travels. Name the subdivisions of the renal tubule.

Glomerular capsule → proximal convoluted tubule → loop of Henle → distal convoluted tubule → collecting duct → minor calyx → major calyx → renal pelvis → ureter → bladder → urethra

17. What is important functionally about the specialized epithelium (transitional epithelium) in the bladder? The cells have the ability to move over one another as the bladder fills, thus decreasing the bladder wall thickness and increasing the internal bladder volume.
Urinalysis

**Time Allotment:** 1 hour.

**Solutions:**

- **Barium Chloride (BaCl), 10%**
  Weigh out 10 grams of barium chloride. Add water to a final volume of 100 milliliters.

- **Bleach Solution, 10%**
  Measure out 100 milliliters of household bleach. Add water to a final volume of 1 liter.

- **Hydrochloric Acid (HCl), Dilute, 3 N**
  Add 250 milliliters of concentrated (approximately 12 N) HCl to 700 milliliters distilled water. Add distilled water to a final volume of 1 liter.

- **Nitric Acid (HNO₃), Dilute, 3 N**
  Add 189 milliliters of concentrated (approximately 16 N) HNO₃ to 700 milliliters distilled water. Add distilled water to a final volume of 1 liter.

- **Silver Nitrate (AgNO₃), 3%**
  Weigh out 3 grams of silver nitrate. Use caution: This is an oxidizing substance. Add distilled water to make 100 milliliters of solution. Store in light-resistant bottles. Make fresh for each use.

- **Urine, Artificial Normal Human***
  - 36.4 grams urea
  - 15 grams sodium chloride
  - 9.0 grams potassium chloride
  - 9.6 grams sodium phosphate
  - 4.0 grams creatinine
  - 100 milligrams albumin
  Add urea to 1.5 liters of distilled water. Mix until crystals dissolve. Add sodium chloride, potassium chloride, and sodium phosphate. Mix until solution is clear. The pH should be within the 5 to 7 pH range for normal human urine. Adjust pH, if necessary, with 1 N HCl or 1 N NaOH. Place a urine hydrometer in the solution and dilute with water to a specific gravity within the range of 1.015 to 1.025. This stock solution may be refrigerated for several weeks or frozen for months. Before use, warm to room temperature and add 4.0 grams creatinine and 100 milligrams of albumin for each 2 liters of solution.

- **Urine, Glycosuria***
  For a minimally detectable level of glucose, add a minimum of 600 milligrams of glucose to 1 liter of “normal” urine solution. For moderate to high glycosuria, add 2.5 to 5.0 grams of glucose to each liter of solution.

- **Urine, Hematuria***
  Add 1 milliliter of heparinized or defibrinated sheep blood to 1 liter of “normal” urine solution.

- **Urine, Hemoglobinuria***
  Add 2 milligrams of bovine hemoglobin to 1 liter of “normal” urine solution.

- **Urine, Hyposthenuria***
  Add distilled water to a sample of “normal” urine until the specific gravity approaches 1.005.
Urine, Ketonuria*
Add a minimum of 100 milligrams of acetoacetic acid or at least 1 milliliter of acetone to 1 liter of “normal” urine solution.

Urine, Leukocyte Presence*
Add 100 to 200 units of pork or rabbit liver esterase to 100 milliliters of the “normal” urine solution. This test must be performed immediately after adding the enzyme.

Urine, pH Imbalance*
Adjust “normal” urine to a pH of 4.0 to 4.5 with 1 N HCl for acid urine. Adjust “normal” urine to a pH of 8 to 9 with 1 N NaOH for alkaline urine.

Urine, Proteinuria*
Add 300 milligrams or more of albumin per liter of “normal” urine solution. For severe renal damage, add 1 gram of albumin to each liter of solution.

Urine, Whole Spectrum Pathological Artificial Human*
Mix appropriate amounts of abnormal condition reagents to 1 liter of “normal” urine solution. Diabetes mellitus: glycosuria and ketonuria Glomerular damage: proteinuria, hemoglobinuria, and hematuria


Laboratory Materials
Ordering information is based on a lab size of 24 students, working in groups of 4. A list of supply house addresses appears in Appendix A.

- Disposable gloves
- Student urine samples collected at the beginning of the lab, or “normal” artificial urine provided by the instructor
- Numbered “pathological” urine specimens provided by the instructor
- 6 packages of wide-range pH paper
- 24 of each of the following dipsticks: Clinistix, Ketostix, Albustix, Hemastix or 24 combination dipsticks (Chemstrip or Multistix)
- Urinometer
- 24 urinometer cylinders and floats
- 120 test tubes and test tube holders
- 24 test tube racks
- 24 glass stirring rods
- 6 hot plates
- 24 10-cc graduated cylinders
- 24 medicine droppers
- 6 dropper bottles of each of the following: dilute HCl, dilute HNO₃, 3.0% silver nitrate, concentrated HNO₃
- 6 dropper bottles containing 100 milliliters of 10% barium chloride
- 6 dropper bottles containing 100 milliliters of dilute ammonium molybdate
- 24 500-milliliter beakers
- 24 microscope slides and coverslips
- 24 compound microscopes, lens paper, lens cleaning solution
- 6 Clinistest color charts
- 24 Clinistest tablets
- 24 Ictotest reagent tablets and mats
- Timer (watch or clock with a second hand)
- 2 laboratory buckets of 10% bleach
- 6 flasks of 10% bleach
- Disposable autoclave bags
- Instructor-prepared specimen of urine sediment set up for microscopic analysis

Advance Preparation
1. Prepare “normal” artificial urine (about 1 liter for a class of 30 students) and “pathological” artificial urine samples and number them.
2. Set out two laboratory buckets containing 10% bleach solution, and a disposable autoclave bag. Put a flask of 10% bleach solution and a sponge at each lab bench.
3. For each student in the class set out disposable gloves, five test tubes, a glass stirring rod, a test tube rack, a medicine dropper, a urinometer cylinder and float, microscope slides, coverslips, individual reagent strips (Clinistix—available online, Ketostix and Hemastix—available from Fisher, Albustix—available online), or combination strips (Chemstrip—available from Carolina, Multistix—available from Fisher), Clinitest tablets (Fisher), a 10-milliliter graduated cylinder, a wax marking pencil, Ictotest reagent tablet and mat (Fisher). Have compound microscopes, lens paper, and lens cleaning solution available.

4. For each group set out wide-range pH paper, a bottle containing 100 milliliters of 10% barium chloride, a bottle containing 100 milliliters of dilute ammonium molybdate (LabChem), a hot plate, a 500-milliliter beaker, and dropper bottles of dilute HCl, dilute HNO₃, freshly prepared 3.0% silver nitrate, and concentrated HNO₃.

5. Set up a demonstration slide of urine sediment stained with Sedi-stain (Fisher). To prepare the slide, centrifuge a 5-milliliter sample of urine at 2000 to 2500 rpm for 5 to 6 minutes. Decant the supernatant and add one or two drops of Sedi-stain to the pellet. Put stained material onto a slide and cover with a coverslip.

**Comments and Pitfalls**

1. When preparing pathological samples, do not substitute sucrose for glucose. Vitamin C contamination will give false positive glucose tests. The artificial urine is suitable for test strips, but not for use with clinical analyzers (Shmaefsky, 1990).

2. Urge students to use extreme caution when using the concentrated HCl and HNO₃ solutions.

3. Because students are usually very interested in the crystals, cells, and casts in urine, have additional references available for them.

**Answers to Pre-Lab Quiz (p. 621)**

1. c, urochrome
2. 6.0
3. false
4. a, Albumin
5. Hematuria
6. b, bilirubinuria
7. Casts
8. A precipitate is an insoluble compound that is no longer in solution.
Characteristics of Urine

1. What is the normal volume of urine excreted in a 24-hour period? **0.8–2.0 liters**

2. Assuming normal conditions, note whether each of the following substances would be (a) in greater relative concentration in the urine than in the glomerular filtrate, (b) in lesser concentration in the urine than in the glomerular filtrate, or (c) absent from both the urine and the glomerular filtrate.

   - **1. water**  
   - **2. phosphate ions**  
   - **3. sulfate ions**  
   - **4. potassium ions**  
   - **5. sodium ions**  
   - **6. amino acids**  
   - **7. glucose**  
   - **8. albumin**  
   - **9. red blood cells**  
   - **10. urea**  
   - **11. uric acid**  
   - **12. creatinine**  
   - **13. pus (WBCs)**  
   - **14. nitrites**

3. Explain why urinalysis is a routine part of any good physical examination. *Finding “abnormal” constituents in the urine may indicate pathology.*

4. What substance is responsible for the normal yellow color of urine? **Urochrome**

5. Which has a greater specific gravity: 1 ml of urine or 1 ml of distilled water? **1 ml of urine** Explain your answer. *Urine contains dissolved solutes, which are not found in distilled water and add to the density of the sample.*

6. Explain the relationship between the color, specific gravity, and volume of urine. *Generally, the smaller the volume, the greater the specific gravity (more solutes/volume) and the deeper the color.*

Abnormal Urinary Constituents

7. A microscopic examination of urine may reveal the presence of certain abnormal urinary constituents.

   Name three constituents that might be present if a urinary tract infection exists. **WBCs (pus)**, **RBCs**, and **casts**

8. How does a urinary tract infection influence urine pH? **Becomes alkaline**

   How does starvation influence urine pH? **Becomes acidic**

9. All urine specimens become alkaline and cloudy on standing at room temperature. Explain why. *This is a result of bacterial metabolism of urinary components.*
10. Several specific terms have been used to indicate the presence of abnormal urine constituents. Identify each of the abnormalities described below by inserting a term from the key at the right that names the condition.

- presence of erythrocytes in the urine: *c. hematuria*
- presence of hemoglobin in the urine: *d. hemoglobinuria*
- presence of glucose in the urine: *b. glycosuria*
- presence of albumin in the urine: *a. albuminuria*
- presence of ketone bodies (acetone and others) in the urine: *e. ketonuria*
- presence of pus (white blood cells) in the urine: *f. pyuria*

**Key:**
- a. albuminuria
- b. glycosuria
- c. hematuria
- d. hemoglobinuria
- e. ketonuria
- f. pyuria

11. What are renal calculi, and what conditions favor their formation? *Kidney stones; urinary retention, urinary tract infection, alkaline urine.*

12. Glucose and albumin are both normally absent in the urine, but the reason for their exclusion differs. Explain the reason for the absence of glucose. *It is completely reabsorbed (unless present in the blood in excessive levels).*

Explain the reason for the absence of albumin. *It is too large to pass through the filtration membrane.*

13. The presence of abnormal constituents or conditions in urine may be associated with diseases, disorders, or other causes listed in the key. Select and list all conditions associated with each numbered item.

- low specific gravity: *b*
- high specific gravity: *c, f, k*
- glucose: *b, c, d*
- albumin: *e, j*
- blood cells: *a, i*
- hemoglobin: *g*
- bilirubin: *h*
- ketone bodies: *a, c, l*
- casts: *e, k*
- pus: *a, f, k*

**Key:**
- cystitis (inflammation of the bladder): *a*
- diabetes insipidus: *b*
- diabetes mellitus: *c*
- eating a 5-lb box of sweets for lunch: *d*
- glomerulonephritis: *e*
- gonorrhea: *f*
- hemolytic anemias: *g*
- hepatitis, cirrhosis of the liver: *h*
- kidney stones: *i*
- pregnancy, exertion: *j*
- pyelonephritis: *k*
- starvation: *l*

14. Name the three major nitrogenous wastes found in the urine. *Urea, uric acid, and creatinine.*

15. Explain the difference between organized and unorganized sediments. *Organized sediments (such as certain salts and uric acid) crystallize or precipitate out of solution, whereas unorganized sediments contain cellular elements (WBCs, epithelial cells, etc.).*
Anatomy of the Reproductive System

Time Allotment: 1 hour.

See Exercise 6A for histology listings.

A.D.A.M.® Interactive Anatomy 4.0 (AIA: CD-ROM, DVD)
Biologix: The Human Female Reproductive System (UL: 29 minutes, VHS, DVD)
Human Biology (FHS: 58 minutes, VHS, DVD)
Human Reproductive Biology (FHS: 35 minutes, VHS, DVD, 3-year streaming webcast)
Human Reproductive System (BC: 32 minutes, VHS)
Practice Anatomy Lab™ 2.0 (PAL) (BC: CD-ROM, Website)
Reproduction: Shares in the Future (FHS: 26 minutes, VHS, DVD, 3-year streaming webcast)

Laboratory Materials

Ordering information is based on a lab size of 24 students, working in groups of 4. A list of supply house addresses appears in Appendix A.

- 3-D models and/or large lab charts of the male and female reproductive tracts
- 24 prepared slides of cross sections of the penis, seminal vesicles, epididymis, uterus showing endometrium (proliferative phase), and uterine tube
- 24 compound microscopes, lens paper, lens cleaning solution

Advance Preparation

1. Set out slides of the penis, epididymis, seminal vesicles, uterine tube, and uterus showing endometrium (proliferative phase). Set out lens paper and lens cleaning solution, and have compound microscopes available.
2. Set out models and anatomical charts of the male and female reproductive systems.

Comments and Pitfalls

1. If you are not planning to do Exercise 43, you may wish to include the microscopic studies of the testis and ovary described there in this laboratory session.
Answers to Pre-Lab Quiz (pp. 629–630)

1. b, gonads
2. scrotum
3. c, epididymis
4. a, seminal fluid
5. interstitial cells
6. b, progesterone
7. clitoris
8. c, uterus
9. endometrium
10. ovulation

Answers to Activity Questions

Activity 2: Penis (p. 633)
The epithelium is stratified columnar epithelium. Its basic function is protection of underlying tissues.

Activity 4: Epididymis (p. 633)
The smooth muscle rhythmically contracts under sympathetic stimulation during emission and ejaculation. The peristaltic movements propel sperm/seminal fluid from the epididymis through the ductus (vas) deferens, ejaculatory duct, and urethra.

Activity 6: Wall of the Uterus (p. 636)
During the birth process the myometrium contracts, pushing the baby toward the cervical canal, and exerting pressure on the amniotic sac.
Gross Anatomy of the Human Male Reproductive System

1. List the two principal functions of the testis. **Sperm production** and **testosterone production**

2. Identify all indicated structures or portions of structures on the diagrammatic view of the male reproductive system below.

   - Urinary bladder
   - Ductus (vas) deferens
   - Penile urethra
   - Corpus cavernosum
   - Penis
   - Corpus spongiosum
   - Glans penis
   - Epididymis
   - Testis
   - Seminal vesicle
   - Ampulla of ductus (vas) deferens
   - Ejaculatory duct
   - Prostate
   - Bulbourethral gland

3. A common part of any physical examination of the male is palpation of the prostate. How is this accomplished?
   
   (Think!) **Through the anterior wall of the rectum.**

4. How might enlargement of the prostate interfere with urination or the reproductive ability of the male?
   
   **Constriction of the urethra at that point may lead to nonpassage of urine or semen.**

5. Why are the testes located in the scrotum rather than inside the ventral body cavity? **Testes are located in the scrotum to provide a slightly cooler temperature necessary for sperm production.**
6. Match the terms in column B to the descriptive statements in column A.

<table>
<thead>
<tr>
<th>Column A</th>
<th>Column B</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. copulatory organ/penetrating device</td>
<td>a. bulbourethral glands</td>
</tr>
<tr>
<td>2. muscular passageway conveying sperm to the ejaculatory duct; in the spermatic cord</td>
<td>b. ductus (vas) deferens</td>
</tr>
<tr>
<td>3. transports both sperm and urine</td>
<td>c. epididymis</td>
</tr>
<tr>
<td>4. sperm maturation site</td>
<td>d. membranous urethra</td>
</tr>
<tr>
<td>5. location of the testis in adult males</td>
<td>e. penis</td>
</tr>
<tr>
<td>6. loose fold of skin encircling the glans penis</td>
<td>f. prepuce</td>
</tr>
<tr>
<td>7. portion of the urethra between the prostate and the penis</td>
<td>g. prostate</td>
</tr>
<tr>
<td>8. empties a secretion into the prostatic urethra</td>
<td>h. prostatic urethra</td>
</tr>
<tr>
<td>9. empties a secretion into the membranous urethra</td>
<td>i. scrotum</td>
</tr>
<tr>
<td></td>
<td>j. seminal vesicles</td>
</tr>
<tr>
<td></td>
<td>k. spongy urethra</td>
</tr>
</tbody>
</table>

7. Describe the composition of semen, and name all structures contributing to its formation. 
*Sperm and the alkaline secretions of the prostate, seminal vesicles (also containing fructose), and the bulbourethral glands.*

8. Of what importance is the fact that seminal fluid is alkaline? *Buffers the sperm against the acid environment of the female reproductive tract.*

9. What structures compose the spermatic cord? *Connective tissue sheath (extension of abdominal fascia), ductus deferens, blood vessels, nerves, and lymph vessels.*

Where is it located? *Passes from the scrotal sac through the inguinal canal into the abdominal cavity.*

10. Using the following terms, trace the pathway of sperm from the testes to the urethra: rete testis, epididymis, seminiferous tubule, ductus deferens.

*seminiferous tubule ➔ rete testis ➔ epididymis ➔ ductus deferens*

**Gross Anatomy of the Human Female Reproductive System**

11. Name the structures composing the external genitalia, or vulva, of the female. *Mons pubis, labia majora and minora, clitoris, vaginal and urethral openings, hymen, and greater vestibular glands.*
12. On the diagram below of a frontal section of a portion of the female reproductive system, identify all indicated structures.

13. Identify the female reproductive system structures described below.

- uterus 1. site of fetal development
- vagina 2. copulatory canal
- uterine tube 3. egg typically fertilized here
- clitoris 4. becomes erect during sexual excitement
- uterine tube 5. duct extending superolaterally from the uterus
- hymen 6. partially closes the vaginal canal; a membrane
- ovary 7. produces oocytes, estrogens, and progesterone
- fimbriae 8. fingerlike ends of the uterine tube

14. Do any sperm enter the pelvic cavity of the female? Why or why not? Yes. The uterine tube opens to the pelvic cavity.

15. What is an ectopic pregnancy, and how can it happen? Implantation of the embryo in a site other than the uterus. May occur when the uterine tubes are blocked (prevents passage) or when the egg is “lost” in the peritoneal cavity and fertilization occurs there.

16. Put the following vestibular-perineal structures in their proper order from the anterior to the posterior aspect: vaginal orifice, anus, urethral opening, and clitoris.

Anterior limit: clitoris urethral opening vaginal orifice anus
17. Assume a couple has just consummated the sex act and the male’s sperm have been deposited in the woman’s vagina. Trace the pathway of the sperm through the female reproductive tract.

\[ \text{vagina} \rightarrow \text{cervix} \rightarrow \text{uterus} \rightarrow \text{uterine tube} \rightarrow \text{peritoneal cavity} \]

18. Define **ovulation**. *Ejection of an egg (actually an oocyte) from the ovary.*

**Microscopic Anatomy of Selected Male and Female Reproductive Organs**

19. The testis is divided into a number of lobes by connective tissue. Each of these lobes contains one to four **spermatogenesis**

\[ \text{spermatogenesis} \]

\[ \text{tubules} \]

\[ \text{seminal vesicles} \]

Which converge to empty sperm into another set of tubules called the **rete testis**

\[ \text{rete testis} \]

20. What is the function of the cavernous bodies seen in the male penis? *This tissue can become engorged with blood, thus making the penis stiff and more effective as a penetrating device.*

21. Name the three layers of the uterine wall from the inside out.

\[ \text{endometrium} \]

\[ \text{myometrium} \]

\[ \text{perimetrium} \]

Which of these is sloughed during menses? **Endometrium**

Which contracts during childbirth? **Myometrium**

22. What is the function of the stereocilia exhibited by the epithelial cells of the mucosa of the epididymis? *Absorb excess fluid and provide nutrients to the maturing sperm.*

23. On the diagram showing the sagittal section of the human testis, correctly identify all structures provided with leader lines.
24. Match the key term with the correct description.

Key:

\(\text{a; alveoli}\) 1. glands that produce milk during lactation \(\text{a. alveoli}\)

\(\text{e; lobule}\) 2. subdivisions of mammary lobes that contain alveoli \(\text{b. areola}\)

\(\text{d; lactiferous sinus}\) 3. enlarged storage chambers for milk \(\text{c. lactiferous duct}\)

\(\text{c; lactiferous duct}\) 4. ducts connecting alveoli to the storage chambers \(\text{d. lactiferous sinus}\)

\(\text{b; areola}\) 5. pigmented area surrounding the nipple \(\text{e. lobule}\)

\(\text{f; nipple}\) 6. releases milk to the outside \(\text{f. nipple}\)

25. Using the key terms, correctly identify breast structures.

Key: a. adipose tissue
    b. areola
    c. lactiferous duct
    d. lactiferous sinus
    e. lobule containing alveoli
    f. nipple

26. Describe the procedure for self-examination of the breasts. (Men are not exempt from breast cancer, you know!)

While lying down, place one arm behind your head and with the three middle fingers of the other arm palpate the breast in a circular motion, pressing first lightly, then with increasing pressure. Check the entire breast systematically using a vertical pattern from superior lateral to inferior medial regions.
Physiology of Reproduction: Gametogenesis and the Female Cycles

Time Allotment: 1 1/2 hours.


Coming Together (FHS: 28 minutes, VHS, DVD, 3-year streaming webcast)
Human Biology (FHS: 58 minutes, VHS, DVD)
Human Reproductive Biology (FHS: 35 minutes, VHS, DVD, 3-year streaming webcast)
Meiosis: The Key to Genetic Diversity (WNS: 30 minutes, VHS)

Laboratory Materials

Ordering information is based on a lab size of 24 students, working in groups of 4. A list of supply house addresses appears in Appendix A.

3-D models illustrating meiosis, spermatogenesis, and oogenesis
12 sets of “pop-it” beads in two colors with magnetic centromeres
24 compound microscopes, lens paper, lens cleaning solution
24 prepared slides of testis, ovary, human sperm, uterine endometrium (showing menses, proliferative, and secretory stages)

Demonstration slides of stages of oogenesis in Ascari's megaloccephala set up on microscopes to show:

a. primary oocyte with fertilization membrane, sperm nucleus, and aligned tetrads apparent
b. formation of first polar body
c. secondary oocyte with dyads aligned
d. formation of the ovum and second polar body
e. fusion of the male and female pronuclei to form the fertilized egg

Advance Preparation

1. Set out models illustrating meiosis, spermatogenesis, and oogenesis.
2. Set out prepared slides of testis, ovary, human sperm, and uterine endometrium (showing menses, proliferative, and secretory stages). Set out lens paper and immersion oil. Have compound microscopes available.
3. Set up five microscopes in a demonstration area with the following slides of stages of oogenesis in Ascari's megaloccephala (Parascaris equorum—Triarch): (1) primary oocyte with fertilization membrane, sperm nucleus, and aligned tetrads apparent; (2) formation of first polar body; (3) secondary oocyte with dyads aligned; (4) formation of ovum and second polar body; and (5) fusion of the male and female pronuclei to form the fertilized egg.
4. Set out sets of colored “pop-it” beads (two colors) and magnetic centromeres (WARD’S).
Comments and Pitfalls

1. If students have trouble counting chromosomes, have them count centromeres.
2. Note that in *Ascaris*, meiosis does not begin until the sperm has penetrated the primary oocyte, whereas in humans, meiosis I occurs before sperm penetration. See the section Demonstration of Oogenesis in *Ascaris* (optional) in the lab manual.

Answers to Pre-Lab Quiz (pp. 645–646)

1. b, 23  
2. d, four haploid daughter cells  
3. tetrad, meiosis  
4. c, Sustentacular  
5. acrosome  
6. follicle  
7. c, primary follicle  
8. true  
9. corpus luteum  
10. b, menstrual

Answers to Activity Questions

Activity 2: Examining Events of Spermatogenesis (pp. 647–648)

3. Tetrads may be visible. Evidence of crossing over may be difficult to see, but the tetrads may appear to have chromatids wrapped around each other. Tetrads are in primary spermatocytes, which are closer to the spermatogonia than to the lumen.
Physiology of Reproduction: Gametogenesis and the Female Cycles

Meiosis

1. The following statements refer to events occurring during mitosis and/or meiosis. For each statement, decide if the event occurs in (a) mitosis only, (b) meiosis only, or (c) both mitosis and meiosis.

   ______ 1. dyads are visible
   ______ 2. tetrads are visible
   ______ 3. product is two diploid daughter cells genetically identical to the mother cell
   ______ 4. product is four haploid daughter cells quantitatively and qualitatively different from the mother cell
   ______ 5. involves the phases prophase, metaphase, anaphase, and telophase
   ______ 6. occurs throughout the body
   ______ 7. occurs only in the ovaries and testes
   ______ 8. provides cells for growth and repair
   ______ 9. homologues synapse; chiasmata are seen
   ______ 10. chromosomes are replicated before the division process begins
   ______ 11. provides cells for perpetuation of the species
   ______ 12. consists of two consecutive nuclear divisions, without chromosomal replication occurring before the second division

2. Describe the process of synapsis. *The homologous chromosomes become closely aligned along their entire length.*

3. How does crossover introduce variability in the daughter cells? *Where crossovers occur, chromosome breakage occurs and parts are exchanged. This results in chromosomes with different parental contributions.*

4. Define *homologous chromosomes.* *Chromosomes that carry genes for the same traits. (One = paternal chromosome, the other = maternal chromosome.)*
Spermatogenesis

5. The cell types seen in the seminiferous tubules are listed in the key. Match the correct cell type(s) with the descriptions given below.

Key:  
a. primary spermatocyte  
b. secondary spermatocyte  
c. spermatogonium  
d. sustentacular cell  
e. spermatid  
f. sperm

<table>
<thead>
<tr>
<th>Cell Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>c.</td>
<td>primitive stem cell</td>
</tr>
<tr>
<td>b, e, f</td>
<td>haploid</td>
</tr>
<tr>
<td>d</td>
<td>provides nutrients to developing sperm</td>
</tr>
<tr>
<td>e</td>
<td>products of meiosis II</td>
</tr>
<tr>
<td>f</td>
<td>product of spermiogenesis</td>
</tr>
</tbody>
</table>

6. Why are spermatids not considered functional gametes? 
Too much superfluous cytoplasm; nonmotile.

7. Differentiate between spermatogenesis and spermiogenesis.
Formation of haploid gametes by the male.
Sloughing off excessive spermatid cytoplasm to form a motile functional sperm.

8. Draw a sperm below, and identify the acrosome, head, midpiece, and tail. Then beside each label, note the composition and function of each of these sperm structures.

![Sperm Diagram]

- **Acrosome**: (penetrating device containing digestive enzymes)
- **Head**: (genetic region, nucleus)
- **Midpiece**: (contains mitochondria which provide ATP)
- **Tail**: Contractile filaments (locomotor region)

9. The life span of a sperm is very short. What anatomical characteristics might lead you to suspect this even if you didn’t know its life span? 
No cytoplasm (to speak of) in which to store nutrients.

Oogenesis, the Ovarian Cycle, and the Menstrual Cycle

10. The sequence of events leading to germ cell formation in the female begins during fetal development. By the time the child is born, all viable oogonia have been converted to **primary oocytes**.

In view of this fact, how does the total germ cell potential of the female compare to that of the male?
Much smaller, and the total number is predetermined.

11. The female gametes develop in structures called **follicles**. What is a follicle? 
A structure consisting of a capsule of follicle (or granulosa) cells that encloses a developing gamete (oocyte).
How are primary and vesicular follicles anatomically different? The primary follicle has one or a small number of layers of follicle cells surrounding the oocyte; the vesicular follicle has a large antrum containing fluid produced by the granulosa cells, and the developing oocyte, surrounded by several layers of granulosa cells, is pushed to one side.

What is a corpus luteum? Glandular ovarian structure that produces progesterone. The ruptured vesicular follicle is converted to a corpus luteum.

12. What is the major hormone produced by the vesicular follicle? Estrogen

By the corpus luteum? Progesterone (and some estrogen)

13. Use the key to identify the cell type you would expect to find in the following structures.

Key: a. oogonium b. primary oocyte c. secondary oocyte d. ovum

b 1. forming part of the primary follicle in the ovary
c 3. in the mature vesicular follicle of the ovary
c 2. in the uterine tube before fertilization
d 4. in the uterine tube shortly after sperm penetration

14. The cellular product of spermatogenesis is four spermatids; the final product of oogenesis is one ovum and three polar bodies. What is the function of this unequal cytoplasmic division seen during oogenesis in the female? To provide the ovum or functional gamete with adequate nutritional reserves so that it can survive during its journey to the uterus.

What is the fate of the three tiny cells produced during oogenesis? They deteriorate.

Why? They lack sustaining cytoplasm with nutrient reserves.

15. The following statements deal with anterior pituitary and ovarian hormones and with hormonal interrelationships. Name the hormone(s) described in each statement.

estrogen 1. produced by primary follicles in the ovary

LH (luteinizing hormone) 2. ovulation occurs after its burstlike release

estrogen and progesterone 3. exert negative feedback on the anterior pituitary relative to FSH secretion

estrogen 4. stimulates LH release by the anterior pituitary

LH 5. stimulates the corpus luteum to produce progesterone and estrogen

LH 6. maintains the hormonal production of the corpus luteum in a nonpregnant woman

16. Why does the corpus luteum deteriorate toward the end of the ovarian cycle? Because blood levels of the anterior pituitary hormone LH are extremely low.
17. For each statement below dealing with hormonal blood levels during the female ovarian and menstrual cycles, decide whether the condition in column A is usually (a) greater than, (b) less than, or (c) essentially equal to the condition in column B.

<table>
<thead>
<tr>
<th>Column A</th>
<th>Column B</th>
</tr>
</thead>
<tbody>
<tr>
<td>b</td>
<td>amount of LH in the blood . . . . . . . . . amount of LH in the blood at ovulation during menses</td>
</tr>
<tr>
<td>a</td>
<td>amount of FSH in the blood on . . . . . . amount of FSH in the blood on day 20 of the cycle</td>
</tr>
<tr>
<td>b</td>
<td>amount of estrogen in the blood . . . . . . amount of estrogen in the blood at ovulation during menses</td>
</tr>
<tr>
<td>b</td>
<td>amount of progesterone in the . . . . . . amount of progesterone in the blood on day 14</td>
</tr>
<tr>
<td>a</td>
<td>amount of estrogen in the blood . . . . . . amount of progesterone in the blood on day 10</td>
</tr>
</tbody>
</table>

18. What uterine tissue undergoes dramatic changes during the menstrual cycle? **Endometrium**

19. When during the female menstrual cycle would fertilization be unlikely? Explain why. **Any time but the three-day interval (days 14–16) around ovulation. (Twenty-eight day cycle is assumed.)**

20. Assume that a woman could be an “on demand” ovulator like the rabbit, in which copulation stimulates the hypothalamic–anterior pituitary axis and causes LH release, and an oocyte was ovulated and fertilized on day 26 of her 28-day cycle. Why would a successful pregnancy be unlikely at this time?

   *The hormonal production of the ovary has ceased; the endometrium is beyond the receptive stage and is ready to slough off in menses.*

21. The menstrual cycle depends on events within the female ovary. The stages of the menstrual cycle are listed below. For each, note its approximate time span and the related events in the uterus; and then to the right, record the ovarian events occurring simultaneously. Pay particular attention to hormonal events.

<table>
<thead>
<tr>
<th>Menstrual cycle stage</th>
<th>Uterine events</th>
<th>Ovarian events</th>
</tr>
</thead>
<tbody>
<tr>
<td>Menstruation</td>
<td>Days 1–5. Endometrium is sloughing off.</td>
<td>Primary follicle begins to grow.</td>
</tr>
<tr>
<td>Secretory</td>
<td>Days 15–28. Vascular supply increases and glands begin secretory activity.</td>
<td>Ruptured follicle is converted to a corpus luteum, which begins to produce progesterone (and some estrogen). Peaks at day 23 and then begins to decline.</td>
</tr>
</tbody>
</table>
Survey of Embryonic Development

**Time Allotment**: 2 hours.


- *A Human Life Emerges* (FHS: 33 minutes, VHS, DVD, 3-year streaming webcast)
- *A New Life* (FHS: 28 minutes, VHS, DVD, 3-year streaming webcast)
- *Human Reproductive Biology* (FHS: 35 minutes, VHS, DVD, 3-year streaming webcast)
- *Into the World* (FHS: 28 minutes, VHS, DVD)
- *Life’s Greatest Miracle* (CBS: 60 minutes, VHS, DVD)

**Laboratory Materials**

*Ordering information is based on a lab size of 24 students, working in groups of 4. A list of supply house addresses appears in Appendix A.*

- 24 compound microscopes, lens paper, lens cleaning solution
- 3-D models of human development
- 3-D model of pregnant human torso
- Dissected pregnant cat, pig, or rat uterus
- 1–2 dissecting kits
- Disposable gloves
- Fresh or formalin-preserved placenta
- 24 prepared slides of placenta tissue
- 24 prepared slides of sea urchin development (zygote through larval stages)

**Advance Preparation**

2. Set out lens paper, lens cleaning solution, and slides of sea urchin development (zygote to larval stages) and of a placenta tissue. Have compound microscopes available.
3. Set out models of human development and pregnant human torso.
4. Obtain a fresh or formalin-preserved placenta from a clinical agency.
5. Set out a pregnant cat, rat, or pig uterus, disposable gloves, safety glasses, and dissecting equipment.

**Comments and Pitfalls**

1. Students may have difficulty with the questions in the text. Additional reference material (developmental biology or embryology books) might be helpful.
Answers to Pre-Lab Quiz (p. 657)

1. zygote
2. b, fertilization
3. true
4. three
5. a, ectoderm
6. c, fetus
7. false
8. amnion
9. It provides nutrients and oxygen to the embryo and fetus and removes carbon dioxide.

Answers to Activity Questions

Activity 2: Examining the Stages of Human Development (pp. 659–661)

2. Yes, but different in the early cleavage planes.
   The cleavage process results in large numbers of smaller cells.
5. The chorionic villi look like feathery projections.
   Areas of the brain and the heart appear very early in development.
   Development is rostral to caudal and proximal to distal.
   Yes, spontaneous movement occurs in utero. The mother can feel the fetal movements, often described as a flapping in the abdomen.
   Yes, the astronaut analogy is appropriate. The fetus, attached to the placenta by the umbilical cord, may resemble an astronaut on a “space walk” connected to life support systems on a space ship.
   The vernix caseosa covers the fetus and consists mainly of sebaceous secretions and dead epidermal cells.
   It may act as a lubricant and protect the growing fetus from chafing injuries.
   Lanugo is a downy coat of fetal hairs that appears at about the fifth month of development and is usually lost at birth or shortly thereafter.

Activity 3: Identifying Fetal Structures (pp. 661–662)

1. The placenta of the pig is diffuse with villi distributed over the surface of the chorion. In the cat, the villi form a belt around the fetus (zonary placenta). The rat has a discoidal placenta similar to the human placenta.
   The umbilical cord connects the placenta to the fetus.
   Amniotic fluid is usually clear and watery.
   Fetal skin is relatively thin. If it is a very young fetus, the skin may be almost transparent.
2. The human placenta is discoidal in shape.
   Implantation usually occurs in the upper part of the uterus.
   One problem that may occur with lower implantation is placenta previa. The placenta may irritate the cervix, resulting in contractions and spontaneous abortion.
   A feet-first position is not as desirable as head-first. The head is the largest structure and if it is delivered first, the rest of the baby is delivered easily. It is also possible to suction and deliver oxygen to a baby in a head-first position if difficulties are encountered.

Activity 4: Studying Placental Structure (p. 662)

1. The fetal side is the smooth side. The ragged side was united with maternal tissue.
   The umbilical vein delivers relatively oxygen-rich blood to the fetus from the placenta.
   The umbilical arteries carry blood from the fetus to the placenta. If any fetal membranes are still attached, one may be the amnion.
Survey of Embryonic Development

Developmental Stages of Sea Urchins and Humans

1. Define zygote. *Fertilized egg.*

2. Describe how you were able to tell by observation when a sea urchin egg was fertilized. *A fertilization membrane is present beneath the outer jelly coat.*

3. Use the key choices to identify the embryonic stage or process described below.

   Key:  
   a. blastula  
   b. cleavage  
   c. fertilization  
   d. gastrulation  
   e. morula  
   f. zygote

   1. fusion of male and female pronuclei
   2. solid ball of embryonic cells
   3. process of rapid mitotic cell division without intervening growth periods
   4. combination of egg and sperm
   5. process involving cell rearrangements to form the three primary germ layers
   6. embryonic stage in which the embryo consists of a hollow ball of cells

4. What is the importance of cleavage in embryonic development? *It provides a large number of smaller cells for morphogenesis.*

   How is cleavage different from mitotic cell division, which occurs later in life? *During cleavage there are no intervening growth periods between the successive divisions. Therefore the cells get smaller and smaller, but the embryonic mass remains essentially the same size.*

5. The cells of the human blastula (blastocyst) have various fates. Which blastocyst structures have the following fates?

   - inner cell mass: 1. produces the embryonic body
   - trophoblast: 2. becomes the chorion and cooperates with uterine tissues to form the placenta
   - inner cell mass: 3. produces the amnion, yolk sac, and allantois
   - yolk sac: 4. produces the primordial germ cells
   - allantois: 5. an embryonic membrane that provides the structural basis for the body stalk or umbilical cord
6. Using the letters on the diagram, correctly identify each of the following maternal or embryonic structures.

\[
\begin{array}{cccc}
 j & \text{amnion} & g & \text{chorion} \\
 i & \text{body stalk} & h & \text{chorionic villi} \\
 b & \text{decidua basalis} & a & \text{decidua capsularis} \\
 f & \text{endoderm} & e & \text{mesoderm} \\
 d & \text{ectoderm} & c & \text{uterine cavity} \\
\end{array}
\]

7. Explain the process and importance of gastrulation. It involves the migration, movement, and rearrangement of embryonic cells, so that a three-layer embryo (three primary germ layers) is formed.

8. What is the function of the amnion and the amniotic fluid? The amnion is a protective, fluid-filled sac that surrounds the embryo. The fluid “buffer” protects the embryo from physical trauma and prevents adhesion formation during rapid growth.

9. Describe the process of implantation, noting the role of the trophoblast cells. The trophoblast cells overlying the inner cell mass adhere to the endometrium. The trophoblast cells then secrete enzymes that erode the endometrial lining to reach the vascular supply beneath it.

10. How many days after fertilization is implantation generally completed? 12–14 What event in the female menstrual cycle ordinarily occurs just about this time if implantation does not occur? Menses, because this is usually the 14th day after ovulation.
11. What name is given to the part of the uterine wall directly under the implanting embryo? Decidua basalis

That surrounding the rest of the embryonic structure? Decidua capsularis

12. Using an appropriate reference, find out what decidua means and state the definition. That which “falls off” or is subject to periodic shedding.

How is this terminology applicable to the deciduas of pregnancy? After birth they slough off and are flushed out of the uterus.

13. Referring to the illustrations and text of *Life Before Birth: Normal Fetal Development*, answer the following:

Which two organ systems are extensively developed in the very young embryo?

nervous system and circulatory system

Describe the direction of development by circling the correct descriptions below:

proximal-distal distal-proximal caudal-rostral rostral-caudal

Does bodily control during infancy develop in the same directions? Think! Can an infant pick up a common pin (pincer grasp) or wave his arms earlier? Is arm-hand or leg-foot control achieved earlier?

Yes. In the limbs, muscle control follows the proximal-distal pattern; arm muscle control (waving) develops before fine finger movements (picking up small objects). Arm-hand control also occurs before leg-foot control mimicking the rostral-caudal developmental pattern.

14. Note whether each of the following organs or organ systems develops from the (a) ectoderm, (b) endoderm, or (c) mesoderm. Use an appropriate reference as necessary.

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>c</td>
<td>a</td>
<td>b</td>
<td>a</td>
<td>b</td>
<td>c</td>
<td>a</td>
<td>b</td>
<td>a</td>
<td>b</td>
</tr>
</tbody>
</table>

15. Make the following comparisons between a human and the pregnant dissected animal structures.

<table>
<thead>
<tr>
<th>Comparison object</th>
<th>Human</th>
<th>Dissected animal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shape of the placenta</td>
<td>Disc-shaped</td>
<td>(depends on animal)</td>
</tr>
<tr>
<td>Shape of the uterus</td>
<td>Pear-shaped</td>
<td>Y-shaped</td>
</tr>
</tbody>
</table>


17. Describe the function(s) of the placenta. Provides nutrients and oxygen to the fetus, removes fetal wastes, and produces the hormones of pregnancy.
What embryonic membranes has the placenta more or less “put out of business”?  
Yolk sac and allantois.

18. When does the human embryo come to be called a fetus?  
Ninth week of development.

19. What is the usual and most desirable fetal position in utero?  
Head down.

Why is this the most desirable position?  
The largest fetal dimension is the skull. Therefore, if the skull is used as a wedge, the rest of the body is delivered easily. Also, if difficulties are encountered, the baby can be suctioned and given oxygen even before delivery is completed.

Gross and Microscopic Anatomy of the Placenta

20. Describe fully the gross structure of the human placenta as observed in the laboratory.  
Smooth on the side from which the umbilical cord issues. Torn, rough, and bloody on the side that was united with maternal tissues. Blood-rich.

21. What is the tissue origin of the placenta: fetal, maternal, or both?  
Both

22. What are the placental barriers that must be crossed to exchange materials?  
The membranes of the villi and capillary walls of the fetal vascular supply.
Principles of Heredity

**Time Allotment:** 2 hours+ with gel electrophoresis and if Punnett squares are done outside of lab.

**Multimedia Resources:** See Appendix B for Guide to Multimedia Resource Distributors.

*Genetics* (FHS: CD-ROM)
*Genetics: A Popular Guide to the Principles of Human Heredity* (FHS: VHS, DVD, 3-year streaming webcast)
  - *Genetic Discoveries, Disorders, and Mutations* (26 minutes)
  - *Practical Applications and the Risks of Genetic Science* (24 minutes)
  - *Understanding the Basic Concepts of Genetics* (30 minutes)
*Reproduction: Shares in the Future* (FHS: 26 minutes, VHS, DVD, 3-year streaming webcast)

**Solutions:**

*Agarose gel, 1.2%*
Weigh out 0.9 gram of agarose and add 1X Tris-Borate/EDTA buffer (ICN) to a volume of 75 ml. Boil on a hot plate or in a microwave oven until the agarose melts, stirring periodically.

*Bleach Solution, 10%*
Measure out 100 milliliters of household bleach. Add water to a final volume of 1 liter.

**Laboratory Materials**

*Ordering information is based on a lab size of 24 students, working in groups of 4. A list of supply house addresses appears in Appendix A.*

12 pennies
24 PTC (phenylthiocarbamide) taste strips
24 sodium benzoate taste strips
Chart drawn on chalkboard or whiteboard for tabulation of class results

*Activity 5: Blood Typing*
Anti-A and anti-B blood typing sera
Sterile lancets
Cotton
Alcohol swabs
24 clean microscope slides

Toothpicks
24 wax markers
2 large beakers of 10% bleach
Disposable autoclave bag

*Activity 6: Hemoglobin Phenotyping*
Disposable gloves
6 plastic baggies
Hemoglobin samples dissolved in TBE solubilizing buffer with bromophenol blue: HbA, HbS, HbA-HbS mixed solution, and unknown samples of each
6 electrophoresis units and power supplies
6 metric rulers
6 1.2% agarose gels
1X TBE (Tris-Borate/EDTA) buffer pH 8.4
Coomassie protein stain solution
Coomassie destaining solution
Staining tray
6 100-milliliter graduated cylinders
Micropipettes
Distilled water
6 marking pens
Safety goggles (student-provided)
Advance Preparation

1. For each student set out PTC taste strips (Carolina), sodium benzoate taste strips (Carolina), pennies, wax markers, lancets, cotton, alcohol swabs, and toothpicks and clean microscope slides, or blood mixing sticks and test cards (Carolina).
2. Set out anti-A and anti-B blood typing sera, beakers of 10% bleach solution, and a disposable autoclave bag.
3. Prepare a chart on the blackboard for tabulation of class data.
4. Preparations for agarose gel electrophoresis:
   a. Prepare the casting tray. Place a clean glass slide into the gel casting tray and seal both ends of the tray with duct tape. Be sure the tray is tightly sealed.
   b. Prepare four gels. Pour 15 ml of the melted 1.2% agarose solution onto the glass slide in the casting tray. Insert the well comb into the slots on the casting tray, and press down. Cool the gel for about 15 minutes and then carefully remove the tape and lift the comb straight up out of the gel. To store for later use, leave the comb in place, wrap the gel with comb in plastic wrap or a baggie, and refrigerate.
   c. Prepare the sample buffer. The hemoglobin samples should be prepared as 10%–20% solutions in TBE solubilization buffer with bromophenol blue (ICN). HbA and HbS can be purchased from Sigma. Solutions can be mixed to make a heterozygous sample. Label the samples AA, AS, SS, and unknown sample.
5. Set out gel electrophoresis equipment, power supplies, micropipets, or variable automatic micropipets (2–20 µl) with tips, and 1.2% agarose gels.
6. Set out Coomassie blue stain (Carolina), staining tray, destaining solution (Carolina), and plastic baggies.
7. Set out hemoglobin samples, TBE buffer pH 8.4, 100-ml graduated cylinders, millimeter rulers, goggles, and disposable gloves.

Comments and Pitfalls

1. Some students will have difficulty with the Punnett squares. It might be best to have these as an out-of-class assignment, and go over the solutions with the class.
2. Using Phenotype to Determine Genotype is usually fun for the students and provides material for them to construct a genetic family tree.
3. Practice using micropipets to fill wells in the agarose gel.

Answers to Pre-Lab Quiz (p. 667)

1. alleles 4. phenotype 7. Y
2. false 5. c, Punnett square 8. true
3. d, recessive 6. a, incomplete dominance 9. false

Answers to Activity Questions

Activity 1: Working Out Crosses Involving Dominant and Recessive Genes (p. 668)

1. 50% Tt, 50% tt; 50% tall, 50% dwarf
2. 25% TT, 50% Tt, 25% tt; 75% tall, 25% dwarf
3. 50% TT, 50% Tt; 100% tall, 0% dwarf
Activity 2: Working Out Crosses Involving Incomplete Dominance (p. 669)

1. a. 100% Rr; 100% pink
   b. 50% Rr, 50% rr; 50% pink, 50% white
   c. 25% RR, 50% Rr, 25% rr; 25% red, 50% pink, 25% white

2. a. 100% Ss; 100% sickle-cell trait
   b. 25% SS, 50% Ss, 25% ss; 25% normal hemoglobin, 50% sickle-cell trait, 25% sickle-cell anemia
   c. 50% Ss, 50% ss; 50% sickle-cell trait, 50% sickle-cell anemia

Activity 3: Working Out Crosses Involving Sex-Linked Inheritance (p. 670)

1. 50% will be color blind.
   50% of the females and 50% of the males will be color blind.
   25% will be carriers.
   The carriers are females.

2. 50% of the males, 0% of the females.
   50% neither exhibit nor carry the allele for hemophilia.
   25% of the individuals (50% of the females) will be carriers. The carriers are female.

Activity 4: Exploring Probability (pp. 670–671)

1. b. The tosses are independent and do not influence each other.
   c. The probability of two heads is 25%; one head and one tail, 50%; and two tails, 25%.

2. The probability of a male is 50%; the probability of a female is 50%.

3. Dad’s chances are 1/512 or 0.19%.
Principles of Heredity

Introduction to the Language of Genetics

1. Match the key choices with the definitions given below.

Key:  
a. alleles  b. autosomes  c. dominant  d. genotype  e. heterozygous  f. homozygous  g. phenotype  h. recessive  i. sex chromosomes

---

d: genotype 1. actual genetic makeup

i: sex chromosomes 2. chromosomes determining maleness/femaleness

f: homozygous 3. situation in which an individual has identical alleles for a particular trait

h: recessive 4. genes not expressed unless they are present in homozygous condition

g: phenotype 5. expression of a genetic trait

e: heterozygous 6. situation in which an individual has different alleles making up his genotype for a particular trait

a: alleles 7. genes for the same trait that may have different expressions

b: autosomes 8. chromosomes regulating most body characteristics

c: dominant 9. the more potent gene allele; masks the expression of the less potent allele

Dominant-Recessive Inheritance

2. In humans, farsightedness is inherited by possession of a dominant allele (A). If a man who is homozygous for normal vision (aa) marries a woman who is heterozygous for farsightedness (Aa), what proportion of their children would be expected to be farsighted? 50%

3. A metabolic disorder called phenylketonuria (PKU) is due to an abnormal recessive gene (p). Only homozygous recessive individuals exhibit this disorder. What percentage of the offspring will be anticipated to have PKU if the parents are Pp and pp? 50%

4. A man obtained 32 spotted and 10 solid-color rabbits from a mating of two spotted rabbits.

Which trait is dominant? spotted  Recessive? solid-color

What is the probable genotype of the rabbit parents? Ss × Ss
5. Assume that the allele controlling brown eyes \((B)\) is dominant over that controlling blue eyes \((b)\) in human beings. (In actuality, eye color in humans is an example of polygenic inheritance, which is much more complex than this.) A blue-eyed man marries a brown-eyed woman, and they have six children, all brown-eyed. What is the most likely genotype of the father?  \(_{bb}\) Of the mother?  \(_{BB}\) If the seventh child had blue eyes, what could you conclude about the parents’ genotypes?  

\(Female \: is \: Bb; \: male \: is \: bb.\)

---

**Incomplete Dominance**

6. Tail length on a bobcat is controlled by incomplete dominance. The alleles are \(T\) for normal tail length and \(t\) for tail-less.

What name could/would you give to the tails of heterozygous \((Tt)\) cats?  \(Bobtail\)

How would their tail length compare with that of \(TT\) or \(tt\) bobcats?  \(Intermediate \: in \: length\)

7. If curly-haired individuals are genotypically \(CC\), straight-haired individuals are \(cc\), and wavy-haired individuals are heterozygotes \((Cc)\), what percentage of the various phenotypes would be anticipated from a cross between a \(CC\) woman and a \(cc\) man?

\(0\) \% curly \hspace{1cm} \(100\) \% wavy \hspace{1cm} \(0\) \% straight

**Sex-Linked Inheritance**

8. What does it mean when someone says a particular characteristic is sex-linked? \(It \: is \: carried \: on \: the \: female \: X \: (sex) \: chromosome.\)

---

9. You are a male, and you have been told that hemophilia “runs in your genes.” Whose ancestors, your mother’s or your father’s, should you investigate?  \(Mother’s\) \hspace{1cm} \(Why? \: Males \: can \: only \: receive \: the \: X \: chromosome \: from \: their \: mothers; \: the \: father’s \: contribution \: is \: always \: Y.\)

---

10. An \(X^C X^c\) female marries an \(X^C Y\) man. Do a Punnett square for this match.

What is the probability of producing a color-blind son? \(25\%\)

A color-blind daughter? \(0\%\)

A daughter who is a carrier for the color-blind allele? \(25\%\)

11. Why are consanguineous marriages (marriages between blood relatives) prohibited in most cultures?

\(Blood \: relatives \: have \: similar \: gene \: pools. \: Thus, \: the \: likelihood \: of \: receiving \: a \: double \: dose \: of \: recessive \: genes \: (many \: of \: which \: are \: detrimen-

\: tal) \: is \: dramatically \: increased.\)
Probability

12. What is the probability of having three daughters in a row? \(\left(\frac{1}{2}\right) \times \left\{\frac{1}{2}\right\} \times \left\{\frac{1}{2}\right\} = \frac{1}{8} \text{ or } 12.5\%\)

13. A man and a woman, each of seemingly normal intellect, marry. Although neither is aware of the fact, each is a heterozygote for the allele for mental retardation. Is the allele for mental retardation dominant or recessive? **Recessive**

What are the chances of their having one mentally retarded child? \(25\% \left(\frac{1}{4}\right)\)

What are the chances that all of their children (they plan a family of four) will be mentally retarded? \(\left(\frac{1}{4}\right) \times \left(\frac{1}{4}\right) \times \left(\frac{1}{4}\right) \times \left(\frac{1}{4}\right) = \frac{1}{256} \text{ or } 0.39\%\)

Genetic Determination of Selected Human Characteristics

14. Look back at your data to complete this section. For each of the situations described here, determine if an offspring with the characteristics noted is possible with the parental genotypes listed. Check (✓) the appropriate column.

<table>
<thead>
<tr>
<th>Parental genotypes</th>
<th>Phenotype of child</th>
<th>Possibility</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>(FI \times ff)</td>
<td>Freckles</td>
<td>✓</td>
<td>No</td>
</tr>
<tr>
<td>(DD \times dd)</td>
<td>Dimples</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>(HH \times Hh)</td>
<td>Proximal finger hair</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>(IAi \times IBi)</td>
<td>Type O blood</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>(IA\beta \times ii)</td>
<td>Type B blood</td>
<td>✓</td>
<td></td>
</tr>
</tbody>
</table>

15. You have dimples, and you would like to know if you are homozygous or heterozygous for this trait. You have six brothers and sisters. By observing your siblings, how could you tell, with some degree of certainty, that you are a heterozygote?

Absence of dimples indicates the homozygous recessive condition. If one or more of your siblings does not have dimples, there was a 50% chance at your conception that you would be heterozygous for this trait.
Using Agarose Gel Electrophoresis to Identify Hemoglobin Phenotypes

16. Draw the banding patterns you obtained on the figure below. Indicate the genotype of each band.

<table>
<thead>
<tr>
<th>Sample genotype</th>
<th>Well</th>
<th>Banding pattern</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. AA</td>
<td>1.</td>
<td>[ ]</td>
</tr>
<tr>
<td>2. AS</td>
<td>2.</td>
<td>[ ] [ ]</td>
</tr>
<tr>
<td>3. SS</td>
<td>3.</td>
<td>[ ] [ ]</td>
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<td>4. unknown</td>
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<td>(student data)</td>
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<td>5. AA</td>
<td>5.</td>
<td>[ ]</td>
</tr>
<tr>
<td>6. AS</td>
<td>6.</td>
<td>[ ] [ ]</td>
</tr>
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<td>7. SS</td>
<td>7.</td>
<td>[ ] [ ]</td>
</tr>
<tr>
<td>8. unknown</td>
<td>8.</td>
<td>(student data)</td>
</tr>
</tbody>
</table>

17. What is the genotype of sickle-cell anemia? **SS** Sickle-cell trait? **AS**

18. Why does sickle-cell hemoglobin behave differently from normal hemoglobin during agarose gel electrophoresis?

*HbS has fewer negative charges than HbA, due to the base substitution of valine for glutamic acid in HbS.*
Time Allotment: 2 hours for a thorough review.

Laboratory Materials

Ordering information is based on a lab size of 24 students, working in groups of 4. A list of supply house addresses appears in Appendix A.

<table>
<thead>
<tr>
<th>Articulated skeletons</th>
<th>Washable markers</th>
<th>Stethoscopes</th>
</tr>
</thead>
<tbody>
<tr>
<td>3-D charts and/or models of skeletal muscles</td>
<td>Hand mirrors</td>
<td>Alcohol swabs</td>
</tr>
</tbody>
</table>

Advance Preparation

1. Have articulated skeletons and skeletal muscle charts and models available.
2. Set out washable markers, hand mirrors, stethoscopes, and alcohol swabs.

Comments and Pitfalls

1. Muscles and other landmarks on the posterior aspect of the body trunk are difficult for students to palpate on themselves. If necessary, ask for volunteers (you may wish to select males) to act as subjects.

Answers to Pre-Lab Quiz (pp. 679–680)

1. b, You can relate external surface landmarks to the location of internal organs.
2. Palpation
3. c, true scalp
4. d, sternocleidomastoid
5. b, triangle of auscultation
6. true
7. true
8. b, dorsal venous network
9. true
10. a, femoral triangle

Answers to Activity Questions

Activity 1: Palpating Landmarks of the Head (pp. 680–681)

Cranium

3. Scalp wounds bleed profusely. However, because the scalp is so well vascularized, these wounds heal quickly.
Activity 2: Palpating Landmarks of the Neck (pp. 681–683)

Triangles of the Neck
2. They result from damage to the cervical plexus and accessory nerve, which supply these skin regions and muscles.

Activity 3: Palpating Landmarks of the Trunk (pp. 683–686)

The Back: Muscles
3. This action draws the scapula anteriorly and enlarges the triangle of auscultation as much as possible.

Activity 5: Palpating Landmarks of the Upper Limb (pp. 687–690)

Forearm and Hand
2. In this fracture, the physician can feel that the styloid process of the radius has moved proximally from its normal position.
Surface Anatomy Roundup

1. A blow to the cheek is most likely to break what superficial bone or bone part? (a) superciliary arches, (b) the philtrum, (c) zygomatic arch, (d) the tragus
2. Rebound tenderness (a) occurs in appendicitis, (b) is whiplash of the neck, (c) is a sore foot from playing basketball, (d) occurs when the larynx falls back into place after swallowing.
3. The anatomical snuff box (a) is in the nose, (b) contains the styloid process of the radius, (c) is defined by tendons of the flexor carpi radialis and palmaris longus, (d) cannot really hold snuff.
4. Some landmarks on the body surface can be seen or felt, but others are abstractions that you must construct by drawing imaginary lines. Which of the following pairs of structures is abstract and invisible? (a) umbilicus and costal margin, (b) anterior superior iliac spine and natal cleft, (c) linea alba and linea semilunaris, (d) McBurney’s point and midaxillary line, (e) philtrum and sternocleidomastoid
5. Many pelvic organs can be palpated by placing a finger in the rectum or the vagina, but only one pelvic organ is readily palpated through the skin. This is the (a) nonpregnant uterus, (b) prostate gland, (c) full bladder, (d) ovaries, (e) rectum.
6. A muscle that contributes to the posterior axillary fold is the (a) pectoralis major, (b) latissimus dorsi, (c) trapezius, (d) infraspinatus, (e) pectoralis minor, (f) a and e.
7. Which of the following is not a pulse point? (a) anatomical snuff box, (b) inferior margin of mandible anterior to masseter muscle, (c) center of distal forearm at palmaris longus tendon, (d) medial bicipital furrow on arm, (e) dorsum of foot between the first two metatarsals
8. Which pair of ribs inserts on the sternum at the sternal angle? (a) first, (b) second, (c) third, (d) fourth, (e) fifth
9. The inferior angle of the scapula is at the same level as the spinous process of which vertebra? (a) C5, (b) C7, (c) T3, (d) T7, (e) L4
10. An important bony landmark that can be recognized by a distinct dimple in the skin is the (a) posterior superior iliac spine, (b) styloid process of the ulna, (c) shaft of the radius, (d) acromion.
11. A nurse missed a patient’s median cubital vein while trying to withdraw blood and then inserted the needle far too deeply into the cubital fossa. This error could cause any of the following problems, except this one: (a) paralysis of the ulnar nerve, (b) paralysis of the median nerve, (c) bruising the insertion tendon of the biceps brachii muscle, (d) blood spurting from the brachial artery.
12. Which of these organs is almost impossible to study with surface anatomy techniques? (a) heart, (b) lungs, (c) brain, (d) nose
13. A preferred site for inserting an intravenous medication line into a blood vessel is the (a) medial bicipital furrow on arm, (b) external carotid artery, (c) dorsal venous arch of hand, (d) popliteal fossa.
14. One listens for bowel sounds with a stethoscope placed (a) on the four quadrants of the abdominal wall; (b) in the triangle of auscultation; (c) in the right and left midaxillary line, just superior to the iliac crests; (d) inside the patient’s bowels (intestines), on the tip of an endoscope.
Dissection and Identification of Cat Muscles

**Time Allotment:** Skin removal: 1 hour. Muscle dissection: 4–6 hours+ (depending on detail required).

**Multimedia Resources:** See Appendix B for Guide to Multimedia Resource Distributors.

*The Anatomy of the Cat* (CBS: 85 minutes, VHS, DVD)
*Cat Dissection* (WNS: 46 minutes, VHS, DVD)

**Solutions:**

*Carboglycerine solution*
30 grams fungicide (Benomyl, Sigma-Aldrich)
250 milliliters glycerine
1 liter water
Mix together and store in a closed container.

**Laboratory Materials**

*Ordering information is based on a lab size of 24 students, working in groups of 4. A list of supply house addresses appears in Appendix A.*

<table>
<thead>
<tr>
<th>6–12 preserved double- or triple-injected cats</th>
<th>6–12 name tags and large plastic storage bags</th>
<th>Disposable gloves or protective skin cream</th>
</tr>
</thead>
<tbody>
<tr>
<td>6–12 dissection trays</td>
<td>Paper towels</td>
<td>Embalming fluid</td>
</tr>
<tr>
<td>6–12 dissection kits with metric rulers</td>
<td></td>
<td>Organic debris container</td>
</tr>
</tbody>
</table>

**Advance Preparation**

1. Order cats well in advance, as they may be in short supply.
2. Make arrangements for appropriate storage, disposal, and cleanup of dissection materials. Check with the Department of Health or the Department of Environmental Protection, or their counterparts, for state regulations. Designate a disposal container for organic debris, set up a dishwashing area with hot soapy water and sponges, and provide lab disinfectant such as Wavicide-01 (Carolina) or 10% bleach solution for washing down the lab benches.
3. Set out disposable gloves (or protective skin cream), safety glasses, dissecting kits, dissection trays, plastic storage bags, paper towels, and name tags.
4. Set out dissection animals (one per group of two to four students).
5. Set out *carboglycerine solution* or small plastic bags to hold embalming fluid.
Comments and Pitfalls

1. Be sure that students understand that the skin is to be removed in one piece.
2. Emphasize the use of the blunt probe as a dissecting instrument, rather than the scalpel. Cut only when everyone in the group agrees that a cut should be made!
3. Cat fur tends to clog the sink drains. Emphasize correct disposal of organic debris.
4. Students often “invent” muscles by tearing tissue apart. Emphasize that they should be separating muscles by breaking through the surrounding connective tissue.
5. Sometimes the dissection animal is in very poor condition, in which case the student should exchange it for a different specimen.
6. To prevent damage to muscles during skinning, separate skin from underlying tissues by inserting a blunt probe into the skin incision in the neck. Continue to use the probe to separate skin from underlying tissues before cutting the skin.

Answers to Activity Questions

Activity 2: Dissecting Neck and Trunk Muscles
Muscles of the Abdominal Wall (p. 701)
2. The external oblique muscles run medially and downward, while the internal oblique muscle fibers run upward and medially. They are not quite perpendicular to each other.

Superficial Muscles of the Shoulder and Dorsal Trunk and Neck (pp. 701–703)
1. The clavotrapezius appears to originate on the occipital bone. This is similar to a part of the origin of the trapezius muscle in humans. The three cat muscles seem to have the same functions as the human trapezius muscle.
2. In humans the levator scapulae elevates the scapula and bends the neck laterally if the scapula is fixed.
3. The clavodeltoid inserts on the proximal end of the ulna. This muscle is used to flex the lower limb in walking.

Activity 3: Dissecting Forelimb Muscles
Muscles of the Lateral Surface (pp. 705–706)
1. The triceps muscle has a similar function in cats and humans.

Muscles of the Medial Surface (pp. 706–707)
1. The biceps brachii has only one head in the cat.

Activity 4: Dissecting Hindlimb Muscles
Posterolateral Hindlimb Muscles (pp. 707–709)
5. In humans the semimembranosus is also medial to and partially obscured by the semitendinosus. The human semimembranosus inserts on the tibia, but not on the femur.

Anteromedial Hindlimb Muscles (pp. 709–712)
2. The origin of the rectus femoris in humans is the anterior inferior iliac spine and just above the acetabulum.
3. The human gracilis muscle has a very similar origin and insertion.

Dissection Review

Many human muscles are modified from those of the cat (or any quadruped) as a result of the requirements of an upright posture. The following questions refer to these differences.
1. How does the human trapezius muscle differ from the cat’s?

*Cat’s trapezius is tripartite (clavo-, acromio-, and spino- portions); the human trapezius is a single muscle.*

2. How does the deltoid differ?

*Cat has three deltoid muscles, the clavodeltoid, acromiodeltoid, and spinodeltoid. The human has a single deltoid muscle.*

3. How do the size and orientation of the human gluteus maximus muscle differ from that in the cat?

*The human gluteus maximus muscle originates on the dorsal ilium, sacrum, and coccyx and inserts on the proximal femur and iliotibial tract as it runs inferiorlateral; it forms the bulk of buttock mass. The cat gluteus maximus muscle originates on the sacrum and inserts on the proximal femur; it is a smaller triangular muscle that runs laterally.*

4. Explain the differences in terms of differences in function.

*The large human gluteus maximus muscle is the major extensor of the thigh, most powerful when the thigh is flexed. It is generally inactive during standing and walking. It also laterally rotates and abducts the thigh. The cat gluteus maximus muscle is much smaller in relation to the size of the cat. Its function is to abduct the thigh.*

5. The human rectus abdominis is definitely divided by four transverse tendons (tendinous intersections). These tendons are absent or difficult to identify in the cat. How do these tendons affect the human upright posture?

*These tendons support the abdominal muscular wall so that the viscera are not allowed to become pendulous in the upright posture of humans.*

6. Match the terms in Column B to the descriptions in Column A.

<table>
<thead>
<tr>
<th>Column A</th>
<th>Column B</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>1. to separate muscles</td>
</tr>
<tr>
<td>c</td>
<td>2. to fold back a muscle</td>
</tr>
<tr>
<td>d</td>
<td>3. to cut through a muscle</td>
</tr>
<tr>
<td>b</td>
<td>4. to preserve tissue</td>
</tr>
</tbody>
</table>
Dissection of Cat
Spinal Nerves

Time Allotment: 1 hour.


The Anatomy of the Cat (CBS: 85 minutes, VHS, DVD)

Cat Dissection (WNS: 46 minutes, VHS, DVD)

Laboratory Materials

Ordering information is based on a lab size of 24 students, working in groups of 4. A list of supply house addresses appears in Appendix A.

- 6–12 preserved double- or triple-injected cats
- 6–12 dissection trays
- 6–12 dissection kits with metric rulers
- 6–12 name tags and large plastic storage bags
- Paper towels
- Disposable gloves
- Embalming fluid
- Organic debris container

Advance Preparation

1. See Dissection Exercise 1 for setup instructions.

2. If cats were not skinned previously, see instructions in Dissection Exercise 1. Allow extra time for skinning: 1/2 hour to skin 1 forelimb and 1 hindlimb.

Dissection Review

1. From anterior to posterior, put the nerves issuing from the brachial plexus in their proper order (i.e., the musculocutaneous, radial, median, ulnar nerves).

   musculocutaneous, radial, median, ulnar

2. Which of the nerves named above serves the cat’s forearm extensor muscles? the radial nerve

   Which serves the forearm flexors? the median nerve

3. Just superior to the gastrocnemius muscle the sciatic nerve divides into its two main branches, the tibial and common fibular nerves.

4. What name is given to the cutaneous nerve of the cat’s thigh? the saphenous nerve
Identification of Selected Endocrine Organs of the Cat

**Time Allotment:** 1 hour.

**Multimedia Resources:** See Appendix B for Guide to Multimedia Resource Distributors.

*The Anatomy of the Cat* (CBS: 85 minutes, VHS, DVD)

*Cadaver Dissection* (WNS: 46 minutes, VHS, DVD)

**Laboratory Materials**

*Ordering information is based on a lab size of 24 students, working in groups of 4. A list of supply house addresses appears in Appendix A.*

- 6–12 preserved double- or triple-injected cats
- 6–12 dissection trays
- 6–12 dissection kits with metric rulers
- 6–12 name tags and large plastic storage bags
- Paper towels
- Disposable gloves
- Embalming fluid
- Organic debris container
- Bone cutters

**Advance Preparation**

1. See Dissection Exercise 1 for setup instructions.
2. If cats were not skinned previously, see instructions in Dissection Exercise 1. Allow extra time for skinning. (Note: It is not absolutely necessary to skin the cats to do dissection of internal structures.)
3. The thymus gland varies in size from very large, sometimes extending from the superior trachea onto the heart, to almost absent.

**Comments and Pitfalls**

1. It is possible to leave identification of glands in the dissection animal until later dissections.

**Dissection Review**

1. How do the location of the endocrine organs in the cat compare with those in the human?

   *They are similar, but in the cat the pancreas is more diffuse and the adrenal glands are medial and separate from, rather than superior and attached to, the kidneys.*

2. Name two endocrine organs located in the neck region. *thyroid gland ________ and thymus gland ________*
3. Name three endocrine organs located in the abdominal cavity.

   pancreas, adrenal glands, ovaries in female

4. Given the assumption (not necessarily true) that human beings have more stress than cats, which endocrine organs would you expect to be relatively larger in humans?

   the adrenal glands

5. Cats are smaller animals than humans. Which would you expect to have a (relatively speaking) more active thyroid gland—cats or humans? cats

   Why? (We know we are asking a lot with this one, but give it a whirl.)

   It is a general rule of thumb that basal metabolic rate increases as body size decreases. The effect of an increased surface to volume relationship in maintaining internal temperature may be one of several factors explaining this phenomenon.
Dissection of the Blood Vessels of the Cat

**Time Allotment:** 1 1/2–2 hours (depending on detail required in dissection).

**Multimedia Resources:** See Appendix B for Guide to Multimedia Resource Distributors.

*The Anatomy of the Cat* (CBS: 85 minutes, VHS, DVD)
*Cat Dissection* (WNS: 46 minutes, VHS, DVD)

**Laboratory Materials**

*Ordering information is based on a lab size of 24 students, working in groups of 4. A list of supply house addresses appears in Appendix A.*

- 6–12 preserved double- or triple-injected cats
- 6–12 dissection trays
- 6–12 dissection kits with metric rulers
- 6–12 name tags and large plastic storage bags
- Paper towels
- Disposable gloves
- Embalming fluid
- Organic debris container
- Bone cutters
- Scissors

**Advance Preparation**

1. See Dissection Exercise 1 for setup instructions.
2. If cats were not skinned previously, see instructions in Dissection Exercise 1. Allow extra time for skinning. (Note: It is not absolutely necessary to skin the cats to do dissection of internal structures.) Allow 1/2 hour to skin 1 forelimb and 1 hindlimb.

**Comments and Pitfalls**

1. As students dissect out the arteries and veins, caution them to avoid damaging other organs that will be studied in later exercises. *Especially caution them against cutting away the greater omentum.*
2. Students may want to forge ahead and do the entire dissection once the ventral body cavity has been opened. Remind them that the individual systems will be studied in detail at a later date.
3. If time is limited, the circulatory system may be studied in conjunction with the study of individual systems rather than as a separate exercise.
4. If desired by the instructor, a previously dissected animal may be put on demonstration.
5. If the specimen has been injected, frequently the right common carotid artery is damaged; therefore, tracing the common carotid artery to find the external and internal carotid arteries is more easily done by following the left common carotid artery.
Dissection Review

1. What differences did you observe between the origins of the left common carotid arteries in the cat and in the human?
   
   *In the cat, both the R and L common carotid arteries branch off the R brachiocephalic artery. In humans, the L common carotid branches directly off the aortic arch; only the R common carotid branches off the brachiocephalic artery.*
   
   Between the origin of the internal and external iliac arteries?
   
   *In the cat, the aorta gives off the two external iliac arteries, then persists briefly before dividing into the two internal iliac arteries and the median sacral artery; there are no common iliac arteries. In humans, the external and internal iliac arteries arise by branching off the common iliac arteries.*

2. How do the relative sizes of the external and internal jugular veins differ in the human and the cat?
   
   *In the cat, the external jugular vein is larger. In humans, the internal jugular vein is larger.*

3. In the cat the inferior vena cava is called the *postcava__________,* and the superior vena cava is referred to as the *precava__________.*

4. Define the following terms:

   Ascending aorta:
   
   *The aorta as it emerges from the heart and travels toward the head.*

   Aortic arch:
   
   *The aorta as it arches to the left.*

   Descending thoracic aorta:
   
   *The aorta as it passes through the thoracic cavity.*

   Descending abdominal aorta:
   
   *The aorta as it passes through the abdominal cavity.*
The Main Lymphatic Ducts of the Cat

Time Allotment: 1/2 hour (may be easily included with Dissection Exercise 4).


The Anatomy of the Cat (CBS: 85 minutes, VHS, DVD)
Cat Dissection (WNS: 46 minutes, VHS, DVD)

Laboratory Materials

Ordering information is based on a lab size of 24 students, working in groups of 4. A list of supply house addresses appears in Appendix A.

- 6–12 preserved double- or triple-injected cats
- 6–12 dissection trays
- 6–12 dissection kits with metric rulers
- 6–12 name tags and large plastic storage bags
- Paper towels
- Disposable gloves
- Embalming fluid
- Organic debris container

Advance Preparation

1. See Dissection Exercise 1 for setup instructions.
2. If cats were not skinned previously, see instructions in Dissection Exercise 1. Allow extra time for skinning. (Note: It is not absolutely necessary to skin the cats to do dissection of internal structures.)

Comments and Pitfalls

1. If the student cats are double injected, it might be of value to order one triple-injected cat for demonstration of the lymphatic system. Before ordering, make sure that triple injection means that the lymphatic system has been injected. Often, triple injection means that the hepatic portal venous system has been injected separately from the vascular system injections.

Dissection Review

1. How does the cat’s lymphatic drainage pattern compare to that of humans?

   It is basically the same.

2. What is the role of the following?

   a. thoracic duct  It returns lymph from the lower body and upper left quadrant of the body to the left subclavian vein.

   b. right lymphatic duct  It returns lymph to the right subclavian vein from the upper right quadrant of the body.
Dissection of the Respiratory System of the Cat

Time Allotment: 1 hour.


The Anatomy of the Cat (CBS: 85 minutes, VHS, DVD)
Cat Dissection (WNS: 46 minutes, VHS, DVD)

Laboratory Materials

Ordering information is based on a lab size of 24 students, working in groups of 4. A list of supply house addresses appears in Appendix A.

- 6–12 preserved double- or triple-injected cats
- 6–12 dissection trays
- 6–12 dissection kits with metric rulers
- 6–12 name tags and large plastic storage bags
- Paper towels
- Disposable gloves
- Embalming fluid
- Organic debris container
- 6–12 stereomicroscopes

Advance Preparation

1. See Dissection Exercise 1 for setup instructions.
2. If cats were not skinned previously, see instructions in Dissection Exercise 1. Allow extra time for skinning. (Note: It is not absolutely necessary to skin the cats to do dissection of internal structures.)
3. Set out dissecting microscopes.

Answers to Activity Questions

Activity 1: Identifying Organs of the Respiratory System (pp. 737–739)

5. The cat has four lobes in the right lung and three lobes in the left lung.

Dissection Review

1. Are the cartilaginous rings in the cat trachea complete or incomplete? incomplete

2. Describe the appearance of the bronchial tree in the cat lung.

The bronchial tree is a series of branching tubing. The primary bronchi are large; subsequent branches are smaller and smaller in diameter.

3. Describe the appearance of lung tissue under the dissection microscope.

Spongy-looking with small, irregular openings
Dissection of the Digestive System of the Cat

**Time Allotment:** 1–1 1/2 hours.

**Multimedia Resources:** See Appendix B for Guide to Multimedia Resource Distributors.

*The Anatomy of the Cat* (CBS: 85 minutes, VHS, DVD)
*Cat Dissection* (WNS: 46 minutes, VHS, DVD)

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**Laboratory Materials**

*Ordering information is based on a lab size of 24 students, working in groups of 4. A list of supply house addresses appears in Appendix A.*

- 6–12 preserved double- or triple-injected cats
- 6–12 dissection trays
- 6–12 dissection kits with metric rulers
- 6–12 name tags and large plastic storage bags
- Embalming fluid
- Organic debris container
- Paper towels
- Bone cutters
- Disposable gloves
- 6–12 hand lenses

---

**Advance Preparation**

1. See Dissection Exercise 1 for setup instructions.
2. Set out bone cutters, water bottles for flushing the intestines, and hand lenses.

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**Comments and Pitfalls**

1. Warn students that they will probably encounter roundworms in the cat’s stomach and intestines.

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**Answers to Activity Questions**

**Activity 1: Identifying Alimentary Canal Organs (pp. 743–745)**

2. The cat liver has five lobes; the human liver has four lobes.
4. The stomach is a curved sac.
6. Blood vessels, lymphatics, and nerves are present in the mesenteries. The mesenteries provide a route for blood and lymphatic vessels and nerves to travel to and from the small intestine. There are no major differences in external anatomy along the length of the small intestine. The inner surface of the ileum feels like velvet. The villi in the duodenum are more elongated than those in the ileum.
7. The cat does not have an appendix.
Activity 2: Exposing and Viewing the Salivary Glands and Oral Cavity Structures (pp. 745–746)

2. Rugae are not as well-developed in humans. Cats do not have a uvula. The numerous filiform papillae are used by the cat for grooming and for removing flesh from bones.

Dissection Review

1. Compare the appearance of tongue papillae in cats and humans.

   The cat has numerous sharp, bristly filiform papillae. Human filiform papillae are less numerous, blunted, and softer.

2. Compare the number of lobes of the liver in cats and humans.

   The cat liver has five lobes; the human liver has four.

3. Does the cat have a uvula? ___ no ___ An appendix? ___ no ___

4. Give an explanation for the different adult dental formulas in cats and humans.

   Cats are carnivores and need extra incisors for biting. They have a reduced need for grinding and thus have fewer molars.

5. How do the villi differ in the duodenum and the ileum? Explain.

   The villi in the duodenum are more elongated and more numerous than those in the ileum. Villi contribute to the increase in surface area that is necessary for absorption of nutrients, especially in the duodenum. Most absorption occurs in the proximal portion of the small intestine.
Dissection of the Urinary System of the Cat

**Time Allotment:** 1 hour.

**Multimedia Resources:** See Appendix B for Guide to Multimedia Resource Distributors.

- *The Anatomy of the Cat* (CBS: 85 minutes, VHS, DVD)
- *Cat Dissection* (WNS: 46 minutes, VHS, DVD)

**Laboratory Materials**

*Ordering information is based on a lab size of 24 students, working in groups of 4. A list of supply house addresses appears in Appendix A.*

- 6–12 preserved double- or triple-injected cats
- 6–12 dissection trays
- 6–12 dissection kits with metric rulers
- 6–12 name tags and large plastic storage bags
- Paper towels
- Disposable gloves
- Embalming fluid
- Organic debris container
- 6–12 hand magnifying lenses

**Advance Preparation:**

1. See Dissection Exercise 1 for setup instructions.

**Comments and Pitfalls**

1. Emphasize the importance of clearing away the peritoneum and fat tissue. Once the kidneys have been isolated there should be no difficulty identifying the ureters.
2. Remind the students that they are responsible for knowing both the male and the female urinary systems.
3. This dissection fits nicely with the dissection of the reproductive system.

**Answers to Activity Questions**

**Activity: Identifying Organs of the Urinary System (pp. 747–750)**

4. The ureters enter the bladder on the right and left lateral surfaces toward the posterior (caudal) end.
Dissection Review

1. a. How does the position of the kidneys in the cat differ from their position in humans?

   \textit{In humans, the left kidney is more superior. In the cat, the kidneys are located at the same level or the right kidney is more anterior.}

b. In what way is the position similar? \textit{Both are retroperitoneal.}

2. Distinguish between a ureter and the urethra.

   \textit{The ureter carries urine from the kidney to the urinary bladder. The urethra carries urine from the urinary bladder to the exterior.}

3. How does the site of urethral emptying in the female cat differ from its termination point in the human female?

   \textit{Human: empties to the body exterior. Cat: with the vagina, it empties into the urogenital sinus, then to the body exterior.}

4. What is a urogenital sinus?

   \textit{It is a common chamber into which the urethra and vagina enter.}

5. What gland encircles the neck of the bladder in the male? \textit{prostate} \text{no} \text{Part of the male reproductive system. Produces a secretion, which contributes to seminal fluid.}

6. Compare the location of the adrenal glands in the cat to the location in humans.

   \textit{In humans the adrenal glands sit atop the kidneys. In the cat they are superior, separate, and medial to the kidneys, close to the inferior vena cava.}
Dissection of the Reproductive System of the Cat

**Time Allotment:** 11/2–2 hours.

**Multimedia Resources:** See Appendix B for Guide to Multimedia Resource Distributors.  
*The Anatomy of the Cat* (CBS: 85 minutes, VHS, DVD)  
*Cat Dissection* (WNS: 46 minutes, VHS, DVD)

---

**Laboratory Materials**

*Ordering information is based on a lab size of 24 students, working in groups of 4. A list of supply house addresses appears in Appendix A.*

- 6–12 preserved double- or triple-injected cats
- 6–12 dissection trays
- 6–12 dissection kits with metric rulers
- 6–12 name tags and large plastic storage bags
- Paper towels
- Disposable gloves
- Embalming fluid
- Organic debris container
- Bone cutters

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**Advance Preparation**

1. See Dissection Exercise 1 for setup instructions.
2. Set out metric rulers and bone cutters.

---

**Comments and Pitfalls**

1. Students usually encounter some difficulty dissecting out the penis. It takes time, as the overlying skin is tightly attached in some places.
2. Caution students with male dissection animals to be careful when dissecting out the spermatic cord to avoid breaking it.
3. Remind students that they are responsible for doing both male and female dissections.
4. It is interesting to have at least one pregnant cat for dissection.
5. Students must use bone cutters to cut through the pubic region of the pelvis to complete the dissection. It is easiest if the cut is through the pubic symphysis.

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**Answers to Activity Questions**

**Activity 2: Identifying Organs of the Female Reproductive System (pp. 753–754)**

4. The human female has separate openings for the vagina and the urethra.
6. The vagina is two to three centimeters long (will vary).
Dissection Review

1. The female cat has a \textit{bipartite} uterus; that of the human female is \textit{simplex}. Explain the difference in structure of these two uterine types.

\textit{Cat: Y-shaped central inferior chamber (body) from which two horns (cornua) extend. Human: undivided single
pear-shaped chamber.}

2. What reproductive advantage is conferred by the feline uterine type?

\textit{Can produce multiple offspring (litters).}

3. Cite the differences between the cat and the human relative to the following structures:

- \textbf{Uterine tubes or oviducts} \textit{Cat's are much reduced in size and length}
- \textbf{Site of entry of ductus deferens into the urethra} \textit{More distal to the bladder in the cat}
- \textbf{Location of the prostate gland} \textit{Smaller and more distal to the bladder in the cat}
- \textbf{Seminal vesicles} \textit{Not present in the cat}
- \textbf{Urethral and vaginal openings in the female} \textit{Open into a common chamber (urogenital sinus) in the cat. In humans, each organ opens independently to the body exterior.}
Dissection and Identification of Fetal Pig Muscles

Time Allotment: Muscle dissection: 4 hours.


The Anatomy of the Fetal Pig (CBS: 62 minutes, VHS, DVD)  
Fetal Pig (DryLab Plus) (WNS: CD-ROM)

Solutions:

Carboglycerine solution  
30 grams fungicide (Benomyl, Sigma-Aldrich)  
250 milliliters glycerine  
1 liter water  
Mix together and store in a closed container.

Laboratory Materials

Ordering information is based on a lab size of 24 students, working in groups of 4. A list of supply house addresses appears in Appendix A.

| 6–12 preserved double- or triple-injected fetal pigs | 6–12 name tags and large plastic storage bags | Twine |
| 6–12 dissection trays | Paper towels | Embalming fluid |
| 6–12 dissection kits with metric rulers | Disposable gloves | Organic debris container |

Advance Preparation

1. Make arrangements for appropriate storage, disposal, and cleanup of dissection materials. Check with the Department of Health or the Department of Environmental Protection, or their counterparts, for state regulations. Designate a disposal container for organic debris, set up a dishwashing area with hot soapy water and sponges, and provide lab disinfectant such as Wavicide-01 (Carolina) or 10% bleach solution for washing down the lab benches.

2. Set out disposable gloves, dissecting kits, dissection trays, plastic storage bags, twine, metric rulers, paper towels, and name tags.

3. Set out dissection animals (one per group of two to four students).

4. Set out carboglycerine solution or small plastic bags to hold embalming fluid.

Comments and Pitfalls

1. Emphasize the use of the blunt probe as a dissecting instrument, rather than the scalpel. Cut only when everyone in the group agrees that a cut should be made!
2. Muscle development may be poor in some fetal pig specimens if they are very young.
3. Students often “invent” muscles by tearing tissue apart. Emphasize that they should be separating muscles by breaking through the surrounding connective tissue.
4. Sometimes the dissection animal is in very poor condition, in which case the student should exchange it for a different specimen.
5. To prevent damage to muscles during skinning, separate skin from underlying tissues by inserting a blunt probe into the skin incision in the neck. Continue to use the probe to separate skin from underlying tissues before cutting the skin.

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**Answers to Activity Questions**

**Activity 3: Dissecting Trunk and Neck Muscles**

*Superficial Muscles of the Posterior Trunk and Neck (pp. 705–706)*

2. The acromiotoracpezius and spinotrapezius muscles appear to have the same functions in the pig as in humans.

**Activity 4: Dissecting Forelimb Muscles**

*Upper Forelimb Muscles (p. 707)*

1. The triceps brachii has a similar function in pigs and humans.
3. The biceps brachii has only one head in the pig.

**Activity 5: Dissecting Hindlimb Muscles**

*Muscles of the Posterolateral Hindlimb (pp. 707–710)*

3. In humans the semimembranosus is also medial to and partially obscured by the semitendinosus. The human semimembranosus inserts on the tibia, but not on the femur.

*Muscles of the Anteromedial Hindlimb (pp. 710–711)*

2. The origin of the rectus femoris in humans is the anterior inferior iliac spine and just above the acetabulum.
3. The human gracilis muscle has a very similar origin and insertion.

---

**Dissection Review**

Many human muscles are modified from those of the pig (or any quadruped) as a result of the requirements of an upright posture. The following questions refer to these differences.

1. How does the human trapezius muscle differ from the pig’s?

   _The pig’s trapezius is tripartite (clavo-, acromio-, and spino- portions); the human trapezius is a single muscle._

2. How does the deltoid differ?

   _The pig’s deltoid is a tripartite muscle; the human deltoid is a single muscle._

3. How do the size and orientation of the human sartorius muscle differ from that in the pig?

   _In humans, the sartorius is a thin straplike muscle running obliquely across the anterior thigh. In the pig it is broad and flat and covers most of the anterolateral thigh. Its course is oblique, but appears less so because it is much larger._
4. Explain the differences in terms of differences in function.

   In humans the sartorius adducts and rotates the thigh. In addition to these functions, it also extends the knee in the pig.

5. The human rectus abdominis is definitely divided by four transverse tendons (tendinous intersections). These tendons are absent or difficult to identify in the pig. How do these tendons affect the human upright posture?

   These tendons support the muscular abdominal wall so that the viscera are not allowed to become pendulous in the upright posture of humans.
Dissection of the Spinal Cord and Spinal Nerves of the Fetal Pig

Time Allotment: 11/2 hours.


The Anatomy of the Fetal Pig (CBS: 62 minutes, VHS, DVD)
Fetal Pig (DryLab Plus) (WNS: CD-ROM)

Laboratory Materials

Ordering information is based on a lab size of 24 students, working in groups of 4. A list of supply house addresses appears in Appendix A.

- 6–12 preserved double- or triple-injected fetal pigs
- 6–12 dissection trays
- 6–12 dissection kits with metric rulers
- 6–12 name tags and large plastic storage bags
- Paper towels
- Disposable gloves
- Embalming fluid
- Organic debris container
- Bone cutters
- Bone cutters
- Embalming fluid
- Organic debris container
- Bone cutters

Advance Preparation

1. See Dissection Exercise 1 for setup instructions.
2. Set out bone cutters.

Dissection Review

1. In what region (cervical, thoracic, lumbar, or sacral) of the spinal cord would you find the following special features?

   Enlargements: cervical and lumbar
   Cauda equina: sacral

2. As you trace a spinal nerve laterally, it divides into dorsal and ventral rami (rami/roots).

3. Describe the appearance of the sympathetic trunk as seen in your dissection animal.

   a white cord with periodic enlargements

4. From anterior to posterior, put the nerves issuing from the brachial plexus of the pig in proper order (i.e., the median, radial, and ulnar nerves): radial, median, ulnar

5. Just superior to the fetal pig’s gastrocnemius muscle, the sciatic nerve divides into two main branches, the internal popliteal and the external popliteal nerves.
Identification of Selected Endocrine Organs of the Fetal Pig

Time Allotment: 1/2–1 hour.


The Anatomy of the Fetal Pig (CBS: 62 minutes, VHS, DVD)
Fetal Pig (DryLab Plus) (WNS: CD-ROM)

Laboratory Materials
Ordering information is based on a lab size of 24 students, working in groups of 4. A list of supply house addresses appears in Appendix A.

- 6–12 preserved double- or triple-injected fetal pigs
- 6–12 name tags and large plastic storage bags
- 6–12 dissection trays
- Paper towels
- 6–12 dissection kits with metric rulers
- Disposable gloves
- Embalming fluid
- Organic debris container
- Bone cutters

Advance Preparation
1. See Dissection Exercise 1 for setup instructions.

Comments and Pitfalls
1. It is possible to leave identification of glands in the dissection animal until later dissections.

Dissection Review
1. How do the location of the endocrine organs in the fetal pig compare with those in the human?

They are similar but in the pig the pancreas is more diffuse, the adrenal glands are medial rather than superior to the kidneys, and the thymus is much larger.

2. Name two endocrine organs located in the throat region. thyroid gland _________ and thymus gland _________

3. Name three endocrine organs located in the abdominal cavity.

pancreas, adrenal glands, ovaries in female
4. Given the assumption (not necessarily true) that human beings have more stress than adult pigs, which endocrine organs would you expect to be relatively larger in humans?

*The adrenal glands*

5. Explain why the thymus in the fetal pig is so large, relatively speaking.

*During fetal development, T cells are rapidly dividing and maturing in the thymus gland.*
Dissection of the Blood Vessels and Main Lymphatic Ducts of the Fetal Pig

**Advance Preparation**

1. See Dissection Exercise 1 for setup instructions.

**Comments and Pitfalls**

1. As students dissect out the arteries and veins, caution them to avoid damaging other organs that will be studied in later exercises. *Especially caution them against cutting away the greater omentum.*
2. Students may want to forge ahead and do the entire dissection once the ventral body cavity has been opened. Remind them that the individual systems will be studied in detail at a later date.
3. If time is limited, the circulatory system may be studied in conjunction with the study of individual systems rather than as a separate exercise.
4. If desired by the instructor, a previously dissected animal may be put on demonstration.
5. If the specimen has been injected, frequently the right common carotid artery is damaged; therefore, tracing the common carotid artery to find the external and internal carotid arteries is more easily done by following the left common carotid artery.

**Dissection Review**

1. Is the fetal pig’s lymphatic drainage pattern basically similar or dissimilar to that of humans?

*Similar*
2. What is the role of the following?
   a. the thoracic duct: The thoracic duct drains lymph from the left side of the head, neck, trunk, and left upper extremity, as well as all of the abdomen and both lower extremities into the left subclavian vein.
   b. the right lymphatic duct: The right lymphatic duct drains lymph from the right side of the head, neck, trunk, and right upper extremity into the right subclavian vein.

3. What differences did you observe between the origin of the common carotid arteries in the pig and in the human?
   In the pig, the common carotid arteries may arise from the bicarotid trunk (a branch off the brachiocephalic trunk) or directly from the brachiocephalic artery. In humans, the right common carotid artery arises from the brachiocephalic artery; the left common carotid artery arises directly from the aortic arch.

4. How do the relative sizes of the external and internal jugular veins differ in the human and the pig?
   In the pig, the external jugular vein is larger. In humans, the internal jugular vein is larger.

5. How do the brachial veins of the pig differ from those of humans?
   In the pig, often there are two brachial veins in each forelimb, which anastomose frequently along their course. In humans, the brachial vein is singular.

6. What differences did you note between the origin of the hepatic portal vein in the pig and in humans?
   Pig: from the union of the gastroepiploic and mesenteric veins.
   Humans: from the union of the splenic and superior mesenteric veins.
   Between the origin of the internal and external iliac arteries?
   Pig: external iliac arteries issue directly from the aorta. The internal iliac arteries are branches of the umbilical arteries at the aorta terminus. Humans: the external and internal iliac arteries arise from the division of the common iliac arteries, which are the final aorta branches.

7. Define the following terms.
   ascending aorta: The aorta as it emerges from the heart and travels toward the head.
   aortic arch: The aorta as it bends to travel caudally.
   descending thoracic aorta: The aorta as it passes through the thoracic cavity.
   descending abdominal aorta: The aorta as it passes through the abdominal cavity.
Dissection of the Respiratory System of the Fetal Pig

**Advance Preparation**

1. See Dissection Exercise 1 for setup instructions.
2. Set out dissecting microscopes and small beakers.

**Answers to Activity Questions**

**Activity 1: Identifying Respiratory Organs of the Fetal Pig (pp. 731–734)**

3. The mucosa helps to warm and moisten the air entering the nasal cavity.
8. The segment of fetal lung tissue will sink to the bottom of the beaker of water. Fetal lungs have not yet inflated and the tissue is more dense than water.

**Dissection Review**

1. Are the cartilaginous rings in the pig trachea complete or incomplete? incomplete

2. How does the number of lung lobes in the pig compare with the number in humans?

5 in humans; 7 in the pig.
3. Describe the appearance of lung tissue under the dissection microscope.

*Dense but spongy-looking.*

4. Why did the segment of lung tissue, cut from the fetal pig’s lung, *sink* when placed in water?

*The lungs have never been inflated; therefore the tissue contains essentially no air and is dense. Lungs that have been inflated contain trapped air and will float.*
Dissection of the Digestive System of the Fetal Pig

Time Allotment: 2 hours.


The Anatomy of the Fetal Pig (CBS: 62 minutes, VHS, DVD)
Fetal Pig (DryLab Plus) (WNS: CD-ROM)

Laboratory Materials

Ordering information is based on a lab size of 24 students, working in groups of 4. A list of supply house addresses appears in Appendix A.

- 6–12 preserved double- or triple-injected fetal pigs
- 6–12 dissection trays
- 6–12 dissection kits with metric rulers
- 6–12 name tags and large plastic storage bags
- Paper towels
- Disposable gloves
- Embalming fluid
- Organic debris container
- 6–12 hand lenses
- Bone cutters

Advance Preparation

1. See Dissection Exercise 1 for setup instructions.
2. Set out bone cutters and hand lenses.

Comments and Pitfalls

1. In the pig the large intestine will have a very different arrangement from that of the human.

Answers to Activity Questions

Activity 2: Identifying Digestive Organs in the Abdominal Cavity (pp. 736–738)

3. The stomach is a curved sac.
5. Blood vessels, lymphatics, and nerves are present in the mesenteries. The mesenteries provide a route for vessels and nerves to travel to and from the small intestine. The inner surface of the ileum feels like velvet. The villi in the duodenum are more elongated than those in the ileum.
6. The ileocecal valve prevents regurgitation of material from the cecum into the ileum. The pig does not have an appendix.
Dissection Review

Several differences between pig and human digestive anatomy should have become apparent during the dissection. Note the pertinent differences between the human and the pig relative to the following structures.

<table>
<thead>
<tr>
<th>Structure</th>
<th>Pig</th>
<th>Human</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of liver lobes</td>
<td><em>Five</em></td>
<td><em>Four</em></td>
</tr>
<tr>
<td>Appendix</td>
<td><em>Absent, cecum present</em></td>
<td><em>Present</em></td>
</tr>
<tr>
<td>Appearance and distribution of colon</td>
<td><em>Ascends and then forms a tight coil before descending</em></td>
<td><em>Basically an inverted U with ascending, transverse, and descending portions</em></td>
</tr>
<tr>
<td>Presence of round ligament</td>
<td><em>Absent. Umbilical vein is still present. It later becomes the round ligament.</em></td>
<td><em>Present</em></td>
</tr>
</tbody>
</table>
Dissection of the Urinary System of the Fetal Pig

**Time Allotment:** 1 hour.

**Multimedia Resources:** See Appendix B for Guide to Multimedia Resource Distributors.

*The Anatomy of the Fetal Pig* (CBS: 62 minutes, VHS, DVD)
*Fetal Pig (DryLab Plus)* (WNS: CD-ROM)

### Laboratory Materials

Ordering information is based on a lab size of 24 students, working in groups of 4. A list of supply house addresses appears in Appendix A.

<table>
<thead>
<tr>
<th>6–12 preserved double- or triple-injected fetal pigs</th>
<th>6–12 name tags and large plastic storage bags</th>
<th>Twine or pins</th>
</tr>
</thead>
<tbody>
<tr>
<td>6–12 dissection trays</td>
<td>Paper towels</td>
<td>Embalming fluid</td>
</tr>
<tr>
<td>6–12 dissection kits with metric rulers</td>
<td>Disposable gloves</td>
<td>Organic debris container</td>
</tr>
</tbody>
</table>

### Advance Preparation

1. See Dissection Exercise 1 for setup instructions.

### Comments and Pitfalls

1. Emphasize the importance of clearing away the peritoneum and fat tissue. Once the kidneys have been isolated there should be no difficulty identifying the ureters.
2. Remind the students that they are responsible for knowing both the male and the female urinary systems.
3. This dissection fits nicely with the dissection of the reproductive system.

### Dissection Review

1. How do the structure and connectivity of the urinary bladder of the fetal pig differ from those of the urinary bladder of the human (or the adult pig, for that matter)?

   The fetal urinary bladder is very elongated and continues into the umbilical cord as the allantoic stalk. After birth, it is transformed into the adult urinary bladder, which empties into the urethra.
2. What differences in fetal elimination of nitrogenous wastes account for the structural differences described above?

Fetal elimination of nitrogenous waste occurs through the placenta. (The extraembryonic portion of the allantois forms a part of the placenta.)

3. How does the site of urethral emptying in the female pig differ from its termination point in the human female?

The pig's urethra and vagina empty into a common chamber, the urogenital sinus. The human female's urethra and vagina terminate independently at the body surface.
Dissection of the Reproductive System of the Fetal Pig

**Time Allotment:** 1 1/2–2 hours.

**Multimedia Resources:** See Appendix B for Guide to Multimedia Resource Distributors.

*The Anatomy of the Fetal Pig* (CBS: 62 minutes, VHS, DVD)

*Fetal Pig (DryLab Plus)* (WNS: CD-ROM)

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**Laboratory Materials**

*Ordering information is based on a lab size of 24 students, working in groups of 4. A list of supply house addresses appears in Appendix A.*

- 6–12 preserved double- or triple-injected fetal pigs
- 6–12 dissection trays
- 6–12 dissection kits with metric rulers
- 6–12 name tags and large plastic storage bags
- Paper towels
- Disposable gloves
- Embalming fluid
- Organic debris container

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**Advance Preparation**

1. See Dissection Exercise 1 for setup instructions.
2. Set out metric rulers and bone cutters.

---

**Comments and Pitfalls**

1. Caution students with male dissection animals to be careful when dissecting out the spermatic cord to avoid breaking it.
2. Remind students that they are responsible for doing both male and female dissections.
3. Students must use bone cutters to cut through the pubic region of the pelvis to complete the dissection. It is easiest if the cut is through the pubic symphysis.

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**Answers to Activity Questions**

**Activity 2: Identifying Organs of the Female Reproductive System (pp. 747–748)**

4. The human female has separate openings for the vagina and the urethra.
6. The vagina is twenty to thirty millimeters long (will vary).
Dissection Review

1. The female pig has a **bipartite** uterus; that of the human female is **simplex**. Explain the difference in structure of these two uterine types.

   *Pig: Y-shaped central chamber (body) from which two horns (cornua) extend. Human: undivided pear-shaped chamber.*

2. What reproductive advantage is conferred by the pig’s uterine type?

   *Can produce litters.*

3. Cite the differences between the pig and the human relative to the following structures:

   - **Uterine tubes or oviducts**: *They are very tiny and relatively much shorter in the pig.*
   - **Urethral and vaginal openings in the female**: *In the pig, both open into a common chamber, the urogenital sinus.* *In humans, both structures empty independently to the body exterior.*
Dissection and Identification of Rat Muscles

**Time Allotment:** Skin removal: 1 hour. Muscle dissection: 4–6 hours+ (depending on detail required).

**Multimedia Resources:** See Appendix B for Guide to Multimedia Resource Distributors.  
*Dissection and Anatomy of the Rat* (CBS: 31 minutes, VHS, DVD)  
*Rat Dissection* (WNS: 30 minutes, VHS, DVD)

**Laboratory Materials**

(Ordering information is based on a lab size of 24 students, working in groups of 4. A list of supply house addresses appears in Appendix A.)

- Disposable gloves
- 24 pairs of safety glasses
- 6–12 dissection kits and trays
- 6–12 preserved and latex-injected rats
- 6–12 name tags and plastic storage bags
- Paper towels
- Organic debris container

**Advance Preparation**

1. Order rats well in advance.
2. Make arrangements for appropriate storage, disposal, and cleanup of dissection materials. Check with the Department of Health or the Department of Environmental Protection, or their counterparts, for state regulations. Designate a disposal container for organic debris, set up a dishwashing area with hot soapy water and sponges, and provide lab disinfectant such as Wavicide-01 (Carolina) or 10% bleach solution for washing down the lab benches.
3. Set out disposable gloves, safety glasses, dissecting instruments, dissection tray, plastic storage bags, paper towels, and name tags.
4. Set out dissection animals (one per student or per group).

**Comments and Pitfalls**

1. Be sure that students understand that the skin is to be removed in one piece.
2. Emphasize the use of the blunt probe as a dissecting instrument, rather than the scalpel. Cut only when everyone in the group agrees that a cut should be made!
4. Students often “invent” muscles by tearing tissue apart. Emphasize that they should be separating muscles by breaking through the surrounding connective tissue.
5. Sometimes the dissection animal is in very poor condition, in which case the student should exchange it for a different specimen.
To prevent damage to muscles during skinning, separate skin from underlying tissues by inserting a blunt probe into the skin incision in the neck. Continue to use the probe to separate skin from underlying tissues before cutting the skin.

Answers to Activity Questions

Activity 3: Dissecting Head, Neck, and Trunk Muscles

Head and Neck Muscles (pp. 699–700)

4. Sternocleidomastoid

Thoracic and Abdominal Muscles (pp. 701–702)

1. Pectoralis major and pectoralis minor, respectively

Both muscles in the rat originate at the sternum and insert on the proximal humerus. The pectoralis major in humans originates on the clavicle, sternum, the cartilages of ribs 1–6, and the aponeurosis of the external oblique muscle. It inserts after the muscle fibers have converged to a short tendon into the intertubercular sulcus of the humerus. The pectoralis minor originates on the anterior surface of ribs 3–5, near their costal cartilages, and inserts on the coracoid process of the scapula.

3. A single deltoid muscle

Muscles of the Abdominal Wall (p. 702)

Rectus abdominis

Activity 4: Dissecting Forelimb Muscles (pp. 703–704)

1. Biceps brachii

Activity 5: Dissecting Hindlimb Muscles (pp. 705–707)

3. The gracilis in the human is a single, narrow muscle.

The semimembranosus muscle in the rat originates from the ischium, sacrum, and first caudal vertebrae, inserts on the medial surface of the tibia, and extends the hindleg. The same muscle in humans originates on the ischial tuberosity, inserts on the medial condyle of the tibia and the lateral condyle of the femur, and extends the thigh, flexes the knee, and medially rotates the leg.

5. Rectus femoris, vastus lateralis, vastus medialis, vastus intermedius

The extension of the gluteus superficialis in rats is called the tensor fasciae latae in humans; the gracilis in humans is a single muscle; and humans have muscles identified as the sartorius and vastus intermedius, which are not found in rats.

Dissection Review

1. What muscles are single muscles in one species and more than one in the other (rat and human)?
2. What is the difference in range of motion of the deltoid muscles in rats and humans?

Both deltoid muscles in the rat flex and rotate the humerus medially, while in humans, the deltoid muscle is the prime mover of arm abduction. Using specific fibers, the human muscle can aid in flexion, extension, and rotation of the humerus.

3. What is the difference in function of the pectoralis muscles in rats and humans?

Both pectoralis muscles in the rat adduct the forelimb. The pectoralis major muscle in humans is a prime mover of arm flexion; it adducts and medially rotates the arm. With the arm fixed, it pulls the chest upward. The pectoralis minor in humans draws the scapula forward and inferiorly with the ribs fixed. With the scapula fixed, it draws the rib cage superiorly.

4. The human rectus abdominis is divided by four transverse tendons (tendinous intersections). These tendons are absent or difficult to identify in the rat. How do these tendons affect human upright posture?

These tendons support the abdominal muscular wall so that the viscera are not allowed to become pendulous in the upright position of humans.
Identification of Selected Endocrine Organs of the Rat

Time Allotment: 1 hour.


Dissection and Anatomy of the Rat (CBS: 31 minutes, VHS, DVD)

Rat Dissection (WNS: 30 minutes, VHS, DVD)

Laboratory Materials
Ordering information is based on a lab size of 24 students, working in groups of 4. A list of supply house addresses appears in Appendix A.

- Disposable gloves
- 24 pairs of safety glasses
- 6–12 dissection kits and trays
- 6–12 magnifying glasses or dissecting microscopes
- 6–12 name tags and plastic storage bags
- 6–12 preserved rats
- Paper towels
- Organic debris container

Advance Preparation
1. See Dissection Exercise 1 for setup instructions.
2. If rats were not skinned previously, see instructions in Dissection Exercise 1. Allow extra time for skinnning.
3. The thymus gland is very large, sometimes extending from the superior trachea onto the heart.

Comments and Pitfalls
1. It is possible to leave identification of glands in the dissection animal until later dissections.

Answers to Activity Questions
Activity 2: Identifying Selected Endocrine Glands (pp. 711–713)

Thyroid and Parathyroid Glands

Adam’s apple
Dissection Review

1. How do the locations of the endocrine organs in the rat compare with those in the human?

   *The thymus is larger in the rat, with a portion that descends into the thorax and covers the cranial area of the heart.*

   *The adrenal glands in the rat are found cranially to the kidneys in the abdominal cavity, while in the human, they are attached to the cranial end of the kidneys. The pancreas in the rat extends farther into the middle of the abdominal cavity than it does in humans. The thyroid gland and gonads are found in the same locations in both species.*

2. How many parathyroid glands are found in humans? *Most commonly four, arranged in two pairs.*

3. Compare the relative size of the thymus in rats and humans. Does the difference indicate anything about the species’ immune systems?

   *The thymus in rats is relatively larger. It may allow the species to have a more active immune system, protecting them from a very large variety of microorganisms.*

4. Which hormones aid in regulating blood calcium levels? Where are they made?

   *Parathyroid hormone (PTH) is made in the parathyroid glands and aids in elevating blood calcium levels. Calcitonin is made in the thyroid gland in cells between the follicles called C cells. Calcitonin aids in lowering blood calcium levels.*

5. Which of the three organs discussed have both exocrine and endocrine functions?

   *The pancreas, testes, and ovaries.*

6. Fill in the following table:

<table>
<thead>
<tr>
<th>Gland</th>
<th>Location</th>
<th>Hormone(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thyroid</td>
<td>neck, cranial to the thyroid cartilage of the larynx</td>
<td>$T_3/T_4$, calcitonin</td>
</tr>
<tr>
<td>Parathyroid</td>
<td>on the posterior aspect of the thyroid gland’s “wings”</td>
<td>parathyroid hormone (PTH)</td>
</tr>
<tr>
<td>Thymus</td>
<td>ventral aspect of throat, covers trachea and neck muscles, portion descends to area of heart</td>
<td>thymosins, thyopoietins, thymulin</td>
</tr>
<tr>
<td>Pancreas</td>
<td>caudal to the liver, in the area of the stomach and duodenum</td>
<td>insulin, glucagon, small amounts of other peptides</td>
</tr>
<tr>
<td>Adrenal</td>
<td>cranial to the kidneys, closer to the midline and the descending, abdominal aorta</td>
<td>Cortex: mineralocorticoids (aldosterone), glucocorticoids (cortisol and others), gonadocorticoids (androgens) Medulla: epinephrine, norepinephrine</td>
</tr>
<tr>
<td>Cortex</td>
<td>outer portion of gland</td>
<td>mineralocorticoids (aldosterone), glucocorticoids (cortisol and others), gonadocorticoids (androgens)</td>
</tr>
<tr>
<td>Medulla</td>
<td>middle portion of gland</td>
<td>epinephrine, norepinephrine</td>
</tr>
<tr>
<td>Ovaries</td>
<td>slightly caudal and lateral to the kidneys, on each side of the cavity at the distal end of the uterine horn</td>
<td>estrogen, progesterone</td>
</tr>
<tr>
<td>Testes</td>
<td>below the pubic area, in the scrotum</td>
<td>testosterone</td>
</tr>
</tbody>
</table>
Dissection of the Blood Vessels of the Rat

**Time Allotment:** 2–2 1/2 hours (depending on detail required in dissection).

**Multimedia Resources:** See Appendix B for Guide to Multimedia Resource Distributors.
- *Dissection and Anatomy of the Rat* (CBS: 31 minutes, VHS, DVD)
- *Rat Dissection* (WNS: 30 minutes, VHS, DVD)

**Laboratory Materials**

*Ordering information is based on a lab size of 24 students, working in groups of 4. A list of supply house addresses appears in Appendix A.*

<table>
<thead>
<tr>
<th>Disposable gloves</th>
<th>6–12 hand lenses or dissecting microscopes</th>
<th>6–12 name tags and plastic storage bags</th>
</tr>
</thead>
<tbody>
<tr>
<td>24 pairs of safety glasses</td>
<td>6–12 preserved and latex-injected rats</td>
<td>Paper towels</td>
</tr>
<tr>
<td>6–12 dissection kits and trays</td>
<td></td>
<td>Organic debris container</td>
</tr>
</tbody>
</table>

**Advance Preparation**

1. See Dissection Exercise 1 for setup instructions.
2. If rats were not skinned previously, see instructions in Dissection Exercise 1. Allow extra time for skinning. Allow 1/2 hour to skin 1 forelimb and 1 hindlimb.

**Comments and Pitfalls**

1. As students dissect out the arteries and veins, caution them to avoid damaging other organs that will be studied in later exercises.
2. Students may want to forge ahead and do the entire dissection once the ventral body cavity has been opened. Remind them that the individual systems will be studied in detail at a later date.
3. If time is limited, the circulatory system may be studied in conjunction with the study of individual systems rather than as a separate exercise.
4. If desired by the instructor, a previously dissected animal may be put on demonstration.
5. If the specimen has been injected, frequently the right common carotid artery is damaged; therefore, tracing the common carotid artery is more easily done by following the left common carotid artery.

**Answers to Activity Questions**

**Activity 1: Dissecting the Heart and Major Blood Vessels Related to the Heart (pp. 715–717)**

2. Left ventricle

**Activity 3: Dissecting Blood Vessels Cranial to the Heart (p. 717)**

3. In both humans and rats: subclavian artery/vein to axillary artery/vein to brachial artery and basilica vein.
Dissection Review

1. Which major blood vessels attached to the heart carry oxygen-rich blood?
   
   Pulmonary veins and aorta.

2. What differences did you observe between the origin of the common carotid arteries in the rat and in the human?
   
   The common carotid arteries originate from the same vessels in both humans and rats. The right common carotid originates from the brachiocephalic trunk and the left common carotid is the second branch off the aorta.

3. How does the venous drainage from the head and neck to the heart differ between humans and rats?
   
   Rats have two cranial venae cavae draining the right and left sides of the head and forelimbs, while humans have a single superior vena cava draining the head and upper limbs.

4. How do the relative sizes of the external and internal jugular veins differ in the human and the rat?
   
   In humans, the internal jugular vein is larger than the external jugular, while in rats, the reverse is the case.

5. What characteristic of the hepatic portal system is unique in the body?
   
   The hepatic portal system has two venous components, one draining the digestive tract leading to the liver and the second draining the liver and connecting to the caudal or inferior vena cava.

6. Define the following terms:

   ascending aorta: the aorta as it leaves the heart and ascends cranially

   aortic arch: curvature of the aorta at the end of the ascending portion, resulting in the artery leading blood 180° caudally

   descending thoracic aorta: that portion of the aorta passing through the thorax

   descending abdominal aorta: that portion of the aorta passing through the abdomen
Time Allotment: 1 hour.


Dissection and Anatomy of the Rat (CBS: 31 minutes, VHS, DVD)
Rat Dissection (WNS: 30 minutes, VHS, DVD)

Laboratory Materials

 Ordering information is based on a lab size of 24 students, working in groups of 4. A list of supply house addresses appears in Appendix A.

Disposable gloves  6–12 magnifying glasses or dissecting microscopes  6–12 name tags and plastic storage bags  6–12 preserved rats
24 pairs of safety glasses  Paper towels
6–12 dissection kits and trays  Organic debris container

Advance Preparation

1. See Dissection Exercise 1 for setup instructions.
2. If rats were not skinned previously, see instructions in Dissection Exercise 1. Allow extra time for skinning.
3. Set out dissecting microscopes.

Answers to Activity Questions

Activity 1: Identifying Cranial Respiratory Structures (pp. 723–725)

2. Animals such as birds have a choana, which is a median fissure in the palate that connects the oropharynx to the nasal cavity. This does not allow swallowed material to enter the nasal cavity.

Activity 2: Identifying Caudal Respiratory Structures (pp. 725–726)

3. The lungs in the rat are divided into five lobes, with four lobes on the right side and one on the left. Humans also have five lobes, but with three on the right and two on the left.
Dissection Review

1. What happens when we try to talk and swallow at the same time? Why?

   *Air coming past the epiglottis causes it to rise and swallowed material tends to enter the larynx and “go down the*  
   *wrong tube.” The larynx and the trachea contain cartilage structures that maintain them open, making it easier for*  
   *food and liquid to enter them, instead of the esophagus, which is closed.*

2. What additional cartilages are found in the human larynx that are not found in the rat?

   *Corniculate and cuneiform cartilages*

3. Why is it important that the trachea be maintained open?

   *Any constriction of the trachea or bronchial tree will restrict the amount of air that can be passed through the*  
   *passageways.*

4. Why do humans not have a postcaval or accessory lobe? *The heart is contained in that space in humans.*

5. What is the advantage of having a diaphragm?

   *The diaphragm seals off the thorax from the abdominal cavity, allowing the lungs to expand. As the diaphragm con-stricts, it allows air to be taken in, without using intercostal muscles to inhale.*

6. Describe the appearance of lung tissue under the dissection microscope.

   *Spongy-looking with small, irregular openings.*
Time Allotment: 1–1 1/2 hours.


Dissection and Anatomy of the Rat (CBS: 31 minutes, VHS, DVD)
Rat Dissection (WNS: 30 minutes, VHS, DVD)

Laboratory Materials

Ordering information is based on a lab size of 24 students, working in groups of 4. A list of supply house addresses appears in Appendix A.

| Disposable gloves | 6–12 rat specimens from previous dissections | Paper towels |
| 24 pairs of safety glasses | 6–12 name tags and plastic storage bags | Organic debris container |
| 6–12 dissection kits and trays | 6–12 hand lenses or dissecting microscopes |

Advance Preparation

1. See Dissection Exercise 1 for setup instructions.
2. Set out water bottles for flushing the intestines, and hand lenses or dissecting microscopes.

Comments and Pitfalls

1. In the rat, the large intestine will have a very different arrangement from that in the human.

Answers to Activity Questions

Activity 1: Identifying Digestive Components of the Head and Neck (pp. 729–730)

2. \( \frac{2,1,2,3}{2,1,2,3} \times 2 \)

4. The soft palate closes off access to the nasal cavity, preventing material from entering it during swallowing.

Activity 2: Identifying Digestive Components of the Abdomen (p. 732)

1. They appear as folds of the stomach lining.
5. Cecum, vermiform appendix, colon (ascending, transverse, descending, and sigmoid), rectum, and anal canal
Dissection Review

1. How do the variety of teeth in rats and humans reflect their diets?

Rats and humans are omnivores; they eat both plant and animal material. Sharp incisors and, in humans, pointed canines allow biting and removal of material. Molars and premolars, also in humans, are used to grind the food.

2. How do the papillae of the tongue differ between rats and humans?

Rats have a single circumvallate papilla in the central, most posterior portion of the tongue, while humans have an inverted V-shaped line of circumvallate papillae in the same region. The filiform papillae cells of rats are keratinized and angle posteriorly. The fungiform papillae of rats tend to be found between the molars in the mouth, while they cover the entire surface of the tongue in humans.

3. The liver in humans also has four lobes. What are their names? Right, left, caudate, and quadrate
Dissection of the Urinary System of the Rat

Time Allotment: 1–1½ hours.


Dissection and Anatomy of the Rat (CBS: 31 minutes, VHS, DVD)
Rat Dissection (WNS: 30 minutes, VHS, DVD)

Laboratory Materials

Ordering information is based on a lab size of 24 students, working in groups of 4. A list of supply house addresses appears in Appendix A.

- Disposable gloves
- 24 pairs of safety glasses
- Lab coat or apron
- 6–12 dissection kits and trays
- 6–12 magnifying glasses or dissecting microscopes
- 6–12 preserved rats
- 6–12 name tags and plastic storage bags
- Paper towels
- Organic debris container

Advance Preparation

1. See Dissection Exercise 1 for setup instructions.

Comments and Pitfalls

1. Emphasize the importance of clearing away the peritoneum and fat tissue. Once the kidneys have been isolated there should be no difficulty identifying the ureters.
2. Remind the students that they are responsible for knowing both the male and the female urinary systems.
3. This dissection fits nicely with the dissection of the reproductive system.

Answers to Activity Questions

Activity 1: Dissecting the Kidney of the Rat (p. 735)

The renal cortex is thinner than the medulla, with a denser consistency. Blood vessels can be seen running along the border between the cortex and medulla. The medulla contains inverted, blunted pyramids that empty into funnel-like structures called calyces.

Dissection Review

1. What is the difference between the fluid filtered in the kidney and in the urine?

\[ \text{Urine is a concentrated form of the filtrate, with needed material and water removed.} \]
2. What are some major functions of the urinary system?

Remove nitrogenous wastes, maintain water, electrolyte, and acid-base balances, and contribute to the control of blood pressure.

3. What is the function of the layers of fat surrounding the kidney? Cushioning to prevent damage to the kidneys.

4. What two anatomical adaptations are present in the bladder to facilitate expansion?

Folds in the bladder wall and an easily stretched lining, transitional epithelium, allow for expansion during filling.

5. How does the site of urethral emptying in the female rat differ from its termination point in the human female?

The termination points do not differ between the species. Both empty to the exterior and do not join with the vagina, as they do in other species.
Dissection of the Reproductive System of the Rat

Time Allotment: 1½–2 hours.

Dissection and Anatomy of the Rat (CBS: 31 minutes, VHS, DVD)
Rat Dissection (WNS: 30 minutes, VHS, DVD)

Laboratory Materials
Ordering information is based on a lab size of 24 students, working in groups of 4. A list of supply house addresses appears in Appendix A.

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</table>

Advance Preparation
1. See Dissection Exercise 1 for setup instructions.

Comments and Pitfalls
1. Students usually encounter some difficulty dissecting out the penis. It takes time, as the overlying skin is tightly attached in some places.
2. Caution students with male dissection animals to be careful when dissecting out the spermatic cord to avoid breaking it.
3. Remind students that they are responsible for information from both male and female dissections.
4. Students must cut through the pubic region of the pelvis to complete the dissection. It is easiest if the cut is through the pubic symphysis.

Answers to Activity Questions
Activity 1: Identifying Organs of the Male Reproductive System of the Rat (pp. 739–741)
1. Spermatogenesis requires temperatures lower than body temperature.
3. Testes, seminal vesicles, coagulating glands, prostate
1. The cortex of the ovary has cuboidal epithelial cells on its surface, called the germinal epithelium. The layers include dense connective tissue called the tunica albuginea and follicles, each containing an immature egg.

3. The urethra in the female rat passes through the clitoris. In humans, the clitoris is anterior to the urethra and hooded by skin folds of the anterior labia minora.

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**Dissection Review**

1. What is found in the spermatic cord? *Vas deferens, spermatic artery and vein, lymphatics, and several nerves.*

2. What is the difference between human and rat prostate structure?

   *The prostate gland in the rat is composed of two parts that fuse and encircle the urethra, while in humans, the prostate is a single gland.*

3. How do eggs enter the uterine tubes of humans?

   *Ovulated eggs, actually secondary oocytes, are cast into the peritoneal cavity. Some enter the fallopian tubes, some are lost.*

4. How does the rat’s uterus facilitate multiple births?

   *The uterus of a rat is shaped like a capital Y (bipartite or bicornuate), but with elongated arms. Two separate tubes or horns of the organ extend from the short fallopian tubes to the uterine body in the mid-ventral area of the pelvic region. Each tube is capable of carrying multiple offspring, enabling the rat to have a litter with each pregnancy.*
Time Allotment: 2 hours minimum, 3 hours preferred.

Your computer should meet the following minimum requirements for PhysioEx™ 8.0:

**WINDOWS**
- OS: Windows® XP, Vista™
- Resolution: 1024 × 768
- Latest version of Adobe® Flash® Player
- Latest version of Adobe Reader®
- Browsers: Internet Explorer 6.0 (XP only); Internet Explorer 7.0; Firefox 2.0
- Internet Connection: 56K modem minimum for website
- Printer

**MACINTOSH**
- OS: 10.3.x, 10.4.x
- Resolution: 1024 × 768
- Latest version of Adobe Flash Player
- Latest version of Adobe Reader
- Browsers: Safari 1.3 (10.3.x only); Safari 2.0 (10.4.x only); Firefox 2.0
- Internet Connection: 56K modem minimum for website
- Printer

**Advance Preparation, Comments, and Pitfalls**

1. *If you are using PhysioEx in a computer lab:* Because PhysioEx requires a browser (such as Firefox or Internet Explorer) and the Flash Player to run, it is recommended that you make sure these items are already installed on student computers before beginning this lab.

2. *If you are using the web version of PhysioEx:* Have your students go to http://www.myaandp.com and follow the registration instructions found in the very front of their lab manual.

3. It is helpful to instruct students in the proper operation of the mouse and menu system as part of the lab introduction.

4. When considering an upgrade for computer systems, memory (RAM) offers the largest performance increase for the least cost.

5. Having students work in pairs results in the most successful lab experience. If students must work in larger groups, have them each get keyboard and mouse experience with the program.

6. Occasionally, data in the Cell Transport Mechanisms and Permeability module will appear with “#” symbols next to numbers. In the Simple Diffusion, Facilitated Diffusion, and Osmosis experiments, the “#” symbol after “rate” data indicates that equilibrium was not reached for that solute. In the Active Transport experiment, the symbol after “rate” data indicates (1) for glucose data, that equilibrium was not reached for glucose; (2) for NaCl and KCl, that transport was interrupted for that solute. In the Osmosis experiment, the symbol after “pressure” data means that osmotic equilibrium was not reached.
Answers to Activity Questions

Activity 1: Simulating Dialysis (Simple Diffusion) (pp. PEx-6–8)

9. All solutes except albumin are able to diffuse into the right beaker.

   Using distilled water in the right beaker and either the 100 MWCO or 200 MWCO membrane will
   remove urea from the left beaker and leave albumin

   If the left beaker contains NaCl, urea, and albumin, you can selectively remove urea by dispensing a con-
   ception of NaCl into the right beaker equivalent to that in the left beaker and by using the 100 or 200
   MWCO membrane. Albumin is too large to diffuse and there will be no net diffusion of NaCl. However,
   urea will move down its concentration gradient into the right beaker.

Activity 2: Simulating Facilitated Diffusion (pp. PEx-8–9)

11. Carrier proteins facilitate the movement of solute molecules across semipermeable membranes, so
   increasing their number will increase the rate of diffusion.

   Because facilitated diffusion requires a concentration gradient, making the concentration on both sides of
   the membrane equal stops net diffusion.

NaCl does not have an effect on glucose diffusion.

Activity 3: Simulating Osmotic Pressure (pp. PEx-10–11)

6. Using the 20 MWCO membrane results in an osmotic pressure increase using any of the solutes. The 50
   and 100 MWCO membranes caused osmotic pressure increase with albumin and glucose. Only albumin
   caused osmotic pressure increase using the 200 MWCO membrane.

   NaCl appeared in the right beaker with all membranes except the 20 MWCO membrane.

8. Increasing the number of non-diffusible particles increases osmotic pressure.

   If solutes are able to diffuse, then equilibrium will be established and osmotic pressure will not be gener-
   ated.

   Osmotic pressure would be zero if albumin concentration was the same on both sides of the membrane.

   If you increased (or doubled) the concentration of albumin, osmotic pressure will increase (or double).

   Glucose is freely diffusible using the 200 MWCO membrane and therefore has no effect on osmotic pres-
   sure.

   The 100 MWCO membrane does not allow glucose to pass and therefore glucose will generate an osmotic
   influence. Because albumin concentration in the left beaker is 9.00 mM and glucose concentration in the
   right beaker is 10.00 mM (1.00 mM higher than the left), the small gradient dictates that an osmotic pres-
   sure increase will appear in the right beaker.

Activity 4: Simulating Filtration (pp. PEx-11–13)

9. Smaller MWCO numbers translate to smaller pore sizes, which correlate with lower filtration rate.

   Powdered charcoal did not appear in the filtrate using any membrane.

   Increasing the force driving filtration increases filtration rate.

   Increasing the pressure gradient effectively increases the filtration rate.

   By examining the filtration results, we can predict that the molecular weight of glucose must be greater
   than NaCl but less than powdered charcoal.

Activity 5: Simulating Active Transport (pp. PEx-14–15)

7. Solute transport stops before the completion of transport because of a lack of ATP.

   Sodium and potassium transport will not occur if ATP is not available.

8. Yes, transport has changed because more ATP is available. This fact supports the earlier supposition that
   ATP is required for active transport.

   The rate of active transport will decrease if fewer solute pumps are available, but will still go to comple-
   tion given enough ATP and time.
You can show that this is an active process by making the sodium concentration in the right beaker greater than the sodium concentration in the left beaker. Transport will occur against the concentration gradient in active transport but not in diffusion.

9. Sodium transport is not affected by putting NaCl into the right beaker.
   Increasing the number of pump proteins will increase solute transport.
   Glucose presence does not affect active transport.
Cell Transport Mechanisms and Permeability: Computer Simulation

Simple Diffusion
1. The following refer to Activity 1: Simulating Dialysis (Simple Diffusion).

Which solute(s) were able to pass through the 20 MWCO membrane?

None

According to your results, which solute had the highest molecular weight? Albumin

Which solute displayed the highest rate of diffusion through the 200 MWCO membrane? NaCl

Using the data from Chart 1, explain the relationship between the rate of diffusion and the size of the solute.

The smaller the solute particle the greater the rate of diffusion.

Facilitated Diffusion
2. The following refer to Activity 2: Simulating Facilitated Diffusion.

Did any of the substances travel against their concentration gradient? Explain why or why not.

No; in facilitated diffusion, a passive process, substances can move only down their concentration gradient.

Using your results from Chart 2, what was the fastest rate of facilitated diffusion recorded? 0.0038. Describe the conditions that were used to achieve this rate.

8mM glucose with 900 glucose carriers in the membrane

Name two ways to increase the rate of glucose transport. Increase amount of glucose in solution; increase number of glucose carriers in the membrane

Did NaCl affect glucose transport? No

Did NaCl require a transport protein for diffusion? Why or why not? No; because of its small size, NaCl is able to diffuse down its concentration gradient without the aid of carriers.
Osmotic Pressure

3. The following refer to Activity 3: Simulating Osmotic Pressure.

For NaCl, which MWCO membrane(s) provided for the net movement of water without movement of NaCl?

20 MWCO

Explain how you determined this. (Hint: Correlate your results to the data in Chart 3.) **Buildup of osmotic pressure due to the presence of non-diffusible NaCl in the solution causes water to diffuse down its concentration gradient.**

For glucose, which MWCO membrane(s) provided for the net movement of glucose without net movement of water?

200 MWCO

Explain how you determined this. **There was no buildup of osmotic pressure, which indicates that glucose is able to diffuse down its concentration gradient.**

Is osmotic pressure generated if solutes diffuse freely? **No**

Explain how the solute concentration affects osmotic pressure. **The higher the solute concentration, the higher the osmotic pressure.**

Filtration

4. The following refer to Activity 4: Simulating Filtration.

Using your results in Chart 4, which MWCO membrane had the greatest filtration rate?

200 MWCO

Explain the relationship between pore size and filtration rate. **The larger the pore size, the greater the filtration rate.**

Which solute did not appear in the filtrate using any of the membranes? **Powdered charcoal**

What is your prediction of the molecular weight of glucose compared to the other solutes in the solution? **The filtration rate of glucose is less than that of NaCl and urea, so its molecular weight would be greater.**

What happened when you increased the driving pressure? **The filtration rate increases.**

Explain why fluid flows from the capillaries of the kidneys into the kidney tubules. **Pressure is higher in capillaries than in kidney tubules so particles that are small enough are filtered from capillaries into kidney tubules.**

How do you think a decrease in blood pressure would affect filtration in the kidneys? **The rate of filtration would decrease.**
5. The following refer to Activity 5: Simulating Active Transport.

With 1 mM ATP added to the cell interior (left beaker) and the extracellular space (right beaker), was all of the Na\(^+\) moved into the extracellular space? Why or why not? _No; ATP was depleted at 3 minutes._

Describe the effect of decreasing the number of sodium-potassium pumps. _The rate of active transport decreases._

Describe how you were able to show that the movement of sodium was due to active transport. _Sodium moved from the left beaker into the right beaker against its concentration gradient; there was no movement of sodium when there were no Na\(^+\)/K\(^+\) pumps added to the membrane._
Skeletal Muscle Physiology

Time Allotment: 2–2½ hours minimum if students are well-prepared, 3 hours preferred.

Your computer should meet the following minimum requirements for PhysioEx™ 8.0:

**WINDOWS**
- OS: Windows XP, Vista
- Resolution: 1024 × 768
- Latest version of Adobe Flash Player
- Latest version of Adobe Reader
- Browsers: Internet Explorer 6.0 (XP only); Internet Explorer 7.0; Firefox 2.0
- Internet Connection: 56K modem minimum for website
- Printer

**MACINTOSH**
- OS: 10.3.x, 10.4.x
- Resolution: 1024 × 768
- Latest version of Adobe Flash Player
- Latest version of Adobe Reader
- Browsers: Safari 1.3 (10.3.x only); Safari 2.0 (10.4.x only); Firefox 2.0
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Advance Preparation, Comments, and Pitfalls

1. *If you are using PhysioEx in a computer lab.* Because PhysioEx requires a browser (such as Firefox or Internet Explorer) and the Flash Player to run, it is recommended that you make sure these items are already installed on student computers before beginning this lab.

2. *If you are using the web version of PhysioEx.* Have your students go to http://www.myaandp.com and follow the registration instructions found in the very front of their lab manual.

3. It is helpful to instruct students in the proper operation of the mouse and menu system as part of the lab introduction.

4. When considering an upgrade for computer systems, memory (RAM) offers the largest performance increase for the least cost.

5. Having students work in pairs results in the most successful lab experience. If students must work in larger groups, have them each get keyboard and mouse experience with the program. If students have a home computer, or access to a computer on campus, they can become familiar with the general operation of the simulations before coming to class.

6. Prior to the lab, suggest to the students that they become familiar with the exercise before coming to class. If students have a home computer, or access to a computer on campus, they can become familiar with the general operation of the simulations before coming to class.

7. You might do a short introductory presentation with the following elements:
   a. Describe the basics of muscle contraction at the cellular level, focusing on the sarcomere. This explanation is especially important for the isometric part of the simulation.
   b. Students often have problems distinguishing between *in vivo* stimulation via the nervous system versus the electrical stimulation we apply to whole skeletal muscle in an experiment. Mention that increasing the intensity of an electrical stimulus to the surface of whole muscle is not the same as stimulation via the nervous system, but that the outcome of increased force production is similar in both methods.
Answers to Activity Questions

Electrical Stimulation

Activity 2: Determining the Latent Period (p. PEx-26)
4. The latent period should be approximately 2.78 msec.
   The muscle cell is biochemically preparing for contraction, including events such as the release of calcium from the sarcoplasmic reticulum, and the movement of the chemicals of contraction within the cell; includes all biochemical events beginning with acetylcholine binding to the sarcolemma through the beginning of cross-bridge binding.

Activity 3: Investigating Graded Muscle Response to Increased Stimulus Intensity (p. PEx-26)
7. The minimal stimulus is about 0.8 volt.
   The maximal stimulus can be estimated at approximately 8.0 volts. However, if you look carefully at the force measurements recorded in the data grid, you will see that force increases until 8.2 volts is achieved.
   As more voltage is delivered to the whole muscle, more muscle fibers are activated and total force produced by muscle is increased.

Multiple Stimulus

Activity 4: Investigating Treppe (pp. PEx-26–27)
4. As long as stimuli are delivered relatively close together, the active force produced by subsequent stimuli slightly increases for the first few stimuli.

Activity 5: Investigating Wave Summation (pp. PEx-27–28)
4. The peak force produced in the second contraction is greater than that produced by the first stimulus.
5. The total force production is even greater when stimuli are delivered more rapidly.
6. Decrease voltage
   1.7–2.5 volts (depends on the rapidity of clicking)
7. The greater frequency of stimulation results in a greater force generated.

Activity 6: Investigating Fusion Frequency/Tetanus (pp. PEx-28–29)
4. The force rises and falls at 30 stimuli/sec.
5. As the stimulation rate is increased, the active force produced by the muscle also increases. Additionally, the force tracing becomes smoother (smaller peaks).
7. The stimulus rate above which there appears to be no significant increase in force is at approximately 120 stimuli/sec.
10. Smooth, sustained force at 2 gms can be produced at approximately 1.2 volts and 120 stimuli/sec.
    Smooth, sustained force at 3 gms can be produced at approximately 1.6 volts and 120 stimuli/sec.
    Increasing the stimulation rate causes smoother force production. Lowering the voltage (intensity) decreases the total force produced. Manipulating both allows the muscle to produce smooth force at any desired level. For example, increasing the stimulus rate while decreasing the voltage allowed the muscle to produce smooth force at a level of 2 gms.
Activity 7: Investigating Muscle Fatigue (p. PEx-29)

4. The muscle force decreases because the muscle is consuming ATP faster than it is being produced.
6. When the stimulator is turned off the muscle is able to “catch up” a little with ATP production.
7. The second tracing shows faster fatigue than the tracing in which the stimulator was turned on and off.

Isometric Contraction

Activity 8: Investigating Isometric Contraction (pp. PEx-30–31)

7. As the muscle length is increased from 50 mm to 100 mm, the passive force is initially zero and then, at approximately 84 mm, begins to sharply rise.
   As the muscle length is increased from 50 mm to 100 mm, the active force increases steadily until a muscle length of 75 mm and then begins to fall with increasing muscle length.
   As the muscle length is increased from 50 mm to 100 mm, the total force initially rises, then, at a muscle length of 76 mm, begins to fall, and finally, at a muscle length of 94 mm, rises again producing a dip in the curve.

Because the total force curve is the result of the numerical sum of the active and passive force data points, we see a rise on the left side of the total force due to the rise in the active force. Note that the passive force has no influence in the rise on the left side. The total force curve begins to fall because the active force falls. However, the total force does not fall as fast as the active force because the passive force is simultaneously rising. Finally, the sharp increase at the right side of the total force curve is almost entirely due to the passive force.

Isotonic Contraction

Activity 9: Investigating the Effect of Load on Skeletal Muscle (pp. PEx-31–32)

5. During the flat part of the tracing, the muscle rises from the surface of the platform and then descends again.
   The force production does not change during the flat part of the tracing (the tracing is flat!); it stays the same.
6. 1.5g
   0.45 mm/sec
7. 1.0g
   1.34 mm/sec
   2.0g
   0.00 mm/sec
9. The greater the resistance (weight), the shorter the initial velocity of shortening.
15. As the starting length of the muscle is increased from 60 mm to 90 mm, the initial velocity of shortening first increases (to a muscle length of 75 mm) and then decreases.
Skeletal Muscle Physiology

Electrical Stimulation

1. Name each phase of a typical muscle twitch, and, on the following line, describe what is happening in each phase.
   a. latent period
      
      The muscle cells are biochemically preparing to contract, includes all biochemical events from acetylcholine binding to sarcolemma through cross-bridge formation.
   
   b. contraction phase
      
      Sarcomeres are shortening, causing the muscle cells to contract in turn, which causes a force increase.
   
   c. relaxation phase
      
      Sarcomeres are lengthening due to relaxation (cross-bridge broken); force is falling.

2. In Activity 2, how long was the latent period? 2.78 msec

   Describe the chemical changes that are occurring during this period.

   Acetylcholine binds to sarcolemma; sarcolemma then T-tubules depolarize; Ca\(^{++}\) released from terminal cisternae travels along SR, is released into sarcoplasm, then binds to troponin to unblock tropomyosin binding sites allowing cross-bridge formation (i.e., myosin heads bind to actin).

The Graded Muscle Response to Increased Stimulus Intensity

3. From Activity 3, describe the effect of increasing the voltage. What happened to the force generated and why did this change occur?

   Force generated increased because the total number of cells contracting is increased.

4. How does this change occur in vivo?

   In vivo increasing force is achieved by neural activation of an increasingly large number of motor units serving the muscle.
5. In Activity 4, you looked at the effect of stimulating the muscle multiple times in a short period with complete relaxation between the stimuli.

Describe the force of contraction with each subsequent stimulus. _The force generated increases slightly with each subsequent stimulus._

6. Describe the chemical changes that are thought to correlate to this change _in vivo_.

_Increasing availability of Ca^{++} in the sarcoplasm (more Ca^{++} expose more active binding sites on the thin filaments for cross-bridge attachment)._  

7. In Activity 5, what was the effect of increasing the frequency of stimulation?

_The force generated increases and the force wave becomes smoother as frequency of stimulation increases._

8. Compare and contrast wave summation with recruitment (multiple motor unit summation). How are they similar? How was each achieved in the simulation?

_Both cause an increase in force generated. Summation is achieved by ↑ frequency of stimulation. Recruitment is achieved by ↑ force of stimulation._

9. Explain how wave summation and recruitment are achieved _in vivo_.

_Summation is achieved by the nervous system ↑ firing rate of motor neurons. Recruitment is caused by neural activation of increasingly large numbers of motor units serving the muscle._

10. For Activity 6, explain how you were able to achieve smooth contraction at a given force level. _Smooth contractions at a given force level are obtained by increasing the force of stimulation for a high force level or decreasing the force of stimulation for a low force level._

11. In Activity 7, explain why the force of the muscle decreased over time during uninterrupted stimulation. Describe the multiple causes of this phenomenon, which occurs _in vivo_ with prolonged use of a muscle. _ATP consumption is greater than its production; lactic acid buildup causes pH to decrease, therefore inhibiting enzyme activity._

**Isometric Contraction**

12. In Activity 8, at what length of the muscle does the passive force start to increase?

_75 mm_

13. Explain what happens to the active force with an increase in the muscle length.

_Active force increases until the optimal length is obtained, then decreases as muscle length continues to increase beyond optimal length._
14. Explain what happens to the active force with a decrease in the muscle length.

*Active force decreases as muscle length decreases.*

15. Explain what is happening in the sarcomere that results in the changes in total force when the muscle length changes. *As muscle length shortens or lengthens, fewer cross bridges will be able to form, thus the active force produced by the muscle is decreased.*

**Isotonic Contraction**

16. In Activity 9, which weight resulted in the highest initial velocity of shortening? *0.5g*

17. Explain the relationship between the amount of resistance and the initial velocity of shortening.

*The lighter the weight, the greater the initial velocity of shortening; inverse relationship.*

18. Explain why it will take you longer to perform 10 repetitions lifting a 20-pound weight than it would to perform the same number of repetitions with a 5-pound weight. *The velocity possible in lifting a 20-pound weight is much less than that of lifting a 5-pound weight.*
Neurophysiology of Nerve Impulses: Computer Simulation

Time Allotment: 2 hours.

Your computer should meet the following minimum requirements for PhysioEx™ 8.0:

**WINDOWS**
- OS: Windows XP, Vista
- Resolution: 1024 × 768
- Latest version of Adobe Flash Player
- Latest version of Adobe Reader
- Browsers: Internet Explorer 6.0 (XP only); Internet Explorer 7.0; Firefox 2.0
- Internet Connection: 56K modem minimum for website
- Printer

**MACINTOSH**
- OS: 10.3.x, 10.4.x
- Resolution: 1024 × 768
- Latest version of Adobe Flash Player
- Latest version of Adobe Reader
- Browsers: Safari 1.3 (10.3.x only); Safari 2.0 (10.4.x only); Firefox 2.0
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Advance Preparation, Comments, and Pitfalls

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2. **If you are using the web version of PhysioEx:** Have your students go to http://www.myaandp.com and follow the registration instructions found in the very front of their lab manual.

3. It is helpful to instruct students in the proper operation of the mouse and menu system as part of the lab introduction.

4. When considering an upgrade for computer systems, memory (RAM) offers the largest performance increase for the least cost.

5. Having students work in pairs results in the most successful lab experience. If students must work in larger groups, have them each get keyboard and mouse experience with the program.

Answers to Activity Questions

**Eliciting (Generating) a Nerve Impulse**

**Activity 1: Electrical Stimulation (pp. PEx-39–40)**

2. At 1.0 V, there is no response—the screen displays a flat line.
   The threshold voltage is at 3.0 V.
4. The slight increase in voltage results in a slight increase in the height of the action potential peak. At threshold voltage, the smaller fibers in a nerve are stimulated and an action potential is seen. Increasing the voltage will cause most, if not all, of the neural fibers to undergo depolarization. A given nerve is made up of literally thousands of neuron processes (axons), so this slight increase is noted when all fibers in the nerve fire.

5. The maximal voltage is 4.0 V.

Activity 2: Mechanical Stimulation (pp. PEx-40–41)
2. An action potential is generated when you touch the rod to the nerve.
   The tracing is identical to the tracing generated at the threshold voltage.

Activity 3: Thermal Stimulation (p. PEx-41)
An action potential is generated when you touch the heated rod to the nerve.
The tracing shows the action potential peaking slightly higher than the peak generated by the unheated rod.
Thermal stimulation can also elicit a nerve response. Heat generates action potentials in more of the neurons in a nerve than are generated by touch.

Activity 4: Chemical Stimulation (p. PEx-41)
1. Yes, dropping sodium chloride on the nerve generates an action potential.
2. No, the tracing does not differ from the original threshold stimulus tracing.
4. Yes, dropping hydrochloric acid on the nerve generates an action potential.
   No, the tracing does not differ from the original threshold stimulus tracing.
6. Electrical, mechnical, thermal, and chemical stimulation are all capable of generating an action potential in a nerve.

Inhibiting a Nerve Response
Activity 5: Testing the Effects of Ether (pp. PEx-42–43)
2. The screen displays a flat line, indicating no nerve response.
   The nerve has been anesthesized by the ether.
4. The nerve begins to respond to electrical stimuli again after about 6 minutes.

Activity 6: Testing the Effects of Curare (p. PEx-43)
2. There is no change to the action potential tracing.
   Nerve propagation is unaffected because curare works on the synaptic ends of the nerve.
   Curare would ultimately kill the organism by blocking nerve transmission.

Activity 7: Testing the Effects of Lidocaine (p. PEx-43)
1. No.
2. At threshold voltage, the screen still displays a flat line.
   Lidocaine is a sodium ion channel antagonist which will block sodium channels from opening, thus inhibiting any action potential from being generated.

Nerve Conduction Velocity
Activity 8: Measuring Nerve Conduction Velocity (pp. PEx-44–46)
5. 5 volts
The chart should look like this:

<table>
<thead>
<tr>
<th>Nerve</th>
<th>Earthworm</th>
<th>Frog</th>
<th>Rat Nerve 1</th>
<th>Rat Nerve 2</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Threshold voltage</strong></td>
<td>5.0 V</td>
<td>3.0 V</td>
<td>2.5 V</td>
<td>3.0 V</td>
</tr>
<tr>
<td><strong>Elapsed time from stimulation to action potential</strong></td>
<td>about 4.86 msec</td>
<td>about 1.56 msec</td>
<td>about 2.5 msec</td>
<td>about 0.92 msec</td>
</tr>
<tr>
<td><strong>Conduction velocity</strong></td>
<td>about 8.85 m/sec</td>
<td>about 27.56 m/sec</td>
<td>about 17.2 m/sec</td>
<td>about 46.74 m/sec</td>
</tr>
</tbody>
</table>

11. The earthworm has the slowest conduction velocity.
   The speed of the earthworm nerve was about 8.85 m/sec.
   Rat nerve 2 had the fastest conduction velocity.
   The speed of rat nerve 2 was about 46.74 m/sec.
   The larger the nerve, the faster the conduction velocity.
   Conduction velocity is faster if the nerve is myelinated than if it is not.
   In myelinated nerves, conduction velocity is faster as the action potential jumps from node of Ranvier (internode) to node of Ranvier and does not travel along the cell membrane.
Neurophysiology of Nerve Impulses: Computer Simulation

Eliciting (Generating) a Nerve Impulse

1. Why don’t the terms depolarization and action potential mean the same thing?

Depolarization (reduction of the negative membrane potential) may only be a short-lived event if the change in the membrane is sub-threshold. When an action potential occurs, there is a large reversal of the membrane polarity that occurs when the membrane depolarizes to threshold.

2. What was the threshold voltage in Activity 1? 3 volts

3. What was the effect of increasing the voltage? How does this change correlate to changes in the nerve? Increasing voltage results in depolarization of increasing numbers of neurons in a nerve.

4. How did the action potential generated with the unheated rod compare to the heated rod? The action potential generated with the unheated rod was less than the action potential generated by the heated rod.

5. Describe the types of stimuli that generated an action potential. Electrical, mechanical, thermal, and chemical stimuli are all capable of generating an action potential.

6. If you were to spend a lot of time studying nerve physiology in the laboratory, what type of stimulus would you use and why?

Although many different stimuli work, electrical stimulators are convenient because the voltage duration and frequency of the shock can be very precisely set for use.

7. Why does the addition of sodium chloride elicit an action potential? Hint: Think about the sodium permeability of the neuron (Figure 18b.2e). While the sodium-potassium pump is pumping sodium out of the cell and potassium into the cell, these ions are leaking back where they came from by diffusion. By adding sodium chloride, a more-than-normal amount of sodium will diffuse into the nerve, causing the resting membrane potential to reach the threshold value, bringing about a membrane depolarization.
Inhibiting a Nerve Impulse

8. What was the effect of ether on eliciting an action potential?  
   The ether narcotizes the nerve fiber in between the stimulating and recording electrodes, thus blocking any action potential from being generated.

9. Does the addition of ether to the nerve cause any permanent alteration in neural response?  
   No, the ether has no lasting effect.

10. What was the effect of curare on eliciting an action potential?  
    Curare had no effect—an action potential was still generated when the nerve was stimulated at threshold voltage.

11. Explain the reason for your answer to question 10 above.  
    Curare works by blocking synaptic transmissions so that neural impulses do not travel from neuron to neuron. The detached nerve which we are experimenting with does not have any synapses to be blocked. In a living animal, however, curare will kill, as neural impulses cannot jump synapses to allow the heart to work or the animal to breathe.

12. What was the effect of lidocaine on eliciting an action potential?  
    Lidocaine is a sodium channel antagonist and will block sodium ion channels from working, preventing the generation of an action potential.

Nerve Conduction Velocity

13. What is the relationship between size of the nerve and conduction velocity?  
    The larger the size of the nerve, the faster the conduction velocity.

14. Keeping your answer to question 13 in mind, how might you draw an analogy between the nerves in the human body and electrical wires?  
    The larger the size of the electrical wire, the faster the speed of electrons within it. Smaller wires have a high resistance to electron flow.

    Myelination will speed the nerve conduction velocity considerably. Myelin is found in Schwann cells which encircle a given axon. It acts mainly as an insulator so that depolarization in one cell does not set off depolarizations in adjoining cells. When a neural membrane is depolarized, local currents are set up between positive and negative ions causing membrane conduction. In myelinated fibers, the local currents go from one internode (or Node of Ranvier) in between two Schwann cells to the next internode. Thus we have “salutatory conduction” where a neural impulse actually jumps from one internode to the next without being conducted down the entire cell membrane.

16. If any of the nerves used were reversed in their placement on the stimulating and recording electrodes, would any differences be seen in conduction velocity? Explain.  
    No. Once a neural membrane is depolarized and the impulse is being conducted along the neural membrane, which direction is which does not matter. We state that a neural impulse is set up in the neuron’s trigger zone (mainly due to the large number of sodium channels there) but once the depolarization is set up, it not only travels down the axon but also around the soma of the cell.
Endocrine System
Physiology: Computer Simulation

Time Allotment: 3 hours.

Your computer should meet the following minimum requirements for PhysioEx™ 8.0:

**WINdows**
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- Resolution: 1024 × 768
- Latest version of Adobe Flash Player
- Latest version of Adobe Reader
- Browsers: Internet Explorer 6.0 (XP only); Internet Explorer 7.0; Firefox 2.0
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- Printer

**MACINTOSH**
- OS: 10.3.x, 10.4.x
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4. When considering an upgrade for computer systems, memory (RAM) offers the largest performance increase for the least cost.

5. Having students work in pairs results in the most successful lab experience. If students must work in larger groups, have them each get keyboard and mouse experience with the program.
Metabolism

Upon completion of all activities, the chart should look like this:

<table>
<thead>
<tr>
<th></th>
<th>Normal Rat</th>
<th>Thyroidectomized Rat</th>
<th>Hypophysectomized Rat</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Baseline</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weight</td>
<td>249–251 g</td>
<td>244–246 g</td>
<td>244–246 g</td>
</tr>
<tr>
<td>ml O₂ used in 1 minute</td>
<td>7.0–7.2 ml</td>
<td>6.0–6.2 ml</td>
<td>6.0–6.2 ml</td>
</tr>
<tr>
<td>ml O₂ used per hour</td>
<td>420–432 ml</td>
<td>360–372 ml</td>
<td>360–372 ml</td>
</tr>
<tr>
<td>Metabolic rate O₂/Kg/Hr</td>
<td>1687–1721 ml</td>
<td>1475–1512 ml</td>
<td>1475–1512 ml</td>
</tr>
<tr>
<td><strong>With Thyroxine</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weight</td>
<td>249–251 g</td>
<td>244–246 g</td>
<td>244–246 g</td>
</tr>
<tr>
<td>ml O₂ used in 1 minute</td>
<td>7.8–8.0 ml</td>
<td>7.4–7.6 ml</td>
<td>7.4–7.6 ml</td>
</tr>
<tr>
<td>ml O₂ used per hour</td>
<td>468–480 ml</td>
<td>444–456 ml</td>
<td>444–456 ml</td>
</tr>
<tr>
<td>Metabolic rate O₂/Kg/Hr</td>
<td>1879–1912 ml</td>
<td>1820–1854 ml</td>
<td>1820–1854 ml</td>
</tr>
<tr>
<td><strong>With TSH</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weight</td>
<td>249–251 g</td>
<td>244–246 g</td>
<td>244–246 g</td>
</tr>
<tr>
<td>ml O₂ used in 1 minute</td>
<td>7.8–8.0 ml</td>
<td>6.0–6.2 ml</td>
<td>7.4–7.6 ml</td>
</tr>
<tr>
<td>ml O₂ used per hour</td>
<td>468–480 ml</td>
<td>360–372 ml</td>
<td>444–456 ml</td>
</tr>
<tr>
<td>Metabolic rate O₂/Kg/Hr</td>
<td>1879–1912 ml</td>
<td>1475–1512 ml</td>
<td>1820–1854 ml</td>
</tr>
<tr>
<td><strong>With Propylthiouracil</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weight</td>
<td>249–251 g</td>
<td>244–246 g</td>
<td>244–246 g</td>
</tr>
<tr>
<td>ml O₂ used in 1 minute</td>
<td>6.0–6.2 ml</td>
<td>6.0–6.2 ml</td>
<td>6.0–6.2 ml</td>
</tr>
<tr>
<td>ml O₂ used per hour</td>
<td>360–372 ml</td>
<td>360–372 ml</td>
<td>360–372 ml</td>
</tr>
<tr>
<td>Metabolic rate O₂/Kg/Hr</td>
<td>1446–1482 ml</td>
<td>1475–1512 ml</td>
<td>1475–1512 ml</td>
</tr>
</tbody>
</table>

Answers to Activity Questions

Activity 1: Determining Baseline Metabolic Rates (pp. PEx-51–53)

16. The normal rat’s metabolic rate is faster than the metabolic rates of the thyroidectomized and hypophysectomized rats.

The thyroidectomized rat lacks a thyroid, thus produced no thyroxine. The hypophysectomized rat lacks a pituitary gland, thus produced no thyroid stimulating hormone to stimulate thyroxine production.

Because the normal rat produced thyroxine normally, its metabolic rate was faster than the other rats.

Activity 2: Determining the Effect of Thyroxine on Metabolic Rate (p. PEx-53)

7. On the normal rat, the metabolic rate after thyroxine injection is faster than the baseline metabolic rate.

The action of thyroxine is to increase the metabolic rate of all cells.
On the thyroidectomized rat, the metabolic rate after thyroxine injection is faster than the baseline metabolic rate.
The injected thyroxine compensated for the thyroxine lost when the thyroid was removed.

On the hypophysectomized rat, the metabolic rate after thyroxine injection is faster than the baseline metabolic rate.
The injected thyroxine compensated for the thyroxine lost when the pituitary gland was removed. The pituitary gland did not produce TSH, therefore the thyroid gland did not produce thyroxine.

**Activity 3: Determining the Effect of TSH on Metabolic Rate (pp. PEx-53–54)**

7. On the normal rat, the metabolic rate after TSH injection is faster than the baseline metabolic rate.
The TSH increased production of thyroxine.

On the thyroidectomized rat, the metabolic rate after TSH injection is the same as the baseline metabolic rate.
Since there is no thyroid gland in the thyroidectomized rat, the injected TSH had nothing to act upon.
There was no organ to receive the pituitary TSH and produce thyroxine.

On the hypophysectomized rat, the metabolic rate after TSH injection is faster than the baseline metabolic rate.
The injected TSH compensated for the TSH lost when the pituitary gland was removed, and spurs production of thyroxine.

**Activity 4: Determining the Effect of Propylthiouracil on Metabolic Rate (p. PEx-54)**

7. On the normal rat, the metabolic rate after propylthiouracil injection is slower than the baseline metabolic rate.
Propylthiouracil is antagonistic to thyroxine and will tend to decrease the effects of thyroxine.

On the thyroidectomized rat, the metabolic rate after propylthiouracil injection is the same as the baseline metabolic rate.
Since the thyroidectomized rat cannot make any thyroxine, the propylthiouracil has nothing to be antagonistic to and therefore has no effect.

On the hypophysectomized rat, the metabolic rate after propylthiouracil injection is the same as the baseline metabolic rate.
Since the hypophysectomized rat does not have a functional thyroid gland, no thyroxine is being made and there is nothing for the propylthiouracil to be antagonistic to.

**Hormone Replacement Therapy**

**Activity 5: Hormone Replacement Therapy (pp. PEx-55–56)**

9. Student answers will vary.
12. T score (control): $-2.7 \pm 0.15$
15. T score (estrogen): $-2.0 \pm 0.15$
16. T score (calcitonin): $-2.6 \pm 0.15$
17. Estrogen injections changed the rat’s T score from the osteoporosis range to the osteopenia range.
The calcitonin injections had little to no effect on the rat.

**Insulin and Diabetes**

**Activity 7: Measuring Fasting Plasma Glucose (pp. PEx-58–61)**

20. Sample 1: glucose concentration of 95–105 mg/deciliter
23. Sample 2: glucose concentration of 110–120 mg/deciliter
    Sample 3: glucose concentration of 126–136 mg/deciliter
    Sample 4: glucose concentration of 115–125 mg/deciliter
    Sample 5: glucose concentration of 135–145 mg/deciliter
Patient 1’s glucose reading was in the normal range.
Patient 3’s and Patient 5’s glucose readings were in the diabetic range.
Patient 2’s and 4’s glucose readings were in the impaired fasting glucose range.
A special diet would be recommended where simple sugars are restricted.
The diagnosis would be gestational diabetes. A special diet would be recommended where simple sugars are restricted.

Activity 8: Measuring Cortisol and Adrenocorticotropic Hormone (pp. PEx-61–63)

17. Patient 1: cortisol 3 ± 1 mcg/dL Low ACTH 18 ± 2 pg/ml Low
Patient 2: cortisol 35 ± 5 mcg/dL High ACTH 13 ± 2 pg/ml Low
Patient 3: cortisol 45 ± 5 mcg/dL High ACTH 86 ± 5 pg/ml High
Patient 4: cortisol 3 ± 1 mcg/dL Low ACTH 100 ± 5 pg/ml High
Patient 5: cortisol 50 ± 5 mcg/dL High ACTH 18 ± 2 pg/ml Low
Endocrine System
Physiology: Computer Simulation

Metabolism

The following questions refer to Activity 1: Determining Baseline Metabolic Rates.

1. Which rat had the fastest baseline metabolic rate? The normal rat
2. Compare the baseline metabolic rates for the thyroidectomized rat and the normal rat and explain your results. The thyroidectomized rat had a lower baseline metabolic rate because the removal of its thyroid gland prevented it from producing any thyroxine.
3. Compare the baseline metabolic rates for the hypophysectomized rat and the normal rat and explain your results. The hypophysectomized rat had a lower baseline metabolic rate because removal of the pituitary gland, or hypophysis, prevented TSH production.

The following questions refer to Activity 2: Determining the Effect of Thyroxine on Metabolic Rate.

4. What effect did administering thyroxine have on each of the rats? The baseline metabolic rate increased in each rat.
5. Explain why thyroxine had these effects. The effect of thyroxine is to increase baseline metabolic rate.

The following questions refer to Activity 3: Determining the Effect of TSH on Metabolic Rate.

6. Was there a change in the metabolic rate of the thyroidectomized rat with the administration of TSH? Explain your results. No; there was no thyroid gland to be stimulated.
7. Did the results for the thyroidectomized rat indicate hyperthyroidism or hypothyroidism? Hypothyroidism

The following questions refer to Activity 4: Determining the Effect of Propylthiouracil on Metabolic Rate.
8. Describe the effect of administering propylthiouracil on each of the rats, and explain why it had this effect. It decreased BMR in normal and hypophysectomized rats because propylthiouracil blocks the attachment of iodine to tyrosine residues and interferes with the conversion of thyroxine to triiodothyronine.

9. Do you think the drug propylthiouracil is used to treat hypothyroidism or hyperthyroidism? Explain your answer. Hyperthyroidism; propylthiouracil is antagonistic to thyroxine and will tend to decrease the effects of thyroxine.

Hormone Replacement Therapy
The following questions refer to Activity 5: Hormone Replacement Therapy.

10. Explain why ovariectomized rats were used in this experiment and correlate this to their baseline T score. Ovariectomized rats were used because they do not produce estrogen. Their baseline T score shows that they have already developed osteoporosis.

11. Recap your predictions regarding the effects of calcitonin and estrogen on bone density and why you made those predictions. Student answers will vary.

12. Why was one of the ovariectomized rats injected with saline? The saline rats are negative controls. Saline should have no effect on bone density. The rats therefore should not show a change in vertebral bone density with saline injection.

13. What effect did the administration of estrogen injections have on the estrogen-treated rat? The estrogen-treated rats showed an increase in vertebral bone density.

14. What effect did the administration of calcitonin injections have on the calcitonin-treated rat? Calcitonin injections had no effect on vertebral bone density.

15. How did your results compare to your predictions? Student answers will vary. In general, their prediction for calcitonin probably won't match because they will expect a change with the calcitonin injections.

Insulin and Diabetes
The following question refers to Activity 6: Obtaining a Glucose Standard Curve.

16. What is a glucose standard curve, and how can you use this tool to determine a concentration of glucose? A glucose standard curve is a point of reference for converting optical density into glucose readings by comparing optical density readings for known amounts of glucose to unknown amounts.
The following questions refer to Activity 7: Measuring Fasting Plasma Glucose.

17. Which patient(s) glucose reading(s) was/were in the normal range? Patient 1 had a normal fasting plasma glucose value.

18. Which patient(s) glucose reading(s) was/were in the diabetic range? Patients 3 and 5 had a fasting plasma glucose value that was in the diabetic range.

19. Which patient(s) had glucose reading(s) in the impaired range? Patients 2 and 4 had a fasting plasma glucose value that was borderline and therefore in the impaired fasting glucose range.

20. Describe the diagnosis for Patient 3. Since Patient 3 is also pregnant, the diagnosis would be gestational diabetes.

The following questions refer to Activity 8: Measuring Cortisol and Adrenocorticotropic Hormone.

21. Which patient would most likely be diagnosed with Cushing’s disease? Why? Patient 3 would be diagnosed with Cushing’s disease because the levels of cortisol and ACTH were both high.

22. Which two patients have hormone levels characteristic of Cushing’s syndrome? Patients 2 and 5 both have high levels of cortisol but the ACTH is low, which is characteristic of Cushing’s syndrome.

23. Patient 2 is being treated for rheumatoid arthritis with prednisone. How does this change the diagnosis? The diagnosis would change to iatrogenic or physician-induced Cushing’s syndrome.

24. Which patient would most likely be diagnosed with Addison’s disease? Why? Patient 4 would be diagnosed with Addison’s disease because the level of ACTH is high but the level of cortisol is low.
Time Allotment: 2 hours

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3. It is helpful to instruct students in the proper operation of the mouse and menu system as part of the lab introduction.

4. When considering an upgrade for computer systems, memory (RAM) offers the largest performance increase for the least cost.

5. Having students work in pairs results in the most successful lab experience. If students must work in larger groups, have them each get keyboard and mouse experience with the program.

**Answers to Activity Questions**

**Activity 1: Hematocrit Determination (pp. PEx-71–72)**

10. The hematocrit value of the healthy male living at sea level in Boston is 48.

   The hematocrit level of the healthy male living at one mile elevation in Denver is 55.

   No, the air in Denver is “thinner” (contains a lower percentage of oxygen) than it is in Boston.

   When the blood flowing through the kidneys is hypoxic (low oxygen level), the kidneys respond by producing a hormone, *erythropoietin*, which stimulates the bone marrow to produce more red blood cells.
If your bone marrow is producing an elevated number of red blood cells, your hematocrit is elevated. The hematocrit value of the male with aplastic anemia is 19. The red blood cell count for an individual with aplastic anemia would be lower than the red blood cell count of a healthy individual. The hematocrit value of the healthy female living in Boston is 44. The female with iron-deficiency anemia does not have as many normal-sized red blood cells as the healthy female living in Boston, so her hematocrit (packed cell volume) is lower. She is not able to make adequate hemoglobin molecules to fill her red blood cells.

Activity 2: Erythrocyte Sedimentation Rate (pp. PEx-72–74)
13. The blood has settled 5 millimeters. The beige-colored portion of the tube is blood plasma.
17. No, the person with sickle-cell anemia did not show an elevated ESR. The ESR for the person with iron-deficiency anemia was higher than the ESR for the healthy individual. The menstruating female is suffering from iron-deficiency anemia, causing her red blood cells to settle. The ESR is elevated in the patient suffering from myocardial infarction (heart attack), but is normal in angina pectoris.

Activity 3: Hemoglobin (Hb) Determination (pp. PEx-76–77)
11. The hematocrit value for the healthy male is 48. The hematocrit value for the healthy female is 44. The ratio of PCV to Hb for the female with iron-deficiency anemia tells you that she may have a normal number of red blood cells, but they do not contain adequate levels of hemoglobin molecules. Yes, the male with polycythemia has a normal ratio of PCV to Hb (a ratio of 3:1). Yes, the red blood cells of the male with polycythemia contain adequate levels of hemoglobin molecules. Yes, the female Olympic athlete has a normal ratio of PCV to Hb (a ratio of 3:1). Yes, the red blood cells of the female Olympic athlete contain adequate levels of hemoglobin molecules.

Activity 4: Blood Typing (pp. PEx-78–79)
19. If the anti-A antibody causes the blood to agglutinate, antigen (agglutinogen) A would be present on the blood cells. If a person has type AB blood, antigen (agglutinogens) A & B are present on their red blood cells. In a person with type AB blood, neither A nor B antibodies (agglutinins) are present. A person with type O blood has neither A nor B antigens (agglutinogens).

Activity 5: Total Cholesterol Determination (p. PEx-81)
10. Patient #2 has elevated cholesterol, which has been associated with increased risk of cardiovascular disease. Patient #4 has borderline elevated cholesterol. He should be advised to decrease his dietary intake of meats and saturated fats. He should also be encouraged to exercise more.
Blood Analysis: Computer Simulation

**Hematocrit Determination**

The following questions refer to Activity 1: Hematocrit Determination.

1. List the following values from Chart 1:
   - Hematocrit value for healthy male living at sea level in Boston = 48
   - Hematocrit value for healthy female living at sea level in Boston = 44

2. Were the values listed in question 1 within normal range? Yes

3. Describe the difference between the male and the female hematocrit for an individual living in Boston. Since males typically have a greater number of RBC than females, they have a higher hematocrit.

4. List the following values from Chart 1:
   - Hematocrit value for healthy male living in Denver = 55
   - Hematocrit value for healthy female living in Denver = 53

5. How did these values differ from the values for Boston? Both male and female had a higher hematocrit than the male and female in Boston.

6. Describe the effect of living at high elevations on a person’s hematocrit. Air at the higher elevation contains a lower percentage of oxygen, so a person living there needs more RBC to carry sufficient O$_2$.

7. Describe how the kidneys respond to a decrease in oxygen and what effect this has on hematocrit. The kidneys of a person living at high elevation are stimulated to produce erythropoietin, which stimulates bone marrow to produce more RBC.

8. List the following values from Chart 1:
   - Hematocrit value for male with aplastic anemia = 32
   - % WBC for male with aplastic anemia = 1%

9. Were the values listed in question 8 within the normal range? Why or why not? Values 1–4 were normal; all were from healthy individuals. Value 5 was very low because it’s from a person with aplastic anemia (failure of bone marrow to make enough RBC). Value 6 was below normal because it’s from a person with iron deficiency anemia (body can’t produce enough hemoglobin).
10. List the following value from Chart 1:

Hematocrit for female with iron-deficiency anemia = 32

11. Was the value in question 10 normal or not? Explain. A hematocrit of 32 is below normal. Iron deficiency causes lower production of hemoglobin and a lower hematocrit.

**Erythrocyte Sedimentation Rate**

The following questions refer to Activity 2: Erythrocyte Sedimentation Rate.

12. Describe the effect that sickle cell anemia has on the sedimentation rate. There was a lower than normal sedimentation rate.

13. Why do you think that it has this effect? Hint: Sickle cell anemia alters the shape of red blood cells. The sickle shape of the RBC does not allow them to settle.

14. Record the sedimentation rate for a menstruating female. 15

15. How did this value compare to the healthy individual? Why? This is an elevated sedimentation rate indicating that she has anemia.

16. What was the sedimentation rate for the iron-deficient individual? 40

17. What effect does iron deficiency have on ESR? Iron deficiency causes an elevated sedimentation rate.

18. Record the following values from Chart 2:

ESR for person suffering from a myocardial infarction = 40

ESR for person suffering from angina pectoris = 5

19. Compare the values in question 18 and explain how they might be used to monitor heart conditions. Elevated ESR can indicate myocardial infarction. Normal ESR indicates angina pectoris. ESR can help distinguish between causes of chest pain.

20. List some other conditions that ESR is used to monitor. Certain cancers, inflammatory diseases such as rheumatoid arthritis, iron deficiency anemia, and sickle cell anemia

**Hemoglobin**

The following questions refer to Activity 3: Hemoglobin (Hb) Determination.

21. Describe the ratio of packed cell volume to Hb (hemoglobin) obtained for the healthy male and female subjects. A normal ratio of packed cell volume to grams of hemoglobin is approximately 3:1.
22. Describe the ratio of packed cell volume to Hb (hemoglobin) for the female with iron-deficiency anemia. 5:1

23. Is the female with iron-deficiency anemia deficient in hemoglobin? Yes

24. Is the male with polycythemia deficient in hemoglobin? No

25. Is the female Olympic athlete deficient in hemoglobin? No

26. List conditions in which Hb would decrease. Hemoglobin values decrease in patients with anemia, hyperthyroidism, cirrhosis of the liver, renal disease, systemic lupus erythematosus, and severe hemorrhaging.

27. List conditions in which Hb would increase. Hemoglobin values increase in patients with polycythemia, congestive heart failure, chronic obstructive pulmonary disease (COPD), and those living at high altitude.

Blood Typing

The following questions refer to Activity 4: Blood Typing.

28. Which blood sample contained the rarest blood type? Sample 3

29. Which blood sample contained the universal donor? Sample 4

30. Which blood sample contained the universal recipient? Sample 5

31. Which blood sample did not coagulate with any of the antibodies tested? Sample 4

Why? Type O− blood does not have any antigens on the RBC with which antibodies can agglutinate.

32. What antibodies would be found in the plasma of blood sample 1? Anti-B

33. When transfusing an individual with blood that is compatible but not the same type, it is important to separate packed cells from the plasma and administer only the packed cells. Why do you think this is done? When only packed cells are transfused, very few antibodies are included in the transfusion so the chance of the transfused antibodies agglutinating the recipient's RBC is very slight.

34. List which blood samples in this experiment represent people who could donate blood to a person with type B+. B+, O−, O+

Blood Cholesterol

The following questions refer to Activity 5: Total Cholesterol Determination.

35. Which patient(s) had desirable cholesterol levels? Patients 1 and 3

36. Which patient(s) had an elevated cholesterol level? Patients 2 and 4
37. Describe the risks for the patient identified in question 36. __________

Patient 2 is at risk of cardiovascular disease; patient 4 is at slight risk of cardiovascular disease.

38. Which advice would you give patient 4? Why? __________

Patient 4 should lower dietary intake of cholesterol (red and organ meats, eggs, cheese) and increase aerobic exercise.

39. Describe some reasons why a patient might have abnormally low blood cholesterol. __________

Low blood cholesterol can be caused by hyperthyroidism, liver disease, inadequate absorption of nutrients from the intestine, and malnutrition.
Cardiovascular Dynamics: Computer Simulation

**Time Allotment:** 2 hours minimum if students are well-prepared, 3 hours preferred.

Your computer should meet the following minimum requirements for PhysioEx™ 8.0:

**WINDOWS**
- OS: Windows XP, Vista
- Resolution: 1024 × 768
- Latest version of Adobe Flash Player
- Latest version of Adobe Reader
- Browsers: Internet Explorer 6.0 (XP only); Internet Explorer 7.0; Firefox 2.0
- Internet Connection: 56K modem minimum for website
- Printer

**MACINTOSH**
- OS: 10.3.x, 10.4.x
- Resolution: 1024 × 768
- Latest version of Adobe Flash Player
- Latest version of Adobe Reader
- Browsers: Safari 1.3 (10.3.x only); Safari 2.0 (10.4.x only); Firefox 2.0
- Internet Connection: 56K modem minimum for website
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3. It is helpful to instruct students in the proper operation of the mouse and menu system as part of the lab introduction.

4. When considering an upgrade for computer systems, memory (RAM) offers the largest performance increase for the least cost.

5. Having students work in pairs results in the most successful lab experience. If students must work in larger groups, have them each get keyboard and mouse experience with the program.

6. Consider doing a short introductory presentation with the following elements:
   a. Describe the basics of peripheral resistance.
   b. Encourage students to try to apply the concepts from the simulation to the human as they work through the program.
   c. If a demonstration computer screen is available, show students both main screens of the simulation and describe the basic equipment parts.
   d. Explain how the simulated pump is similar to the left ventricle (or the right ventricle) of the heart.
   e. Point out the fact that the pump operates much like a syringe, with adjustable starting and ending volumes.
f. It is often helpful to explain the basics of end diastolic and end systolic volumes and their relationship to the simulated pump.

g. Indicate the analogies between the parts of the simulation and the parts of the human cardiovascular system.

Answers to Activity Questions

Vessel Resistance

Activity 1: Studying the Effect of Flow Tube Radius on Fluid Flow (pp. PEx-88–90)

5. Fluid flow increases as the radius of the flow tube is increased.
   Because fluid flow is proportional to the fourth power of the radius, increases/decreases in tube radius cause increases/decreases in fluid flow.
   The relationship between fluid flow and flow tube radius is exponential.
   We alter blood flow in the human body by increasing or decreasing the diameter of blood vessels by the contraction or relaxation of smooth muscle tissue in vessel walls.
   After a heavy meal when we are relatively inactive, we might expect blood vessels in the skeletal muscles to be somewhat constricted while blood vessels in the digestive organs are probably dilated.

Activity 2: Studying the Effect of Viscosity on Fluid Flow (p. PEx-90)

6. Fluid flow decreases as viscosity is increased.
   Fluid flow versus viscosity is an inverse relationship.
   The effect of viscosity does not affect fluid flow as much as vessel radius.
   Anemia would result in fewer red cells than normal, which would decrease the viscosity of the blood.
   Consequently, blood flow rate would be increased.
   If you increased the numbers of red blood cells, blood flow rate would decrease.
   Blood viscosity would increase in conditions of dehydration, resulting in decreased blood flow.

Activity 3: Studying the Effect of Flow Tube Length on Fluid Flow (p. PEx-91)

6. Increasing flow tube length will decrease fluid flow rate.
   Obesity would result in decreased blood flow because vessels must increase in length in order to serve the increased amount of adipose tissue in the body.

Activity 4: Studying the Effect of Pressure on Fluid Flow (pp. PEx-91–92)

6. Increasing the pressure increases fluid flow.
   The length versus flow rate plot is linear, whereas the plots for radius, viscosity, and length are all exponential.
   Changing pressure would not be a reasonable method of flow control because a large change in pressure is needed to significantly change flow rate.

Pump Mechanics

Activity 5: Studying the Effect of Radius on Pump Activity (pp. PEx-93–94)

2. a. When the piston is at the bottom of its travel, the volume remaining in the pump is analogous to the (EDV, ESV) of the heart.
   b. The amount of fluid ejected into the right beaker by a single pump cycle is analogous to (stroke volume, cardiac output) of the heart.
   c. The volume of blood in the heart just before systole is called (EDV, ESV) and is analogous to the volume of fluid present in the simulated pump when it is at the (top, bottom) of the stroke.

5. The radius plot in this experiment appears different from the radius plot in the vessel resistance experiment because only the outflow of the pump was changed. Since the inflow remained constant during the course of the experiment, an entirely different flow pattern is established.
a. As the right flow tube radius is increased, fluid flow rate (increases, decreases). This is analogous to (dilation, constriction) of blood vessels in the human body.
b. Even though the pump pressure remains constant, the pump rate (increases, decreases) as the radius of the right flow tube is increased. This happens because the resistance to fluid flow is (increased, decreased).
c. The heart must contract (more, less) forcefully to maintain cardiac output if the resistance to blood flow in the vessels exiting the heart is increased.
d. Increasing the resistance (e.g., a constriction) of the blood vessels entering the heart would (increase, decrease) the time needed to fill the heart chambers.

If the left flow tube radius is increased, flow rate into the pump is increased, which increases the pump rate. A decrease in the left flow tube radius causes flow rate and pump rate to decrease.

**Activity 6: Studying the Effect of Stroke Volume on Pump Activity (pp. PEx-94–95)**
5. As the stroke volume is increased, it takes longer to fill the pump and the pump rate slows.
   To maintain adequate blood flow to tissues, the stroke volume must be greater in an athlete if his heart rate is lower.
   If we keep the rate constant, increasing the stroke volume causes cardiac output to increase.

**Activity 7: Studying Combined Effects (pp. PEx-95–96)**
When the right flow tube radius is kept constant and the left flow tube radius is changed, there is an indirect change in pump filling time which in turn directly changes the pump rate. (An increase in the left tube radius causes a decrease in filling time and an increase in pump rate.)

Although decreasing the radius of the left flow tube increases the time required to fill the pump, it does not affect the ability of the pump to empty.
A decrease in stroke volume causes an increase in pump rate because the pump is ejecting a lower volume with each pump stroke and thus is able to empty the chamber more rapidly.
Increasing the pressure in the left beaker increases fluid delivery to the pump from the left beaker.
Decreasing the pressure in the left beaker to 10 mm Hg greatly increases the time required to fill the pump.
The pump’s rate increases if the filling time is decreased.
If the pressure in the right beaker equals the pump pressure, fluid can not flow.

**Activity 8: Studying Compensation (p. PEx-96)**
If the right flow tube radius is decreased to 2.5 mm, the flow rate decreases.

The increased peripheral resistance can be overcome by: (1) increasing the pump’s pressure, (2) decreasing the pressure in the right beaker, and (3) increasing the radius of the left flow tube to decrease the pump’s filling time.

Decreasing the right flow tube radius is similar to a partial (leakage, blockage) of the aortic valve or (increased, decreased) resistance in the arterial system.
The human heart could compensate for this condition by increasing its force of contraction to overcome the increased resistance.
To control blood flow to specific organs, it is necessary to adjust the radius of the blood vessels feeding them. It would not be reasonable to adjust the heart rate because that would affect all organs equally.

a. If we decreased overall peripheral resistance in the human body (as in an athlete), the heart would need to generate (more, less) pressure to deliver an adequate amount of blood flow and arterial pressure would be (higher, lower).
b. If the diameter of the arteries of the body were partly filled with fatty deposits, the heart would need to generate (more, less) force to maintain blood flow, and pressure in the arterial system would be (higher, lower) than normal.
Cardiovascular Dynamics: Computer Simulation

Vessel Resistance

The following questions refer to Activity 1: Studying the Effect of Flow Tube Radius on Fluid Flow.

1. At which radius was the fluid flow rate the highest? 6.0 mm

2. What was the flow rate at this radius? 1017.4

3. Describe the relationship between flow rate and radius size. The larger the tube radius, the greater the flow. This is a direct relationship.

4. What happens to blood vessels in the body if increased blood flow is needed? Blood vessels dilate to increase blood flow.

The following questions refer to Activity 2: Studying the Effect of Viscosity on Fluid Flow.

5. At what viscosity level was the fluid flow rate the highest? 1.0

6. Describe the relationship between flow rate and viscosity. The greater the viscosity, the less the flow. This is an inverse relationship.

7. Was the effect of viscosity greater or less than the effect of radius on fluid flow? Why? Viscosity has less effect than radius on fluid flow because flow is directly proportional to the fourth power of vessel radius (r^4).

8. What effect would anemia have on blood flow? Why? Anemia would increase blood flow because it decreases blood viscosity.

The following questions refer to Activity 3: Studying the Effect of Flow Tube Length on Fluid Flow.

9. At what flow tube length was the flow rate the highest? 10 mm

10. Describe the relationship between flow tube length and fluid flow rate. The longer the tube, the lower the flow rate. This is an inverse relationship.

11. What effect do you think obesity would have on blood flow? Why? Obesity would result in decreased blood flow because vessels must increase in length in order to serve the increased amount of adipose tissue in the body.
The following questions refer to Activity 4: Studying the Effect of Pressure on Fluid Flow.

12. What effect did increased pressure have on the fluid flow rate? As pressure increased, flow increased. This is a direct relationship.

13. In the body, where does the driving pressure for fluid flow come from? Ventricular contractions provide the driving pressure for blood flow.

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**Pump Mechanics**

The following questions refer to Activity 5: Studying the Effect of Radius on Pump Activity.

14. What happened to the flow rate as the right vessel radius was increased? Flow rate increased as the right vessel radius increased.

15. What happened to the rate (strokes/min) as the right vessel radius was increased?
   
   Why did this occur? Stroke rate increased as the right vessel radius increased because beaker emptying time decreased.

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The following questions refer to Activity 6: Studying the Effect of Stroke Volume on Pump Activity.

16. At what stroke volume tested was the pump rate the lowest? 120

17. Describe the relationship between stroke volume and pump rate. As stroke volume increases, pump rate decreases. This is an inverse relationship.

18. Use the relationship in question 17 to explain why an athlete’s resting heart rate would be lower than that of a sedentary individual. An athlete has a higher stroke volume than a sedentary individual, therefore the athlete needs fewer heart beats (stroke volume) to achieve the same cardiac output.

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The following questions refer to Activity 7: Studying Combined Effects.

19. How did decreasing the left flow tube radius affect pump chamber filling time? Hint: Look at the change in flow rate and relate this to filling time. Decreasing the left flow tube caused an increase in pump chamber filling time.

20. When the left beaker pressure was decreased to 10 mm Hg, what happened to the filling time? Filling time increased in response to decreased pressure in the left beaker.
The following questions refer to Activity 8: Studying Compensation.

21. With the right flow tube radius decreased to 2.5 mm, what conditions did you change to bring the flow rate back to normal? ____________________________________________________________________________________________

Increase left flow tube radius, increase pump pressure, increase left beaker pressure, and decrease right beaker pressure.

22. A decreased tube radius is analogous to atherosclerosis (plaque formation in vessels). Describe the effect this would have on resistance in the arterial system and how the human heart might compensate for this change. ____________________________________________________________________________________________

Atherosclerosis causes an increased arterial resistance; the heart compensates by increasing pumping pressure.
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- Browsers: Safari 1.3 (10.3.x only); Safari 2.0 (10.4.x only); Firefox 2.0
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4. When considering an upgrade for computer systems, memory (RAM) offers the largest performance increase for the least cost.

5. Having students work in pairs results in the most successful lab experience. If students must work in larger groups, have them each get keyboard and mouse experience with the program.

6. If students will be using an older computer and are having difficulty with the tracings, have them adjust the tracing to suit them. To make the tracings faster, click the **Tools menu, choose Modify Tracing**, and then click **Increase Speed**. On the other hand, if they want to see a higher-quality tracing, choose **Improve Tracing**.

7. Suggest to the students that they become familiar with the exercise before coming to lab. If students have a home computer, or access to a computer on campus, they can become familiar with the general operation of the simulations.

8. A short introductory presentation with the following elements is often helpful:
   a. Review the basics of heart anatomy and physiology, particularly the sequence of atrial to ventricular contraction.
b. Reinforce the concept of the electrical system of the heart, including the basics of electrical function at the cellular level.

c. Mention the sympathetic and parasympathetic connections to the heart, including the neurotransmitters and their functions.

d. Compare how this procedure is accomplished in a traditional wet lab to what they expect to see in the simulation.

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**Answers to Activity Questions**

**Activity 1: Recording Baseline Frog Heart Activity (p. PEx-103)**

2. 62 bpm

**Activity 2: Investigating the Refractory Period of Cardiac Muscle (pp. PEx-103–104)**

3. It is possible to induce an extrasystole in the relaxation part of the cardiac cycle.

4. The heart can not be tetanized by multiple stimuli.
   
   Tetanization would make the heart ineffective as a pump.

**Activity 3: Examining the Effect of Vagus Nerve Stimulation (p. PEx-104)**

5. Vagal stimulation initially decreased heart rate and force of contraction, and then caused the heartbeat to stop for a brief period before returning to a relatively normal contraction state after vagal escape initiates.

**Activity 4: Assessing the Effect of Temperature (pp. PEx-104–105)**

2. Cold Ringer’s solution decreased heart rate.
   
   (Various answers depending on students’ predictions.)

5. Warm Ringer’s solution increased heart rate.
   
   51 bpm at 5° C; 70 bpm at 32° C
   
   Increasing the temperature causes an increase in heart rate.

**Activity 5: Assessing the Effect of Pilocarpine (pp. PEx-105–106)**

5. 46 bpm

   Pilocarpine mimics vagal stimulation and slows the heart.

**Activity 6: Assessing the Effect of Atropine (p. PEx-106)**

4. 71 bpm

   The heart rate should increase.

   When atropine blocks the effect of acetylcholine, the effect is to allow the sympathetic neurotransmitter to bind to cardiac muscle tissue, thus increasing heart rate.

   Atropine and pilocarpine are antagonistic in their action.

**Activity 7: Assessing the Effect of Epinephrine (p. PEx-106)**

4. 80 bpm

   Epinephrine increases the heart rate and force of contraction.

   Epinephrine mimics the effects of the sympathetic nervous system.

**Activity 8: Assessing the Effect of Digitalis (p. PEx-106)**

4. 42 bpm

   Digitalis slows and steadies the heart.

**Activity 9: Assessing the Effect of Various Ions (p. PEx-107)**

6. Calcium increases the strength of contraction; probably induces spasticity.
• The heart rate does not stabilize until 23°C Ringers solution is applied.
• The heartbeat is irregular, speeding up at times, slowing down at others.

Sodium decreases the strength and rate of contraction.
• The heart rate does not stabilize until 23°C Ringers solution is applied.
• The heartbeat is irregular, speeding up at times, slowing down at others.

Potassium weakens cardiac contractions.
• The heart rate does not stabilize until 23°C Ringers solution is applied.
• The heartbeat decreases considerably at first, then becomes erratic—alternately speeding up and slowing down.

Yes, all three ions may induce arrhythmias.
Baseline Frog Heart Activity

The following questions refer to Activity 1: Recording Baseline Frog Heart Activity.

1. What was the baseline heart rate for the frog? 62 bpm

2. Which wave is larger, the one for atrial contraction or the one for ventricular contraction? Ventricular
   Why? Ventricular contraction produces a larger wave because the ventricle contracts more forcefully than do the atria.

The following questions refer to Activity 2: Investigating the Refractory Period of Cardiac Muscle.

3. At what time during the contraction cycle was it possible to induce an extrasystole?
   It is possible to induce an extrasystole in the relaxation part of the cardiac cycle.

4. By clicking the Multiple Stimulus button and delivering 20 stimuli/sec, were you able to achieve tetanus? Why or why not?
   The heart did not achieve tetanus because of the long absolute refractory period of cardiac muscle tissue.

The following questions refer to Activity 3: Examining the Effect of Vagus Nerve Stimulation.

5. What happens to the heart rate with vagal stimulation? Heart rate slows and eventually stops during vagal stimulation.

Assessing Physical and Chemical Modifiers of Heart Rate

The following questions refer to Activity 4: Assessing the Effect of Temperature.

7. List the frog heart rate for the following conditions:

   51 bpm with 5°C Ringer’s solution

   70 bpm with 32°C Ringer’s solution

8. Describe the effect of temperature on heart rate. Decreasing temperature causes a decrease in heart rate; increasing temperature causes an increase in heart rate. There is a direct relationship between temperature and heart rate.

9. Did this effect match your prediction? Explain. Various answers based on students’ predictions.

The following questions refer to Activity 5: Assessing the Effect of Pilocarpine.

10. What was the heart rate after treatment with pilocarpine?

    46 bpm with pilocarpine

11. Did this effect match your prediction? Explain. Various answers based on students’ predictions.

The following questions refer to Activity 6: Assessing the Effect of Atropine.

12. What was the heart rate after treatment with atropine?

    71 bpm with atropine

13. Are the effects of pilocarpine and atropine the same or opposite?

    The effects of pilocarpine and atropine are opposite.

The following questions refer to Activity 7: Assessing the Effect of Epinephrine.

14. What was the heart rate after treatment with epinephrine?

    81 bpm with epinephrine

15. Did this effect match your prediction? Explain. Various answers based on students’ predictions.

16. What division of the autonomic nervous system does the addition of epinephrine imitate? Epinephrine imitates the sympathetic nervous system.
17. What was the heart rate after treatment with digitalis?
   \[ \text{42 bpm with digitalis} \]

18. Describe the effect that digitalis had on the heart. \textit{Digitalis slows the heart rate.}

The following questions refer to Activity 9: Assessing the Effect of Various Ions.

19. Which ions resulted in arrhythmia of the frog heart? \textcolor{red}{
   Calcium ions, sodium ions, and potassium ions all caused arrhythmia of the frog heart.}

20. Which ion had the greatest effect on the frog heart? Explain. \textcolor{red}{
   Potassium ions had the greatest effect because increased potassium (hyperkalemia) decreases the resting potential of cardiac muscle plasma membranes, thus decreasing the force of heart contraction.}
Respiratory System Mechanics: Computer Simulation

Time Allotment: 11/2–2 hours.

Your computer should meet the following minimum requirements for PhysioEx™ 8.0:

**WINDOWS**
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- Resolution: 1024 × 768
- Latest version of Adobe Flash Player
- Latest version of Adobe Reader
- Browsers: Internet Explorer 6.0 (XP only); Internet Explorer 7.0; Firefox 2.0
- Internet Connection: 56K modem minimum for website
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**MACINTOSH**
- OS: 10.3.x, 10.4.x
- Resolution: 1024 × 768
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- Browsers: Safari 1.3 (10.3.x only); Safari 2.0 (10.4.x only); Firefox 2.0
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3. It is helpful to instruct students in the proper operation of the mouse and menu system as part of the lab introduction.

4. When considering an upgrade for computer systems, memory (RAM) offers the largest performance increase for the least cost.

5. Having students work in pairs results in the most successful lab experience. If students must work in larger groups, have them each get keyboard and mouse experience with the program.

6. Demonstrate the mechanics of the lungs during respiration if a bell jar and balloon lungs are available.

7. Prior to the lab, suggest to the students that they become familiar with the exercise before coming to class. If students have a home computer, or access to a computer on campus, they can become familiar with the general operation of the simulations before coming to class. In particular, they should understand the lung volumes.

8. A short introductory presentation with the following elements is often helpful:
   a. Review the basics of respiratory anatomy, particularly the inspiratory and expiratory sequence.
   b. Reinforce the fact that there are no fibrous or muscular connections between the lungs and the thoracic wall when doing the bell jar demonstration. Students often remember this demonstration more than most others.
c. Mention that inspiration requires muscle action but that expiration is passive.
d. If a demonstration computer and bell jar lungs are available, compare the operation of the on-screen lungs with the balloon lungs in the bell jar.
e. A pair of microscope slides with a thin film of water between makes an excellent demonstration of the concept of water tension.
f. Briefly explain the idea of carbon dioxide retention in the blood during hypoventilation and its removal from the blood by hyperventilation.
g. Review Boyle’s Law.
h. Remind students that the respiratory center in the brain is more sensitive to $P_{CO_2}$ than to $P_{O_2}$.

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**Answers to Activity Questions**

**Activity 1: Measuring Respiratory Volumes (pp. PEx-114–116)**

7. Expiratory reserve volume (ERV) does not include tidal volume

Expiratory reserve volume is the amount of air that can be expelled after a normal tidal exhalation. This means that tidal volume is not included in the ERV measurement.

**Activity 2: Examining the Effect of Changing Airway Resistance on Respiratory Volumes (p. PEx-116)**

7. FEV$_1$ (%) will decrease as the airway radius is decreased.

FEV$_1$ (%) is the amount of air that can be expelled from the lungs in one second during forced expiration. If the airway becomes smaller, then the resistance to airflow will increase and FEV$_1$ (%) will become lower.

**Activity 3: Examining the Effect of Surfactant (pp. PEx-117–118)**

8. FEV$_1$ (%) decreases as the radius of the airway is decreased.

Airflow increases when surfactant is applied because the resistance to lung inflation has been reduced. Surfactant is not produced in premature infants. Because surfactant is necessary for the lungs to inflate, it is not normally needed until birth.

**Activity 4: Investigating Intrapleural Pressure (pp. PEx-118–119)**

8. The lung in the left side of the bell jar deflated.

The pressure in the left lung was zero and the pressure in the right lung changed constantly. Because there was an opening to the atmosphere in the left side of the bell jar, air moved into the intrapleural space through the opening, which is the path of least resistance, causing intrapleural pressure to increase and equal atmospheric pressure.

The total airflow was reduced by one half.

Both lungs would collapse when the thoracic wall was punctured if the two lungs were in a single cavity instead of individual cavities.

9. The lungs did not reinflate when the valve was closed.

In addition to closing off the opening to the atmosphere, the excess air in the intrapleural space must be removed to decrease intrapleural pressure below atmospheric pressure before the lungs will reinflate.

14. After clicking Reset and running the experiment again, the function of the simulated lungs returned to normal. This happened because the air was removed from the intrapleural space, allowing the lungs to reinflate. Intrapleural pressure was decreased below atmospheric pressure by clicking Reset.

**Activity 5: Exploring Various Breathing Patterns (p. PEx-120)**

5. $P_{CO_2}$ decreased during rapid breathing because more $CO_2$ was removed from the blood than normal. Each breath expels a certain amount of $CO_2$. If the breathing rate increases, then more $CO_2$ is expelled.

**Rebreathing**

2. $P_{CO_2}$ increases during rebreathing because the $CO_2$ gradient is being increased by breathing air with a high $CO_2$ content.
The depth and rate of respirations increased during rebreathing. This is due in part to the increased CO₂ in the blood stimulating the respiratory centers in the brain stem.

**Breath Holding**

3. P_CO₂ increased dramatically during breath holding.
   The rate and depth of breathing increased slightly for a brief period when normal breathing resumed to allow P_CO₂ rates to decrease to the normal range.

**Activity 6: Comparative Spirometry (pp. PEx-121–123)**

**Normal Breathing**

8. FVC measures the amount of gases expelled when a subject takes a deep breath and then forcefully exhales maximally and as rapidly as possible; FEV₁ determines the amount of air expelled during the first second.
   The ratio of these two values is clinically important in determining whether the subject has healthy lungs, obstructive pulmonary disease, or restrictive disease.

**Emphysema Breathing**

6. FVC is reduced.
   FEV₁ is reduced.
   FEV₁ shows the greatest reduction from normal.
   A person with emphysema has a loss of intrinsic elastic recoil in the lung tissue as well as increased airway resistance; therefore, while the lungs can expand and fill easily, they can no longer passively recoil and deflate, so that person exhales slowly.

**Acute Asthma Attack Breathing**

6. FVC is reduced.
   FEV₁ is reduced.
   FEV₁ shows the greatest reduction from normal.
   During an asthma attack, bronchiole smooth muscle will spasm and constrict, and bronchioles clogged with mucous secretions cause increased airway resistance. The effect of an asthma attack is similar to emphysema in that both result in reductions in FVC and FEV₁. The cause of asthma is different from emphysema; asthma is caused by an increased airway resistance due to airway constriction, while emphysema is caused by lungs that no longer have the ability to passively recoil and deflate.
   A spirogram of a person with restrictive lung disease would have waves with lower amplitude than that of a person with normal lungs.
   A spirogram of a person with restrictive lung disease would show reduced VC, TLC, FRC, and RV. FEV₁/FVC percentage is less than normal.

**Acute Asthma Attack Breathing with Inhaler Medication Applied**

6. FVC is increased with medication but is still below normal.
   FEV₁ is increased with medication but is still below normal.
   The FEV₁ changed more than the FVC.
   Asthma medication causes smooth muscle spasms to relax, thus increasing the airway; therefore, it is much easier for a greater percentage of gases to be expelled in one second.
   Various answers (opinion question)

**Breathing During Exercise**

a., b., c., d., e. are student predictions

5. TV increased over normal breathing with both moderate and heavy exercise. The respiratory rate is much higher during heavy exercise.
Respiratory System Mechanics: Computer Simulation

Pulmonary Function Tests

The following questions refer to Activity 1: Measuring Respiratory Volumes.

1. What activity are you simulating when you click the ERV button? Maximal exhale following normal TV exhale

   What additional muscles are used in this activity? Internal intercostals and abdominal muscles

2. What was the MRV calculated in Activity 1? 7543–7485

3. What does the pump rate simulate? Respiratory rate

The following questions refer to Activity 2: Examining the Effect of Changing Airway Resistance on Respiratory Volumes.

4. How did changing the radius effect FEV₁ (%)? Decreasing radius caused a decrease in FEV₁ (%)

5. What was the FEV₁ at a radius of 5.00 mm? 3541

6. Do the results suggest that there is an obstructive or restrictive problem? Explain.
   There is no problem because the airway is of normal radius.

Simulating Factors Affecting Respirations

The following questions refer to Activity 3: Examining the Effect of Surfactant.

7. What effect does the addition of surfactant have on the airflow? The addition of surfactant causes increased airflow.

8. Why does surfactant affect airflow? Surfactant causes reduced surface tension in the alveoli, therefore the alveoli are able to expand to a greater degree.

9. Why do premature infants have difficulty breathing? Premature infants lack a sufficient amount of surfactant.
The following questions refer to Activity 4: Investigating Intrapleural Pressure.

10. What effect does opening the valve have on the left lung? Why does this happen?

_The left lung collapses because intrapleural and atmospheric pressure are equal._

11. What condition does opening the valve simulate? _Pneumothorax_

12. What is the value of the pressure in the left lung when the valve is opened? _0.00_

13. What happened to the total flow when the valve was opened? _Total flow was half the amount of flow recorded when both lungs were functioning._

14. In the last part of this activity, when the reset button was clicked, what procedure would be used with real lungs? _Insertion of a chest tube to remove air from the pleural cavity._

### Simulating Variations in Breathing

The following questions refer to Activity 5: Exploring Various Breathing Patterns.

15. What was the value of the P\textsubscript{CO}_2 with rapid breathing? _\sim 39.74_

_How does this compare to the value with normal breathing? Explain any differences._

\( P\text{\textsubscript{CO}_2} \) _is lower in rapid breathing than normal breathing because more CO\textsubscript{2} is expelled than is made during cellular respiration._

16. What was the value of the P\textsubscript{CO}_2 with rebreathing? _\sim 53.96_

_Explains any difference._ _Air high in CO\textsubscript{2} is being inhaled._

17. What happened to the rate of respirations with rebreathing? _Slightly faster than normal breathing_

_Why do you think this happened? (Hint: Think about the effects of chemoreceptors in the body.)_ _\uparrow CO\textsubscript{2} stimulates breathing center to \uparrow breathing rate._

18. What was the value of the P\textsubscript{CO}_2 with breath holding? Explain any difference.

\( P\text{\textsubscript{CO}_2} = \sim 49.11; P\text{\textsubscript{CO}_2} \) _increased during breath holding, then decreased during resumption of normal breathing._

19. Was there a change in the rate of respirations when the breathing was resumed?

_The rate of respirations increased when breathing resumed._
The following questions refer to Activity 6: Comparative Spirometry.

20. What was the value obtained for the \((\text{FEV}_1/\text{FVC}) \times 100\%\) with “normal breathing”?
   
   80%

21. What effect did “emphysema breathing” have on FVC and FEV₁?
   
   Both FVC and FEV₁ were reduced.

22. In “emphysema breathing” which of the two values, FVC and FEV₁, changed the most? FEV₁ changed the most.

23. What effect did “acute asthma attack breathing” have on FVC and FEV₁?
   
   Both FVC and FEV₁ were reduced.

24. In “acute asthma attack breathing” which of the two values, FVC and FEV₁, changed the most? FEV₁ changed the most.

25. Describe the effect that the inhaler medication had on the FVC and FEV₁.
   
   Inhaler medication caused an increase of FVC and FEV₁ to near normal values.

26. Did the values return to “normal”? Explain. Neither value returned to normal because the smooth muscles in the bronchioles did not relax to normal and/or there was a residue of mucus blocking the airway.

27. During “moderate exercise breathing,” which volumes changed the most?
   
   Tidal volume changed the most.

28. During “heavy exercise breathing,” which volumes changed the most?
   
   Tidal volume increased greatly; ERV and IRV both were greatly reduced.
Chemical and Physical Processes of Digestion: Computer Simulation

**Time Allotment:** 2 hours minimum if students are well-prepared. 3 hours preferred for the full exercise. 2 hours minimum if only the simulation is used.

Your computer should meet the following minimum requirements for PhysioEx™ 8.0:

**WINDOWS**
- OS: Windows XP, Vista
- Resolution: 1024 × 768
- Latest version of Adobe Flash Player
- Latest version of Adobe Reader
- Browsers: Internet Explorer 6.0 (XP only); Internet Explorer 7.0; Firefox 2.0
- Internet Connection: 56K modem minimum for website
- Printer

**MACINTOSH**
- OS: 10.3.x, 10.4.x
- Resolution: 1024 × 768
- Latest version of Adobe Flash Player
- Latest version of Adobe Reader
- Browsers: Safari 1.3 (10.3.x only); Safari 2.0 (10.4.x only); Firefox 2.0
- Internet Connection: 56K modem minimum for website
- Printer

**Advance Preparation, Comments, and Pitfalls**

1. *If you are using PhysioEx in a computer lab:* Because PhysioEx requires a browser (such as Firefox or Internet Explorer) and the Flash player to run, it is recommended that you make sure these items are already installed on student computers before beginning this lab.

2. *If you are using the web version of PhysioEx:* Have your students go to http://www.myaandp.com and follow the registration instructions found in the very front of their lab manual.

3. It is helpful to instruct students in the proper operation of the mouse and menu system as part of the lab introduction.

4. When considering an upgrade for computer systems, memory (RAM) offers the largest performance increase for the least cost.

5. Having students work in pairs results in the most successful lab experience. If students must work in larger groups, have them each get keyboard and mouse experience with the program.

6. Suggest to the students that they become familiar with the exercise before coming to class. If students have a home computer or access to a computer on campus they can become familiar with the general operation of the simulations before coming to class.

7. A short introductory presentation with the following elements is often helpful:
   a. Describe the basics of enzymatic hydrolysis, mentioning how the enzyme-substrate interaction puts stress on the chemical bonds within the substrate to aid in the hydrolytic action.
   b. Students need to clearly understand why the different control tubes are necessary. Explain this concept with plenty of examples.
   c. Because enzymes work as well *in vitro* as they do *in vivo*, encourage students to apply what they see in the simulation to what must occur in the lumen of the digestive system.
   d. If a demonstration computer screen is available, briefly show students the basic equipment parts.
8. As the lab progresses, ask students questions directing them to think about the logic of the experiment. For example, if a group of students makes the statement: “Amylase digests starch to maltose,” try asking some of the following questions as the opportunity arises:

- How do you know that the amylase preparation was not contaminated with maltose?
- How do you know that the buffer was not contaminated with maltose?
- How do you know that the water was not contaminated with maltose?
- How do you know that you even started with starch, and that the starch was not contaminated with maltose?

9. Be prepared to help the students answer the more difficult “What if …” questions.

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Answers to Activity Questions

Activity 1: Assessing Starch Digestion by Salivary Amylase (pp. PEx-132–133)

10. Tubes 2, 6, and 7 showed the effect of pH on amylase activity. The results of this experiment indicate that the activity maximum of amylase is at pH 7.0, whereas pH 2.0 and pH 9.0 demonstrated very little activity.

In this experiment, pH 7.0 showed the highest level of amylase activity.

Tube 3 showed that amylase did not contain maltose contamination.

Tubes 3, 4, and 5 showed that water had no starch or maltose contamination. Tube 3 directly showed that water did not have maltose or starch contamination. Tube 4 was a starch control (with the same water) that showed no maltose, and tube 5 was a maltose control (also with water) that showed no starch.

If control tubes 3, 4, or 5 were not done, then what is perceived as digestion might really be starch or maltose contamination.

Saliva would not be active in the stomach because the stomach pH is too low.

Boiling inactivates, or denatures, enzymes.

Activity 2: Assessing Cellulose Digestion (pp. PEx-133–135)

10. Tubes #4, 5, and 6 showed that starch or cellulose was still present.

Tubes #1, 2, 3, and 7 showed positive tests for the Benedict’s reagent, indicating the presence of reducing sugar.

Freezing had no effect.

Freezing does not restrict enzyme activity, unlike boiling.

Amylase had no effect on the cellulose in tube #4.

Cellulose is digestible by bacteria.

Peptidase had no effect on animal starch. Peptidase does not work on carbohydrate substrates so has no effect on digestion of these molecules.

Activity 3: Assessing Protein Digestion by Pepsin (pp. PEx-136–137)

8. pH 2.0 allowed the highest pepsin activity.

Pepsin would not be active in the mouth. The pH optimum of pepsin is pH 2.0 and the pH in the mouth is relatively neutral.

Boiling tube 1 inactivated pepsin. Pepsin digested BAPNA in tube 2.

Because there was no activity in tube 1, its optical density was 0.0. In contrast, there was relatively high activity in tube 2.

Tubes 3 and 4 proved that neither pepsin nor deionized water contain any contaminating digested BAPNA since the optical density in both of these tubes was 0.0.

If the incubation time were decreased to 30 minutes, slightly less BAPNA would be digested, and the optical density reading would be slightly lower.

Because digestive enzymes work best at body temperature, incubating at a cooler temperature would decrease the amount of BAPNA digested.
Activity 4: Assessing Fat Digestion by Pancreatic Lipase and the Action of Bile (pp. PEx-137–139)

7. Tube 1 investigated the action of bile on enzyme activity, and tube 2 examined lipase activity without bile. Bile enhances fat digestion by lipase.

Yes, you can determine if activity occurred in tube 6 because the pH would drop below pH 9.0. A small amount of fat digestion occurred because pH decreased from 9.0 to 8.97.

The optimum pH for lipase activity was pH 7.0.

Using a pH method to assay for activity at pH 2.0 does not work because the buffer is already quite acidic. There could have been activity at pH 2.0 that was not detectable by this method.

In theory, lipase would be active in the mouth because its pH optimum is relatively neutral. However, it would not be active in the stomach because of the acidic pH condition.

The substrate is vegetable oil (fat). The subunit formed is fatty acid (and monoglycerides).

Activity 5: Studying Mechanisms of Food Propulsion and Mixing: Deglutition (Swallowing) (pp. PEx-139–140)

1. The tongue is depressed while water enters the mouth; elevated during swallowing.

2. The larynx is elevated during swallowing.

   These movements close the nasopharynx and the laryngopharynx to prevent water from entering the airway.
Chemical and Physical Processes of Digestion: Computer Simulation

Carbohydrate Digestion

The following questions refer to Activity 1: Assessing Starch Digestion by Salivary Amylase.

1. At what pH did you see the highest activity of salivary amylase? 7. Why?
   
   Salivary amylase is active in the mouth, which has a pH of 7.

2. How do you know that the amylase did not have any contaminating maltose?
   
   Tube 3 showed that amylase had no contaminating maltose.

3. What effect did boiling have on enzyme activity? Why?
   
   Boiling caused the protein salivary amylase to be denatured, thus inactivating the enzyme.

4. Describe the substrate and the subunit product of amylase.
   
   The substrate is starch; the product is maltose.

The following questions refer to Activity 2: Assessing Cellulose Digestion.

5. Does amylase use cellulose as a substrate? Explain.
   
   No; amylase is an enzyme that does not digest cellulose, only starch.

6. Did freezing have an effect on the activity of amylase? Explain.
   
   No; the enzyme activity was the same at freezing as it was at 37°.

7. Do you think that the bacterial suspension contained the enzyme cellulase (an enzyme that digests cellulose)? Why or why not?
   
   Yes; cellulose had been digested to maltose in tube 7.

8. What is the substrate of peptidase? Explain, based upon your results.
   
   In the carbohydrate digestion simulation, there was no substrate of peptidase because no maltose was produced in the tube containing cellulose and peptidase.
Protein Digestion by Pepsin

The following questions refer to Activity 3: Assessing Protein Digestion by Pepsin.

9. At which pH did you see the highest activity of pepsin? 2 How does this correlate to the location of pepsin in the body? Pepsin is found in the stomach where the pH is 2.

10. What effect did boiling have on pepsin? Pepsin did not digest BAPNA in tube 1 so it can be concluded that boiling denatures pepsin.

11. Was there any digested BAPNA contaminating the pepsin or deionized (DI) water? No

   How can you tell? Tubes 3 and 4 had an optical density reading of 0.0.

12. What is the substrate in this experiment? BAPNA

   What is the usual substrate for pepsin, and what subunits are formed with pepsin activity?

   Substrate—proteins

   Subunits formed—proteoses, peptones, peptides (all small protein fragments), and free amino acids

13. What was the effect of decreasing the incubation time on the optical density results?

   Decreasing incubation time resulted in a slightly lower optical density.

14. What effect would decreased incubation temperature have on pepsin activity? Why?

   Decreased incubation temperature reduced pepsin activity because the optimal temperature for pepsin activity is body temperature.

15. What was the significance of using 37°C for the incubation? 37°C is body temperature.

Fat Digestion by Pancreatic Lipase and the Action of Bile

The following questions refer to Activity 4: Assessing Fat Digestion by Pancreatic Lipase and the Action of Bile.

16. Describe the activity of lipase with and without the addition of bile salts. Refer to Chart 4 for pH values. The activity of lipase is greater with the addition of bile salts.

17. Is the activity of bile a chemical or a physical process? Explain. Bile activity is a physical process; it breaks fat particles into smaller fat particles.
18. What pH resulted in the maximum pancreatic lipase activity? **7.0**

How does this optimal pH correlate to the enzyme’s location in the body? **The pH of the small intestines is neutral.**

19. Explain whether or not we can determine fat hydrolysis in tube 5. Why or why not?

*We cannot determine if fat hydrolysis occurred in tube 5, which had a buffer of 2.0, and the pH of the solution after incubation was still 2.0. There could have been activity at pH 2.0 that was not detectable by this assay method.*

20. What is the substrate in this experiment? **vegetable oil (fat)**

What subunits does lipase form? **fatty acids and monoglyceride**

**Physical Process: Mechanisms of Food Propulsion and Mixing**

The following questions refer to Activity 5: Studying Mechanisms of Food Propulsion and Mixing: Deglutition (Swallowing).

21. Explain the significance of the movement of the tongue during swallowing. *The tongue initiates and controls the buccal phase of swallowing by pushing contents into the pharynx.*

22. Describe three events that occur during the pharyngeal-esophageal phase of deglutition. *Mouth, nasopharynx, and larynx are blocked; upper esophageal sphincter relaxes to open esophagus; food moves through esophagus by pressure gradients created by peristalsis.*

23. What was the time interval that you recorded between the first and second sound? **1–2 seconds**
Time Allotment: 2 hours.

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4. When considering an upgrade for computer systems, memory (RAM) offers the largest performance increase for the least cost.

5. Having students work in pairs results in the most successful lab experience. If students must work in larger groups, have them each get keyboard and mouse experience with the program.

6. Prior to the lab, suggest to the students that they become familiar with the exercise before coming to class. If students have a home computer, or access to a computer on campus, they can become familiar with the general operation of the simulations before coming to class. In particular, they should examine the structure of the nephron in the textbook.

7. A good working knowledge of diffusion, filtration, and osmosis is important in understanding renal function. Suggest to the students that they review those concepts before coming to class.

8. A short introductory presentation with the following elements is often helpful:
   a. Review the basics of nephron anatomy and basic renal physiology, focusing on the major concepts such as glomerular filtration and the movement of substances due to passive and active forces.
   b. Reinforce the idea of how changing the arteriole diameter influences the filtration pressure in the glomerulus.
c. Use the analogy of a coffee filter when describing the filtration that takes place in the glomerulus.
d. If the students have not been exposed to the concept of carrier transport, a short introduction using glucose as an example might be helpful.
e. Encourage students to make the transition from what they see in the simulation to what they see under microscopic examination.
f. Remind students that they are manipulating a single nephron that represents the function of the entire kidney, but that the living kidney contains many nephrons.

9. Be prepared to help the students answer the more difficult “What if …” questions.

Answers to Activity Questions

Activity 1: Investigating the Effect of Flow Tube Radius on Glomerular Filtration (p. PEx-147)

8. Glomerular filtration rate increases as afferent arteriole diameter increases due to the increased blood flow into the glomerulus.
   
   If the diameter of the efferent arteriole was increased, filtration pressure in the glomerulus would decrease, thereby decreasing glomerular filtration rate. If the radius of the efferent arteriole was decreased, upstream pressure would increase and glomerular filtration would also increase.

Activity 2: Studying the Effect of Pressure on Glomerular Filtration (pp. PEx-147–148)

8. Glomerular filtration rate increased.

   GFR increased because the net filtration pressure was increased. Net filtration pressure relies on glomerular hydrostatic pressure, which rises when the pressure in the beaker is increased.

Activity 3: Exploring Intrinsic Controls: Renal Autoregulation (p. PEx-148)

9. 129.61 mm Hg
13. 151.24 mm Hg
14. Increase/decrease in the afferent radius, increase/decrease in the efferent radius.
16. Afferent radius 52 mm
    Efferent radius 52 mm

Activity 4: Exploring the Role of the Solute Gradient on Maximum Urine Concentration Achievable (pp. PEx-149–150)

9. When ADH is present, urine concentration increases as the interstitial gradient increases.

   When ADH is present, urine volume decreases as the interstitial gradient increases.
   The osmolarity of the interstitial gradient determines the maximum possible urine concentration.
   Yes, because osmotic forces draw water out of the collecting tubule. Therefore, increasing the concentration of solutes outside the tubule will increase the maximum possible urine concentration. The maximum possible urine concentration will therefore be equal to the interstitial solute concentration.

Activity 5: Studying the Effect of Glucose Carrier Proteins on Glucose Reabsorption (pp. PEx-150–151)

9. The amount of glucose in the urine decreased as the number of glucose carriers was increased.

   If there was more glucose than could be transported by the number of available glucose carriers, then glucose would be present in the urine.
   We would expect to find glucose in the urine of a diabetic person because there is too much glucose in the filtrate to be reabsorbed.
5. Baseline urine volume 201.00
6. Urine volume with aldosterone present 180.90
   When aldosterone is present, urine volume is decreased.
   Aldosterone causes sodium reabsorption in the distal tubule at the expense of potassium, which will be
   transported to the lumen of the tubule and into the urine.
7. When ADH is present, urine volume is greatly reduced.
   There is no difference in the amount of potassium in the urine. Although the concentration is higher when
   ADH is present and the volume of urine has been reduced, the total amount of potassium has not changed.
   The effects of aldosterone and ADH are similar.
   The amount of aldosterone would need to be increased while the amount of ADH would need to decrease.
Renal System Physiology: Computer Simulation

Simulating Glomerular Filtration

The following questions refer to Activity 1: Investigating the Effect of Flow Tube Radius on Glomerular Filtration.

1. Describe the effect of increasing the afferent radius on glomerular filtration rate and glomerular pressure.

*GFR and glomerular pressure both increase.*

2. Describe the effect of decreasing the efferent radius on glomerular filtration rate and glomerular pressure.

*GFR and glomerular pressure both increase.*

3. Describe the effect of increasing the efferent radius on glomerular filtration rate and glomerular pressure.

*GFR and glomerular pressure both decrease.*

The following questions refer to Activity 2: Studying the Effect of Pressure on Glomerular Filtration.

4. Describe the effect of increasing the beaker pressure on glomerular filtration rate.

*GFR increases.*

5. Describe the effect of increasing the beaker pressure on glomerular pressure.

*Glomerular pressure increases.*

6. In the absence of any regulatory mechanisms, what effect do you think an increase in blood pressure would have on glomerular filtration rate? *Increased blood pressure causes an increase in GFR.*
The following questions refer to Activity 3: Exploring Intrinsic Controls: Renal Autoregulation.

7. What was the glomerular filtration rate at 80 mm Hg beaker pressure, 0.55 mm afferent radius, and 0.45 mm efferent radius? 
   129.61

8. With the beaker pressure increased to 85 mm Hg, at what afferent radius was the glomerular filtration rate in question 7 restored? 
   Between 0.52 and 0.53 mm

9. With the beaker pressure increased to 85 mm Hg, at what efferent radius was the glomerular filtration rate in question 7 restored? 
   Between 0.51 and 0.52 mm

10. In the body, what mechanisms play a role in maintaining glomerular filtration rate with fluctuating blood pressure?
    The myogenic mechanism, tubuloglomerular feedback mechanism, sympathetic nervous system controls, renin-angiotensin mechanism, and release of prostaglandin E2, intrarenal angiotensin II, and adenosine

Simulating Urine Formation

The following questions refer to Activity 4: Exploring the Role of the Solute Gradient on Maximum Urine Concentration Achievable.

11. As you increased the concentration gradient of the interstitial fluid, what happened to the concentration of the urine? 
    When ADH is present, urine concentration is increased.

12. What happened to the volume of the urine as you increased the concentration gradient of the interstitial fluid? 
    When ADH is present, urine volume is decreased.

13. What effect does the concentration gradient of the interstitial fluid have on the maximum urine concentration? 
    When ADH is present, urine concentration equals interstitial fluid concentration.

The following questions refer to Activity 5: Studying the Effect of Glucose Carrier Proteins on Glucose Reabsorption.

14. What happens to the concentration of glucose in the urine as the number of glucose carriers increases? 
    Concentration of glucose in urine decreases.

15. Glucose can be elevated in the blood of a diabetic person. Relate this information to glucose in the urine and glucose carriers. 
    Since a diabetic has insufficient insulin to transport glucose from the blood into cells, there is increased glucose in the blood, therefore increased glucose in filtrate and urine.
The following questions refer to Activity 6: Testing the Effects of Hormones on Urine Formation.

16. What was the volume of urine in the presence of aldosterone? \(180.90\) 
   How did aldosterone affect the urine volume? Slight decrease

17. What happened to the concentration of potassium in the urine in the presence of aldosterone? Increased

18. What was the volume of the urine in the presence of ADH? \(20.14\) 
   How did ADH affect the urine volume? Dramatic decrease

19. Why did the concentration of potassium change in the presence of ADH without a change in the excretion of potassium? 
   *With ADH, urine volume is one-tenth of volume without ADH. With ADH, potassium concentration is 10 times that of the concentration without ADH. There is no increase in potassium secretion with ADH.*

20. Does ADH favor the formation of dilute or concentrated urine? Explain. ADH favors formation of concentrated urine because 
   *ADH causes an increase of water permeability in the DCT and collecting ducts. Water moves from these tubules into the interstitial fluid by osmosis.*
Time Allotment: 2 hours.

Your computer should meet the following minimum requirements for PhysioEx™ 8.0:

**WINDOWS**
- OS: Windows XP, Vista
- Resolution: 1024 × 768
- Latest version of Adobe Flash Player
- Latest version of Adobe Reader
- Browsers: Internet Explorer 6.0 (XP only); Internet Explorer 7.0; Firefox 2.0
- Internet Connection: 56K modem minimum for website
- Printer

**MACINTOSH**
- OS: 10.3.x, 10.4.x
- Resolution: 1024 × 768
- Latest version of Adobe Flash Player
- Latest version of Adobe Reader
- Browsers: Safari 1.3 (10.3.x only); Safari 2.0 (10.4.x only); Firefox 2.0
- Internet Connection: 56K modem minimum for website
- Printer

**Advance Preparation, Comments, and Pitfalls**

1. If you are using PhysioEx in a computer lab: Because PhysioEx requires a browser (such as Firefox or Internet Explorer) and the Flash player to run, it is recommended that you make sure these items are already installed on student computers before beginning this lab.

2. If you are using the web version of PhysioEx: Have your students go to http://www.myaandp.com and follow the registration instructions found in the very front of their lab manual.

3. It is helpful to instruct students in the proper operation of the mouse and menu system as part of the lab introduction.

4. When considering an upgrade for computer systems, memory (RAM) offers the largest performance increase for the least cost.

5. Spend time reviewing acid and base as well as the $\text{H}_2\text{O} + \text{CO}_2 \leftrightarrow \text{H}_2\text{CO}_3 \leftrightarrow \text{H}^+ + \text{CO}_3^-$ equation.

**Answers to Activity Questions**

**Activity 1: Normal Breathing (p. PEx-160)**

1. Answers will vary from run to run, but always remain constant within an individual run. The pH will always be between 7.38 and 7.42.

5. No, the pH level of the blood did not change during normal breathing.
   - Yes, the pH level remained within the normal range for the human body.
   - No, the $\text{PCO}_2$ level did not change during the course of normal breathing.
Activity 2a: Hyperventilation: Run 1 (p. PEx-160)

1. at 20 seconds, pH = about 7.45
   at 40 seconds, pH = about 7.54
   at 60 seconds, pH = about 7.67
   maximum pH = 40

5. Yes, the pH level of the blood increased over time.
   No, the pH level was not always within the normal range.
   The pH value began to exceed the normal range between 10 and 20 seconds—as soon as it rose above 7.45. This indicated the condition of alkalosis.
   Yes, the PCO2 level decreased over time.
   You would expect the renal system to compensate for alkalosis by retaining [H+] and excreting bicarbonate in order to lower the blood pH levels back to within the normal range.
   The hyperventilation trace had higher peaks and valleys than the normal breathing trace. The tidal volumes were also larger in the hyperventilation trace.
   Causes of hyperventilation include fever or anxiety.

Activity 2b: Hyperventilation: Run 2 (pp. PEx-160–161)

4. After the 20-second mark, when hyperventilation was stopped, the trace flat-lined, indicating that breathing was suspended. Breathing did not return to normal immediately. The body temporarily stopped breathing in order to restore P CO2 levels to normal values.

Activity 3: Rebreathing (p. PEx-161)

1. at 20 seconds, pH = about 7.35
   at 40 seconds, pH = about 7.3
   at 60 seconds, pH = about 7.25

5. Yes, the pH level of the blood decreased over time.
   No, the pH level was not always within the normal range.
   The pH value began to dip below the normal range between 20 and 30 seconds—as soon as it was below 7.35. This indicated the condition of acidosis.
   Yes, the PCO2 level increased over time.
   You would expect the renal system to compensate for acidosis by excreting [H+] and retaining bicarbonate in order to raise the blood pH levels back to within normal range.
   The rebreathing trace had slightly higher peaks and valleys than the normal breathing trace. The tidal volumes were also larger in the rebreathing trace.
   Respiratory problems that would result in lowered pH values and higher P CO2 levels include lung disease and airway obstruction—anything that impairs breathing.

Activity 4: Renal Response to Normal Acid-Base Balance (p. PEx-162)

3. At normal P CO2 and pH levels, a normal level of [H+] was present in the urine.
   A normal level of [HCO3−] was present in the urine.
   The blood pH value changes as P CO2 changes because P CO2 levels directly affect blood pH levels. As P CO2 increases, pH values decrease. As P CO2 levels decrease, pH values increase.
   Blood pH values increase as P CO2 decreases. There is an inverse relationship between blood pH values and P CO2.

Activity 5: Renal Response to Respiratory Alkalosis (p. PEx-163)

5. At P CO2 = 35, a normal level of [H+] was present in the urine. At P CO2 = 30 and 20, a decreased level of [H+] was present in the urine.
   At P CO2 = 35, a normal level of [HCO3−] was present in the urine. At P CO2 = 30 and 20, an elevated level of [HCO3−] was present in the urine.
   You would expect P CO2 levels to eventually increase.
You would expect pH levels to eventually decrease.
Reduced $P_{CO_2}$ levels most closely resemble the $P_{CO_2}$ levels we observed during hyperventilation.
Hyperventilation resulted in alkalosis because more carbon dioxide is being expelled by the body during this kind of breathing. The reduction of carbon dioxide inside the blood results in less $[H^+]$ being generated, which can cause pH levels to rise to the point of alkalosis.

**Activity 6: Renal Response to Respiratory Acidosis (p. PEx-163)**

6. At $P_{CO_2} = 60$, 75, and 90, an elevated level of $[H^+]$ was present in the urine.
   At $P_{CO_2} = 60$, 75, and 90, decreased levels of $[HCO_3^-]$ were present in the urine.
   You would expect $P_{CO_2}$ levels to eventually decrease.
   You would expect pH levels to eventually increase.
   Elevated $P_{CO_2}$ levels most closely resemble the $P_{CO_2}$ levels we observed during rebreathing.
   Rebreathing resulted in acidosis because carbon dioxide is being retained by the body during this kind of breathing. The increase in carbon dioxide inside the blood results in more $[H^+]$ being generated, which can cause pH levels to dip to point of acidosis.

**Activity 7: Respiratory Response to Normal Metabolism (p. PEx-164)**

5. The respiratory rate is 15 breaths per minute.
   Blood pH was approximately 7.4.
   Yes, the blood pH and $P_{CO_2}$ values are within normal ranges.

**Activity 8: Respiratory Response to Increased Metabolism (pp. PEx-165–166)**

6. As the body’s metabolic rate increased:
   - respiration rate and tidal volume increased
   - blood pH decreased
   - $P_{CO_2}$ values increased
   - $[H^+]$ increased
   - $[HCO_3^-]$ decreased
   As the body’s metabolic rate increased, more carbon dioxide was formed as a metabolic waste product. This caused an increase in $[H^+]$ generation, which lowered the plasma pH, causing respiration to increase in order to expel the elevated levels of carbon dioxide and restore pH to a normal value.
   Metabolic rates of 70 and 80 resulted in acidosis.
   At metabolic rate = 70, the pH value was about 7.27. At metabolic rate = 80, the pH value was about 7.25. Acidosis occurs at pH levels below 7.35. (The pH values will vary slightly from run to run.)
   By the time the respiratory system fully compensated for acidosis, you would expect pH levels to rise to normal values.

**Activity 9: Respiratory Response to Decreased Metabolism (p. PEx-166)**

6. As the body’s metabolic rate decreased:
   - respiration decreased
   - blood pH increased
   - $P_{CO_2}$ values decreased
   - $[H^+]$ decreased
   - $[HCO_3^-]$ increased
   As the body’s metabolic rate decreased, less carbon dioxide was formed as a metabolic waste product. This caused a decrease in $[H^+]$ generation, which increased the plasma pH, causing respiration to decrease in order to retain more carbon dioxide in the blood and restore pH to a normal value.
   Metabolic rates of 30 and 20 resulted in alkalosis.
   At metabolic rate = 30, the pH value was about 7.47. At metabolic rate = 20, the pH value was about 7.51. Alkalosis occurs at pH values above 7.45. (The pH values will vary slightly from run to run.)
   By the time the respiratory system fully compensated for alkalosis, you would expect pH levels to decrease to normal values.
Acid-Base Balance: Computer Simulation

Respiratory Acidosis and Alkalosis

The following questions refer to Activity 1: Normal Breathing.

1. What was the pH level during normal breathing? 7.38–7.42 (Answers vary from run to run, but always remain constant within an individual run.)

2. Was this pH within the normal pH range? Yes

The following questions refer to Activity 2: Hyperventilation.

3. In run 1, what was the maximum pH recorded with hyperventilation? 7.68

4. What acid-base imbalance occurred with hyperventilation? Respiratory alkalosis

5. What happened to the tidal volume during hyperventilation? Tidal volume increased during hyperventilation.

6. Describe the trace when hyperventilation stopped in run 2. After hyperventilation stopped there was a pause in breathing during which PCO₂ levels increased.

The following questions refer to Activity 3: Rebreathing.

7. What was the effect on pH over time with rebreathing? During rebreathing, pH levels decreased.

8. Did rebreathing result in acidosis or alkalosis? Why? Hint: Specifically relate this to the level of CO₂. Acidosis; because an increase in PCO₂ results in increased H⁺ (H₂O + CO₂ ↔ H₂CO₃ ↔ H⁺ + HCO₃⁻).

9. List some potential causes that would mimic the patterns of pH and CO₂ levels seen in this rebreathing simulation. Lung disease and airway obstruction such as asthma.

Renal System Compensation

The following questions refer to Activity 4: Renal Response to Normal Acid-Base Balance.

10. Describe how the pH of the blood changes with an increase in the level of CO₂. Blood pH decreases with an increase in the level of CO₂.
11. Why does this change occur? The increase in $P_{CO_2}$ causes more $[H^+]$ to be generated.

The following questions refer to Activity 5: Renal Response to Respiratory Alkalosis.

12. What happened to the level of $[H^+]$ in the urine as the level of $CO_2$ decreased? As the level of $CO_2$ decreased, the amount of $[H^+]$ in the urine decreased.

13. Explain how the renal system compensates for respiratory alkalosis. The renal system retains $[H^+]$ and releases $[HCO_3^-]$ to compensate for respiratory alkalosis.

14. Which type of breathing results in respiratory alkalosis? Hyperventilation

The following questions refer to Activity 6: Renal Response to Respiratory Acidosis.

15. Explain how the renal system compensates for respiratory acidosis. The renal system releases $[H^+]$ and retains $[HCO_3^-]$ to compensate for respiratory acidosis.

16. Which type of breathing results in respiratory acidosis? Rebreathing and breath holding

**Metabolic Acidosis and Alkalosis**

The following questions refer to Activity 8: Respiratory Response to Increased Metabolism.

17. What waste product is increased with an increased rate of metabolism? $CO_2$

18. Which metabolic rates results in metabolic acidosis? Metabolic rates of 70 and 80

19. List some other potential causes of metabolic acidosis. Ketoacidosis, salicylate poisoning, ingestion of too much alcohol, diarrhea, strenuous exercise

The following questions refer to Activity 9: Respiratory Response to Decreased Metabolism.

20. Which metabolic rates resulted in metabolic alkalosis? Metabolic rates of 30 and 20

21. List some other potential causes of metabolic alkalosis. Alkali ingestion (i.e., antacids or bicarbonate), vomiting, constipation
Frequently Asked Questions

CD Version

Q: Why do I need a browser and Flash Player to run a CD?
A: PhysioEx was developed in browser format so that users could have the option to access PhysioEx online at www.myaandp.com or at www.physioex.com. The lab interfaces for the CD and the web are exactly the same. Flash Player is a browser plugin used to display high-impact animations on the web with minimal download time.

Q: Does this mean I need a live Internet connection to use the CD?
A: No—you do not need a live Internet connection to use the CD.

Q: How can I access the web version of PhysioEx?
A: At the front of the manual is a “tip-in” sheet containing access codes that you will need to access the website at www.myaandp.com.

Q: Are there any differences between the CD and web versions of PhysioEx?
A: No. The lab interfaces are identical.

Web Version

Q: I am using the web version of PhysioEx. Is it possible to improve the download time of the labs?
A: PhysioEx was developed using the best technology available for fast download times. If you have DSL or cable access to the Internet, the labs should load very quickly. On a 56k modem, it can take 20 seconds to 1 minute to load some labs. Once the lab is loaded, your computer will store it in its cache, and you should not experience any further delays as you work through it. (The one exception to this is the Histology Atlas and Review Supplement, which is recommended for use only with DSL or cable access to the Internet.)

Q: What if I forget my user ID and password?

General Troubleshooting

Q: Help! Within the labs, one or more of the following things are happening:
   • The screen is flashing very fast.
   • Nothing happens when I click on the buttons.
   • There are green numbers in all the display fields, as though someone has already entered data.
A: There are two possibilities here:
1) You do not have the Flash Player plugin properly installed.
2) You are using a computer that does not meet the minimum system requirements. See the liner notes for the minimum requirements. (Nothing happening when buttons are clicked is a known problem on Macintosh 8.1. The minimum Mac requirement to use PhysioEx is Macintosh OS 10.3.x.)
Q: Why am I having trouble printing?
A: Make sure your printer is set to print in either grayscale or color. Most printers already have one of these as the default setting. If you have a black and white printer, make sure it is set to print in grayscale. Also make sure that your computer meets the minimum system requirements. If your computer has less than the minimum requirement of 128 MB RAM, printing may be very slow.

Q: My question isn't answered here. How can I reach someone?
This is a partial list of suppliers of equipment, animals, and chemicals, and should not be considered a recommendation for these companies. Many supply companies have regional addresses. Only one address is listed below.

**American Scientific LLC**  
6450 Fiesta Drive  
Columbus, OH 43235  
888-490-9002/614-764-9002  
www.american-scientific.com

**BIOPAC® Systems, Inc.**  
42 Aero Camino  
Goleta, CA 93117  
805-685-0066  
www.biopac.com

**Carolina Biological Supply Company**  
2700 York Road  
Burlington, NC 27215  
800-334-5551  
www.carolina.com

**Craig Medical Distribution, Inc.**  
1185 Park Center Drive, Building P  
Vista, CA 92081  
760-598-7170  
www.craigmedical.com

**CSI Forensic Supply**  
P.O. Box 16  
Martinez, CA 94553  
800-227-6020  
www.csiforensic.com

**EDVOTEK, Inc.**  
P.O. Box 34132  
Bethesda, MD 20827-1232  
800-338-6835  
www.edvotek.com

**Fisher Scientific**  
3970 John’s Creek Court, Suite 500  
Suwanee, GA 30024  
800-766-7000/770-871-4726  
www.fishersci.com

**Fotodyne, Inc.**  
950 Walnut Ridge Drive  
Hartland, WI 53029  
800-362-3686/262-369-7000  
www.fotodyne.com

**ICN Biochemicals**  
1263 South Chillicothe Road  
Aurora, OH 44202-8064  
800-854-0530  
www.icnbiomed.com

**Immucor, Inc.**  
3130 Gateway Drive  
P.O. Box 5625  
Norcross, GA 30091-5625  
800-510-5110  
www.immucor.com

**Intelitool® (Phipps & Bird)**  
P.O. Box 7475  
Richmond, VA 23221-0475  
800-955-7621  
www.intelitool.com

**LabChem, Inc.**  
200 William Pitt Way  
Pittsburgh, PA 15238  
412-826-5230  
www.labchem.net

**Modern Biology, Inc.**  
111N 500W  
West Lafayette, IN 47906  
800-733-6544  
www.modernbio.com

**Nasco**  
901 Janesville Avenue  
P.O. Box 901  
Fort Atkinson, WI 53538-0901  
800-558-9595  
www.enasco.com

**Nutri-Meds™**  
888-265-3353  
www.nutri-meds.com

**Sigma-Aldrich®**  
P.O. Box 14508  
St. Louis, MO 63178-9974  
800-325-3010  
www.sigma-aldrich.com

**Sirchie® Finger Print Laboratories**  
100 Hunter Place  
Youngsville, NC 27596  
800-356-7311  
www.sirchie.com

**Triarch, Inc.**  
P.O. Box 98  
Ripon, WI 54971  
800-848-0810  
www.triarchmicroslides.com

**VWR International, Inc.**  
200 Center Square Road  
Bridgeport, NJ 08014  
800-932-5000  
www.vwrsp.com

**WARD’S Natural Science**  
5100 West Henrietta Road  
Rochester, NY 14692-9012  
800-962-2660  
www.wardsci.com
## Guide to Multimedia Resource Distributors

Please Note: Distribution company names and web addresses change frequently.

<table>
<thead>
<tr>
<th>Code</th>
<th>Company Name</th>
<th>Address 1</th>
<th>Address 2</th>
<th>City, State Zip</th>
<th>Phone 1</th>
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<td>AIA</td>
<td>A.D.A.M., Inc.</td>
<td>10 10th Street NE, Suite 500</td>
<td>Atlanta, GA 30309</td>
<td>800-755-ADAM</td>
<td><a href="http://adameducation.com">http://adameducation.com</a></td>
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<tr>
<td>AS</td>
<td>Academic Superstore™</td>
<td>2101 E. Saint Elmo Rd., Suite 360</td>
<td>Austin, TX 78744</td>
<td>800-817-2347</td>
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<td>BC</td>
<td>Benjamin Cummings</td>
<td>1301 Sansome Street</td>
<td>San Francisco, CA 94111-2525</td>
<td>800-950-2665/415-402-2500</td>
<td><a href="http://www.pearsonhighered.com">www.pearsonhighered.com</a></td>
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<tr>
<td>CBS</td>
<td>Carolina Biological Supply Company</td>
<td>2700 York Road</td>
<td>Burlington, NC 27215</td>
<td>800-334-5551</td>
<td><a href="http://www.carolina.com">www.carolina.com</a></td>
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<tr>
<td>CS</td>
<td>Communication Skills, Inc.</td>
<td>49 Richmondville Avenue</td>
<td>Westport, CT 06880</td>
<td>800-824-2398/203-226-8820</td>
<td><a href="http://www.communicationskills.com">www.communicationskills.com</a></td>
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<tr>
<td>CVB</td>
<td>Connecticut Valley Biological Supply Company</td>
<td>P.O. Box 326</td>
<td>Southampton, MA 01073</td>
<td>800-628-7748</td>
<td><a href="http://www.ctvalleybio.com">www.ctvalleybio.com</a></td>
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<tr>
<td>DE</td>
<td>Discovery Education</td>
<td>1 Discovery Place</td>
<td>Silver Spring, MD 20910</td>
<td>800-323-9084</td>
<td><a href="http://www.discoveryeducation.com">www.discoveryeducation.com</a></td>
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<tr>
<td>EN</td>
<td>Nasco</td>
<td>901 Janesville Avenue</td>
<td>P.O. Box 901</td>
<td>Fort Atkinson, WI 53538-0901</td>
<td>800-558-9595</td>
<td><a href="http://www.enasco.com">www.enasco.com</a></td>
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<tr>
<td>ET</td>
<td>Edu-Technology</td>
<td>1351 Idylberry Rd</td>
<td>San Rafael, CA 94903</td>
<td>866-609-8913</td>
<td><a href="http://www.edu-technology.com">www.edu-technology.com</a></td>
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<td>HRM</td>
<td>HRM Video</td>
<td>41 Kensico Drive</td>
<td>Mount Kisco, NY 10549</td>
<td>800-431-2050</td>
<td><a href="http://www.hrmvideo.com">www.hrmvideo.com</a></td>
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<tr>
<td>NIMCO</td>
<td>NIMCO, Inc.</td>
<td>102 Highway 81 N</td>
<td>Calhoun, KY 42327-0009</td>
<td>800-962-6662</td>
<td><a href="http://www.nimcoinc.com">www.nimcoinc.com</a></td>
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