

Hole's Essentials of Human Anatomy and Physiology

High School Second Edition

**Sampler includes: Preface, Table of Contents,
Student Edition and Teacher Manual Chapter.**

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Graw
Hill**

Charles J. Welsh

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Hole's Essentials of Human Anatomy and Physiology

High School Second Edition

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ABOUT THE AUTHOR



CHARLES WELSH began his Anatomy & Physiology teaching career upon graduating with a B.S. in Biology from the University of Pittsburgh in 1989. He entered graduate school in 1992 and continued teaching night classes. He accepted his first full-time teaching position at Clarion University of Pennsylvania in 1996. In 1997, he completed his Ph.D. in Comparative Anatomy, Evolutionary Biology, and Ornithology. Teaching primarily in nursing and other allied health programs, he now brings his 30 years of classroom experience to the second high school edition of *Hole's Essentials of Human Anatomy & Physiology*. Since 2009, he has been teaching at Duquesne University in Pittsburgh, Pennsylvania. During this time, he has received several teaching awards, as well as the Mentor of the Year

Award for training graduate students to teach Anatomy & Physiology. Chuck and his wife, Lori, have three children and three grandchildren. They live in the historic town of Harmony, thirty miles north of Pittsburgh, with their youngest son, where they raise chickens and have a huge garden.



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Beyond her professional pursuits, Cynthia's passions include reading and listening to books, attending exercise classes, walking outdoors, attending concerts, traveling, and spending time with her family.

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DIGITAL AUTHORS

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JULIE PILCHER began teaching during her graduate training in Biomedical Sciences at Wright State University, Dayton, Ohio. She found, to her surprise, that working as a teaching assistant held her interest more than her research. Upon completion of her Ph.D. in 1986, she embarked on her teaching career, working for many years as an adjunct in a variety of schools as she raised her four children. In 1998, she began full-time at the University of Southern Indiana, Evansville. Her work with McGraw-Hill began several years ago, doing reviews of textbook chapters and lab manuals. When the opportunity arose to become more involved in the authoring of digital content for McGraw-Hill, she could not pass it up. Based on her own experience, students are using more and more online resources, and she is pleased to be part of that aspect of A&P education.

HIGH SCHOOL CONTRIBUTORS

ELIZABETH CO grew up in Vermont and received a BA in Biology from Mount Holyoke College and a PhD in Biomedical Sciences from the University of California, San Francisco. She has been teaching Anatomy, Physiology, Biology and Infectious Disease for the last ten years in California and, more recently, at Boston University in Massachusetts. Liz loves to watch students master and engage with the material through its application to real life. In her classrooms, Liz writes case studies for her students to work through in order to strengthen their critical thinking skills. Liz is also active in the field of pedagogical research.

ERIN HUIZINGA has spent more than 20 years as an educator who has developed rigorous, relevant curricular experiences for high school students. Erin has designed specialized programs that allow students to develop as scientists with an emphasis on real-world applications. Erin has been involved with health science career academies since 2005, teaching anatomy and physiology as part of an integrated curriculum focused on medical and health sciences. Through these highly collaborative and innovative programs, she has been able to implement research-based strategies that directly relate to improving student achievement.

PREFACE

Welcome! As you read this (with your eyes) and understand it (with your brain), perhaps turning to the next page (with muscle actions of your fingers, hand, forearm, and arm), you are using the human body to do so. Indeed, some of you may be using your fingers, hand, forearm, and arm to read through the eBook on your computer, tablet, or smartphone. Whether you use traditional or new technology, the second edition of *Hole's Essentials of Human Anatomy & Physiology* offers an interesting and readable introduction to how the human body accomplishes these tasks. The functioning of the body is not simple, and at times understanding may not seem easy, but learning how the body works is always fascinating and can be both useful and fun!

Many of you are on a path toward a career in healthcare, athletics, science, or education. Be sure to check out the **Career Corners** in every chapter. They present interesting options for future careers. Try to look at this course not as a hurdle along your way but as a stepping stone. This book has been written to help you succeed in your coursework and to help prepare you to make that journey to a successful and rewarding career.

New Authorship

With this new edition of *Hole's Essentials of Human Anatomy & Physiology* we introduce Charles Welsh as primary author of this revised text. This new edition provides a cohesive narrative with a single voice. With over 30 years of experience in anatomy and physiology classrooms instructing future nurses and other allied health professions, Dr. Welsh brings a fresh perspective to this well-respected text.

To the Teacher

Written for ease of readability and organized for classroom use, the text serves the student as well as the instructor. This edition of *Hole's Essentials of Human Anatomy & Physiology* continues the Learn, Practice, Assess approach that has substantially contributed to instructional efficiency and student success.

Each chapter section opens with Learning Outcomes, contains many opportunities to Practice throughout, and closes with Assessments that are closely tied to the Learning Outcomes. Teachers can assign these, and students can use these features not only to focus their study efforts, but also to take an active role in monitoring their own progress toward mastering the material. In addition, thanks to the expertise of Leslie Day and Julie Pilcher, the digital platforms continue to enhance the printed content and the Learn, Practice, Assess approach. We are proud to have developed and to offer the latest and most efficient technologies to support teaching and learning.

Chuck Welsh

NEW TO THIS EDITION

As we prepared for this new edition, we surveyed anatomy and physiology teachers to help us strengthen an already robust program. We updated and revised the student edition, teacher manual, and digital resources to further aid student learning. Below are the updates for this edition.

- The **Engineer a Healthier World Unit Projects** have been revised to provide additional guidance to students and teachers, as well as help students make connections between advancements in science and the engineering process.
- A **Case Study** has been added to each chapter. This feature ties to the chapter opener vignette and provides students with the opportunity to study a topic covered in the chapter in more depth.
- **Chapter Reviews** have been expanded and include new multiple-choice, short-answer, and critical thinking and clinical application questions. They also include a **Lab Data Analysis**, **Case Study Wrap-up** and a **Chapter Project**, designed to help students enhance their engagement with, and proficiency in, the science and engineering practices.
- **Features** have been updated to reflect new discoveries and technological advances and include critical thinking questions.
- We now offer a print **Teacher Manual** that provides additional activities, pacing, and answers to all student edition questions.
- Online **Focus Activities** provide interactive labeling and vocabulary activities to check student mastery of difficult structures, vocabulary, and concepts.
- Online **Chapter** and **Unit Projects** that enable students to apply the science and engineering practices they have developed through the course of study.
- **Concept Overview Interactives** are ground-breaking interactive animations, that encourage students to explore key physiological processes and difficult concepts.

ADDITIONAL DIGITAL RESOURCES

- The **auto-graded test banks** provide additional chapter review and assessment opportunities.
- **Anatomy & Physiology Revealed® (APR 4.0)** is the interactive cadaver dissection tool used to enhance lectures and labs.
- **Animations** help to explain complex topics and processes.
- **eFlashcards** help to build student vocabulary skills.
- **PowerPoint** slides to help teachers build dynamic presentations.
- A **searchable resources library** that makes it easy to quickly find, display, and assign resources.
- A **powerful gradebook** provides real-time access to the student data teachers need to inform classroom instruction.

Best in Class Digital Resources

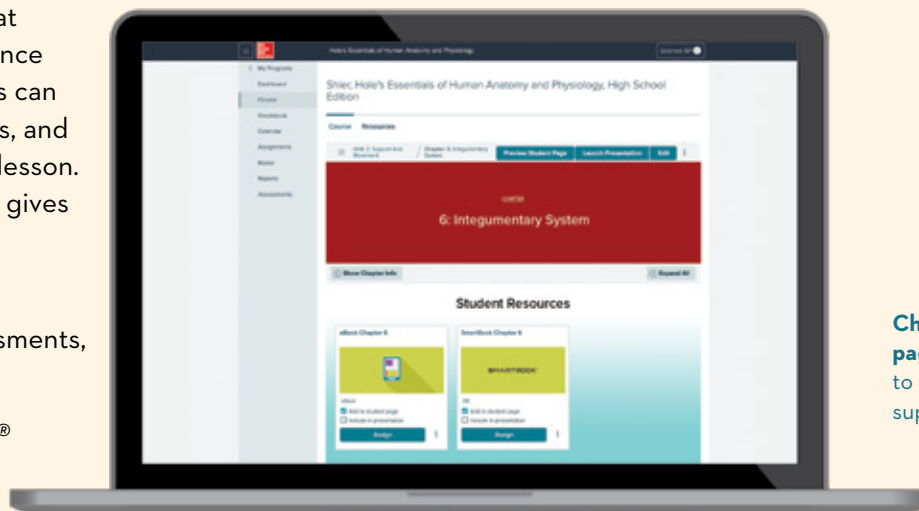
Hole's Essentials of Human Anatomy & Physiology is enriched with multimedia content including videos, animations, and simulations that enhance the teaching and learning experience both inside and outside of the classroom.

Authored by the world's leading subject matter experts and organized by chapter level, the resources provide students with multiple opportunities to contextualize and apply their understanding. Teachers can save time, customize lessons, monitor student progress, and make data-driven decisions in the classroom with the flexible, easy-to-navigate instructional tools.

Intuitive Design

Resources are organized at the chapter level. To enhance the core content, teachers can add assignments, activities, and instructional aides to any lesson. The chapter landing page gives students access to

- assigned activities,
- resources and assessments,
- interactive eBook,
- adaptive *SmartBook*® assignments,
- APR interactive dissection tool.



Chapter landing page links students to resources that support success.



Mobile Ready

Access to course content on-the-go is easier and more effective than ever before with the ReadAnywhere mobile app.

Adaptive Study Tools

SMARTBOOK® is the assignable, mobile-compatible, adaptive study tool. The interactive features engage students and personalize the learning experience with self-guided tools that

- assess a student's proficiency and knowledge,
- track which topics have been mastered,
- identify areas that need more study,
- deliver meaningful practice with guidance and instant feedback,
- recharge the learning with access to previously completed assignments and personalized recommendations,
- allow teachers to assign material at the topic level.



Highlighted content continuously adapts as students work through exercises.

Practice questions measure depth of understanding and present a personalized learning path based on student responses.



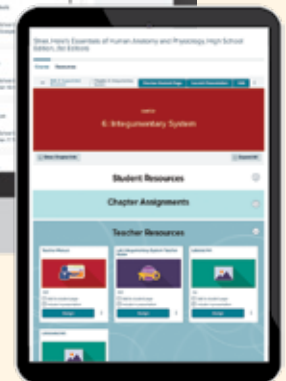
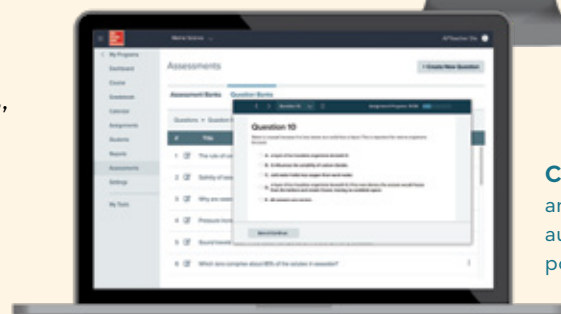
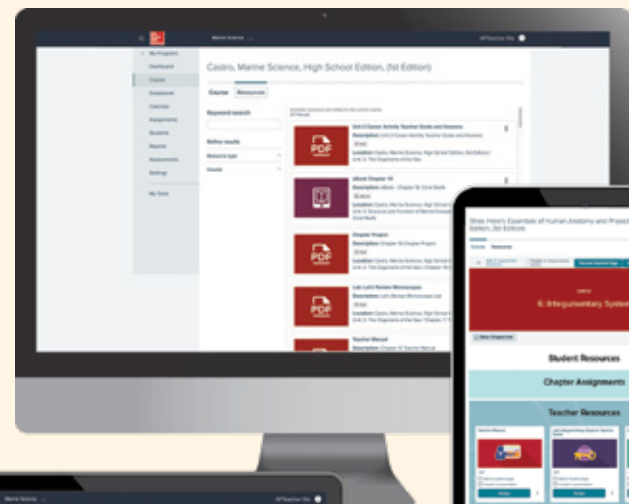
Teacher Resources

Teachers have access to the interactive eBook, adaptive SmartBook®, plus a wealth of customizable chapter resources and powerful gradebook tools.

Resources include

- an online version of the print teacher manual with chapter outlines, teaching suggestions, reading strategies, and pacing guides,
- actionable reporting features track student progress with data-driven insights to guide in-class instruction,
- customizable PowerPoint presentations,
- labeled diagrams, visual aids, animations, and additional ideas for lecture enrichment.

Searchable library makes it easy to find and assign resources.



Customizable assignments and quiz banks are automatically graded and populate easy-to-read reports.



KEY HIGH SCHOOL FEATURES

Hole's Essentials of Human Anatomy & Physiology, High School Edition combines the high-quality content that you've come to expect with "Hole's Essentials" with a high-school specific design and additional content to help students succeed. Activities in the high school edition allow students to apply science and engineering practices, work with real data, and provide support for ELL and ELA.

Establishing a Solid Framework

Hole's Essentials of Human Anatomy & Physiology is divided into six distinct units, each covering a different system within the human body. Each of these units introduces the Engineer a Healthier World projects. These projects are designed to help students make connections between advancements in science and the engineering process.



UNIT 2 Support and Movement

Introduction

The previous five chapters have taken you through the organizational levels of atoms, molecules, cells, and tissues. The remaining chapters in this book will focus on organs and organ systems, and how these systems interact to carry out the functions of life. The integumentary, skeletal, and muscular systems are responsible for the support and movement of the body. The next three chapters will introduce you to how skin, bone, and muscle allow the human body to hold together and move through the world.

Chapter 6
Integumentary System

Chapter 7
Skeletal System

Chapter 8
Muscular System


Key Features


Unit Project: Engineer a Healthier World

Clinicians and researchers use several tools to study the complex interactions within our bodies. In Engineer a Healthier World: Engineering in Anatomy and Physiology, you will explore how the principles of engineering intersect with the sciences of anatomy and physiology. Read the feature "Stem Cells to Treat Disease" (p. 197), then go online to access your next unit project, where you will apply the engineering design process to a problem facing healthcare today.

Spotlight on Career

Massage Therapist (p. 165)
Radiology Technologist (p. 188)
Physical Therapy Assistant (p. 240)

 **Learn, Practice, Assess**
This icon indicates learning tools that help you practice and apply knowledge

 **Anatomy & Physiology REVEALED**
This symbol indicates the correlating system in Anatomy & Physiology REVEALED

160 UNIT 2 | Support and Movement

• The **Introduction** reveals the common organizational concept connecting each chapter in the unit.

• The **Engineer a Healthier World** projects are based on features within each unit, which prompt students to go online to complete the full project.

• **Spotlight on Careers** indicates which careers are profiled in the unit and connects the unit content to real-world applications.

KEY HIGH SCHOOL FEATURES

Each chapter introduces a theme and case study. These elements enhance student understanding of chapter content and develop important investigative skills key to the study of science.

CHAPTER
6

Chapter Contents

6.1

Introduction

6.2

Layers of the Skin

6.3

Accessory Structures of the Skin: Epidermal Derivatives

6.4

Skin Function

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Module 4: Integumentary System

Integumentary System

Theme: Scale, Proportion, and Quantity

The integumentary system protects the body from bacteria and other external threats, and composes the largest organ system in the body.

Tattoos

With their dramatic rise in popularity and being more socially acceptable than ever, you probably know someone with a tattoo. Often referred to as body art, the canvas for these illustrations is your skin.

The outer layer of the skin, the epidermis, is what we usually see. But the ink used for tattooing resides in the deeper layer called the dermis. Initially, the ink is injected into the region between the epidermis and dermis. The damaged epidermis is shed. Trapped by white blood cells as part of an immune response, the pigments remain in the upper part of the dermis. This becomes the long-term image, or art, that is visible. The fading of a tattoo over time is the result of the pigments migrating into deeper layers of the dermis.

Tools for tattooing recovered from some archeological sites are as old as 12,000 years. This long history of tattoos reveals ancient knowledge of anatomy and the healing arts.

Contemporary tattoos are usually decorative, and most often are a form of self-expression. They exhibit a wide range of images in various categories. Others are known as “functional tattoos.” Alzheimer’s patients often get them to recall important information such as their names and home address. Tattoos have also been used to mark criminals and prisoners of war. The most notorious was the tattooing of prisoners in Nazi concentration camps during the Second World War.

The American Academy of Dermatology warns against tattoos due to the possibility of infection, scarring, and the desire to have a tattoo removed later in one’s life. To minimize potential danger, they recommend employing only certified and licensed tattoo artists.

Aids To Understanding Words

(Appendix A has a complete list of Aids to Understanding Words.)

cut- [skin]	subcutaneous: beneath the skin.	kerat- [horn]	keratin: protein produced as epidermal cells die and harden.
derm- [skin]	dermis: inner layer of the skin.	melan- [black]	melanin: dark pigment produced by certain cells.
epi- [upon]	epidermis: outer layer of the skin.	seb- [grease]	sebaceous glands: gland that secretes an oily substance.
follic- [small bag]	hair follicles: tubelike depression in which a hair develops.	sudor- [sweat]	sudoriferous glands: exocrine glands that secrete sweat.

A **Case Study** begins each chapter and is essential to enhancing student understanding of clinical situations. These case studies tie to the chapter opener vignette and provide students with the opportunity to study a topic covered in the chapter in more depth.

Themes

The **themes** at the beginning of each chapter align the chapter under one of seven crosscutting concepts. The themes highlight that anatomy and physiology share concepts applicable across all fields of science and engineering. These unifying concepts include patterns, cause and effect, and structure and function.

Case Study

The ability to make claims and defend those claims is an essential skill for any anatomy and physiology student. As part of the **Case Study**, students are asked to make a claim, collect evidence, and explain their reasoning using the CER chart provided online. Throughout the chapter there are several **Case Study Connections** that provide students with an opportunity to further refine their claim. The **Case Study Wrap-Up** at the end of the chapter pulls the entire investigation together in a final deliverable.

Case Study

An archaeologist comes to talk at your school. She describes the discovery of the mummified iceman, Otzi. Otzi the Iceman was found preserved in 1991 in the Italian Alps. He lived about 5,300 years ago. Two notable items stood out to you in the description of the forensic analysis of Otzi: he had tattoos and Beau’s lines. From these two observations, the archeological team was able to conclude that Otzi had been ill three times in the six months before his death and likely other times in his life. You learn that Beau’s lines are indentations in the fingernails that develop when nail growth is temporarily halted, usually due to severe illness. Otzi’s 61 tattoos were concentrated around joints that showed signs of disease and wear. The tattoos may have been the result of early acupuncture, or were markings for areas of focus for medical intervention. You had heard that tattoos were permanent, but to last for 5,300 years?

Claim, Evidence, Reasoning

Make your claim:

Use your CER chart to make a claim about which part or parts of the skin are involved in the tattooing process.

Collect Evidence:

Use the information in this chapter to collect evidence to support your claim. Record your Evidence as you move through the chapter.

Explain your Reasoning:

You will revisit your claim and explain your reasoning at the end of this chapter.

Administering a tattoo.

KEY HIGH SCHOOL FEATURES

Engaging Activities, Support for all Learners

The array of skill-building activities throughout the text offer students a variety ways to engage with the content and addresses the needs of students with diverse learning styles.

Study Strategy include • listening, speaking, and peer interaction to provide ELL/ELA support for students.

The **Case Study • Connection** boxes prompt students to think critically with questions to consider as they evaluate the claim they made at the beginning of the chapter.

Use the Practices • activities allow students to apply the science and engineering practices to the content of the section.



Case Study Connection

Where are the tattoo pigments located, can you find the location on this skin diagram? Think about the pathway of the tattooist's needle as it comes into the skin to deposit the pigment.

6.1 Introduction

Study Strategy

Group Study Form a study group consisting of five students. Assign each person a section of the chapter. Each person should read their assigned section, prepare a presentation, and present the information to the group. Members of the group should ask questions about any part that they do not understand.



Learning Outcomes

1. Describe what constitutes an organ, and name the large organ of the integumentary system.

The skin receives a great deal of care and medical attention. This is mostly because it is what the rest of the world sees. That is, it composes a great part of our outward appearance. You only need to look at the amount of time and money we spend caring for skin, hair, and nails to understand this. Dermatology is the medical specialty that investigates and treats issues with the skin. Changes in skin can also indicate problems with other body systems.

Two or more tissue types that are structurally connected and perform shared, specialized functions constitute an **organ** (see fig. 1.3). Likewise, two or more organs working toward the same goals are considered an organ system. The two main tissues of the skin—epithelial and connective—constitute the largest organ in the body by weight. The skin and its associated accessory structures and organs (hair, nails, muscles, sensory receptors, and glands) make up the **integumentary** (in-teg-u-men'tar-e) **system**. The integument forms a barrier between ourselves and the outside world. It is a strong, yet flexible covering for our bodies, with a variety of functions.



Practice

1. What constitutes an organ?

Use the Practices

Using Mathematics The skin is the largest organ in the body by weight, making up approximately 16%. Calculate how much the skin of a 150-pound person contributes to that person's body weight.

6.2 Layers of the Skin



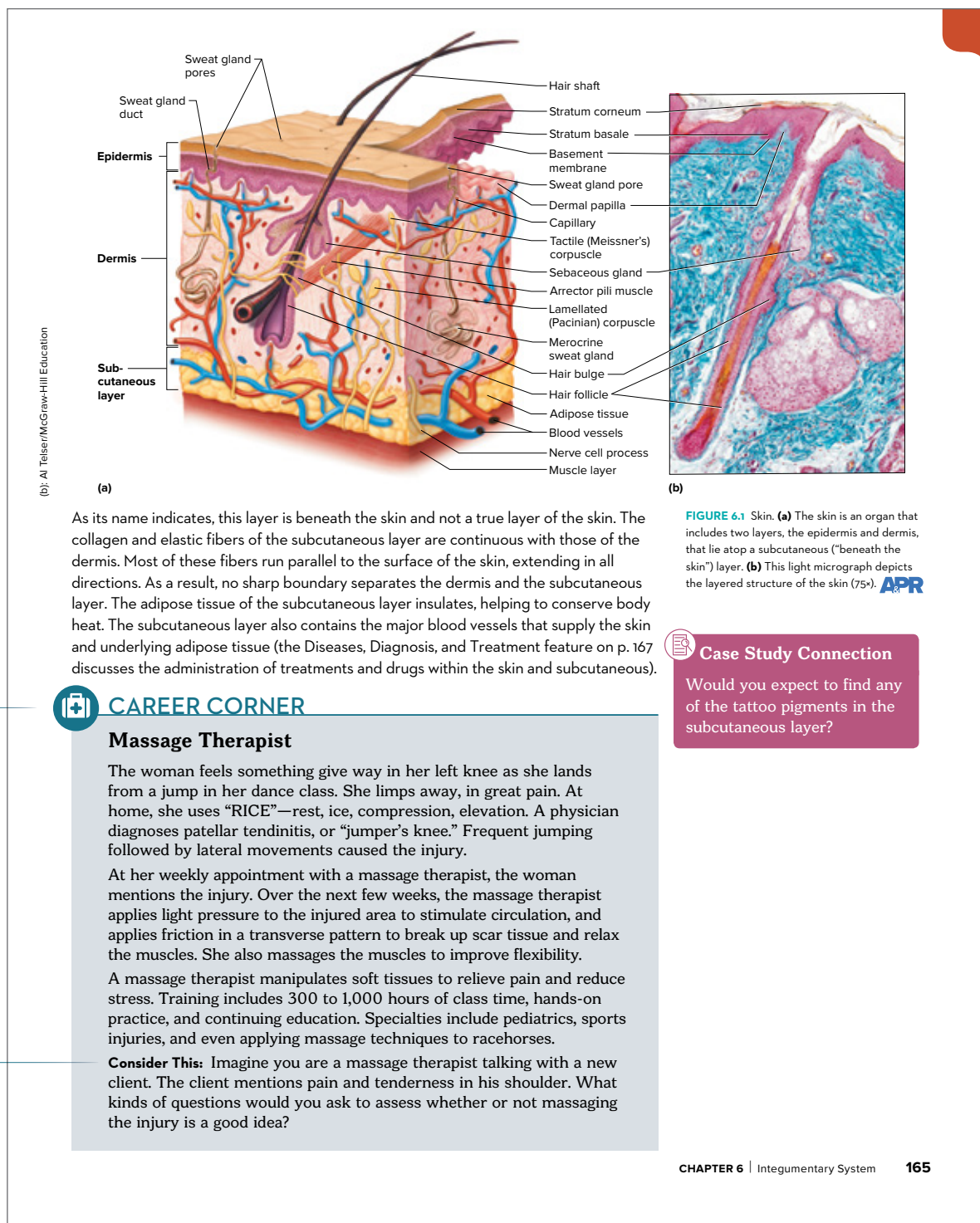
Learning Outcomes

1. Describe the structure of the layers of the skin.
2. Summarize the factors that determine skin color.

The skin includes two distinct layers (**FIG. 6.1**). The outer layer, called the **epidermis** (ep'i-der'mis), is composed of stratified squamous epithelium. The inner layer, or **dermis** (der'mis), is thicker than the epidermis. It is composed of connective tissue consisting of collagen and elastic fibers, along with smooth muscle tissue, nervous tissue, and blood. A **basement membrane** anchors the epidermis to the dermis and separates these two skin layers.

Beneath the dermis are masses of areolar tissue and adipose tissue that bind the skin to the underlying organs, forming the **subcutaneous** (sub'kū-tā'nē-us) **layer** (hypodermis).

KEY HIGH SCHOOL FEATURES



Career Corner features provide background on career opportunities related to anatomy and physiology to make meaningful connections, and gain valuable insight, beyond the classroom.

Consider This questions allow students to think critically about what they would do in a given clinical situation immersing them in real-world scenarios.

CAREER CORNER

Massage Therapist

The woman feels something give way in her left knee as she lands from a jump in her dance class. She limps away, in great pain. At home, she uses "RICE"—rest, ice, compression, elevation. A physician diagnoses patellar tendinitis, or "jumper's knee." Frequent jumping followed by lateral movements caused the injury.

At her weekly appointment with a massage therapist, the woman mentions the injury. Over the next few weeks, the massage therapist applies light pressure to the injured area to stimulate circulation, and applies friction in a transverse pattern to break up scar tissue and relax the muscles. She also massages the muscles to improve flexibility.

A massage therapist manipulates soft tissues to relieve pain and reduce stress. Training includes 300 to 1,000 hours of class time, hands-on practice, and continuing education. Specialties include pediatrics, sports injuries, and even applying massage techniques to racehorses.

Consider This: Imagine you are a massage therapist talking with a new client. The client mentions pain and tenderness in his shoulder. What kinds of questions would you ask to assess whether or not massaging the injury is a good idea?

Case Study Connection

Would you expect to find any of the tattoo pigments in the subcutaneous layer?

KEY HIGH SCHOOL FEATURES

Special Features

The special features located throughout the text are categorized into three strands: **Diseases, Diagnosis, and Treatment**, **Healthy Lifestyle Choices**, and **Genetic Engineering**. These features examine current topics and issues such as cancer, steroid use, or eating disorders in more depth. Some of these features are used as the jumping off point for the Engineer a Healthier World projects introduced at the beginning of each unit.

Diseases, Diagnosis, and Treatment

Administering Treatments and Drugs

Various treatments temporarily smooth facial wrinkles. "Botox" is an injection of a very dilute solution of botulinum toxin.

Produced by the bacterium *Clostridium botulinum*, the toxin causes food poisoning. It also blocks nerve activation of certain muscle cells, including the facial muscles that control smiling, frowning, and squinting. After three months, though, the facial nerves contact the muscles at different points, and the wrinkles return. Other anti-wrinkle treatments include chemical peels and dermabrasion to reveal new skin surface, as well as collagen

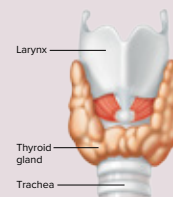
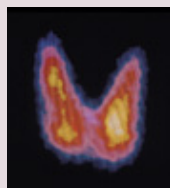
Some drugs are introduced through the skin by means of an adhesive transdermal patch that includes a small reservoir containing the substance. The drug passes from the reservoir through a permeable membrane at a known rate. It then diffuses into the epidermis and enters the blood vessels of the dermis. Transdermal patches deliver drugs that protect against motion sickness, alleviate chest pain associated with heart disease, and lower blood pressure. A transdermal patch that delivers nicotine may be used to help people stop smoking.

Healthy Lifestyle Choices

Radioactive Isotopes: Helpful and Harmful

9) Chris Priest/Science Source

Radioactive chemicals are useful in studying life processes and in diagnosing and treating some diseases. Atomic radiation is detected with special equipment, such as a scintillation counter (FIG. 2A). A radioactive isotope can be introduced into an organism and then traced as it enters into metabolic activities. For example, the human thyroid gland is unique in using the element iodine in its metabolism. Therefore, radioactive iodine-131 is used to study thyroid functions and to evaluate



(b)

the thyroid gland 24 hours after the patient received how closely the scan in (a) resembles the shape of the

o can change chemical structures and in this ar processes. For this reason, doctors active isotopes, such as cobalt-60, to treat on from the cobalt preferentially kills the er cells.

n can cause disease, such as certain cancers. gy as radiation is emitted damages DNA in make them cancerous. Exposure to in sunlight, for example, causes skin cancer, X rays or gamma rays increase the risk of certain body parts.

Researchers use several tools and technologies to complex problems facing our health. Access your *Engineer a Healthier World: Engineering in Biology*, online, based on this feature.

Genetic Engineering

Cancer

Cancer is a group of closely related diseases that can affect many different organs. The lifetime risk of developing cancer is one in two for males and one in three for females. These diseases result from changes in genes (mutations) that alter the cell cycle in somatic cells (cells other than sperm or eggs). Cancers share the following characteristics:

1. **Hyperplasia** is uncontrolled cell division. Normal cells divide a set number of times, signaled by the shortening of chromosome tips. Cancer cells make *telomerase*, which keeps chromosome tips long and silences signals that would stop division.
2. **Dedifferentiation** is loss of the specialized structures and functions of the normal type of cell from which the cancer cells descend (FIG. 3A).
3. **Invasiveness** is the ability of cancer cells to break through boundaries, called *basement membranes*, that separate cell layers.
4. **Angiogenesis** is the ability of cancer cells to induce extension of nearby blood vessels. This blood supply nourishes the cells and removes wastes, enabling the cancer to grow.
5. **Metastasis** is the spread of cancer cells to other tissues, through the bloodstream or lymphatic system.

Mutations in certain genes cause cancer. Such a mutation may activate a cancer-causing oncogene (which normally controls mitotic rate) or inactivate a protective tumor-suppressor gene. A person may inherit one abnormal cancer-causing gene variant, present in all cells, that imparts susceptibility to developing cancer. The disease begins when a mutation disrupts the second copy of that gene in a cell of the affected organ. This second mutation may be a response to an environmental trigger. Most cancers do not result from such an inherited susceptibility, and instead occur when two mutations occur in both copies of a gene in the same somatic cell.



Normal cells (with hairlike cilia)
Cancer cells

FIGURE 3A The absence of cilia on these cancer cells, compared to the nearby cilia-fringed cells from which they arose, is one sign of their dedifferentiation (2250x).

Cancers that affect different body parts may be caused by mutations in the same genes. A precision medicine approach to cancer treatment is to select drugs based on which genes have causative mutations, rather than by body part alone.

Concept Connection

1. Describe the characteristics shared by the different types of cancer.
2. Describe how the cell cycle is abnormal in cancer.

• **Concept Connections** questions assess student understanding of the feature topic and how it relates to the overall content of the chapter.

Use the Practices

Analyzing Data A student observes dividing cells under the microscope and notes that 58% are in interphase, 28% in prophase, 8% in metaphase, 4% in anaphase, and 2% in telophase. Based on these data, what can you conclude about the time a cell spends in each phase of the cell cycle?

KEY HIGH SCHOOL FEATURES

Meaningful Review and Assessment

Review and assessment opportunities offer students multiple ways to demonstrate their understanding and mastery of the concepts and content. Students apply their learning through projects, data analysis, writing assignments, and traditional assessment questions.

Chapter Project

Modeling the Integumentary System

The study of anatomy includes the use of many physical models so we can easily visualize all of the working parts of the human body. An excellent way to learn how everything works together is by building a model yourself. By shaping the parts of the human body yourself, instead of being told what each part does in a system, or trying to memorize a diagram, you will gain a better understanding of the human body.

In this chapter, you learned about the different layers of the integumentary system and how the epidermis and dermis together to form a barrier to protect our insides from the world. In this activity, you will show exactly how it does this.

building a model of the different boundaries and accessory structures of the skin.

You will:

- Use modeling clay to build a cross-sectional model of the integumentary system
- Label the epidermis, dermis, and subcutaneous layer, and at least four accessory structures found within the skin
- Describe the function of each part of your model in a few

- The **Chapter Project** asks students to apply the science and engineering practices they have developed to explore in-depth a topic related to the chapter content. Additional information about the Chapter Project can be found online.

13. How do sweat glands help regulate body temperature?
14. What is the function of the arrector pili muscle?
15. Describe the structure of a nail. How does the structure of a nail relate to its function?

16. Distinguish between first, second, and third-degree burns.
17. What are the different types of skin cancer? What are their characteristics?

Critical Thinking and Clinical Applications

1. **WRITING Connection** Explain why it is painful to pull a hair out your head, but not when your hair is cut.
2. Acne is caused by a bacterium called *P. acnes*. What are some potential treatment options?
3. If someone asked you if those with darker skin might have more medical problems associated with lack of calcium, what would be your answer and why?
4. **CLINICAL Connection** Which of the following would result in the more rapid absorption of a drug: a subcutaneous injection or an intradermal injection? Why?
5. As a rule, a superficial partial-thickness burn is more painful than one involving deeper tissues. How would you explain this observation?

Lab Data Analysis activities allow students to analyze and interpret real data from current research in anatomy and physiology.

Lab Data Analysis: Wound Healing Rates

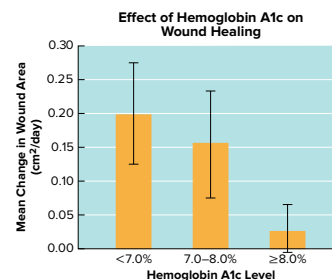
The integumentary system maintains a barrier between the body and the outside world, which can prevent infection. Wound healing repairs this barrier when it is compromised. Some diseases—such as diabetes—impair proper wound healing, thus increasing the risk of infection.

Data and Observations

The graph to the right displays the rate of wound healing in square centimeters per day (y-axis). Three groups of patients with different Hemoglobin A1c levels (HbA1c) are listed along the x-axis. The higher the A1c level, the more severe a patient's diabetes.

Think Critically

1. Which HbA1c category of patients has the fastest wound healing? The slowest?
2. Which HbA1c category likely includes patients with severe diabetes?
3. Which group of patients would you most want to counsel on the risks of eventually developing severe diabetes?



Data obtained from: Christman, Andrea L., et al. 2011. Hemoglobin A1c Predicts Healing rate in Diabetic Wounds. *Journal of Investigative Dermatology*, 131(10): 2121–2127.

The **Case Study Wrap-up** provides students an opportunity to complete a final assessment of their CER chart and analyze the evidence they collected.



Case Study Wrap-up

Recall the Case Study at the beginning of this chapter (pg. 163). You read about some the structure and function of the integumentary system. Now it is time to revisit your claim, summarize your evidence and analyze what you have learned.

Claim Evidence Reasoning

Revisit your Claim: Review your CER chart where you recorded your claim about which part or parts of the skin are involved in the tattooing process.

Summarize your Evidence: Summarize the evidence gathered from your investigations and research and finalize your Summary Table.

Explain your Reasoning: Does your evidence support your claim? Explain why your evidence supports your claim. If it does not, revise your claim.



LEARN, PRACTICE, ASSESS

At the Unit and Chapter levels, *Hole's Essentials of Human Anatomy and Physiology* features an integrated learning system, **Learn, Practice, Assess**. Each phase of this instructional model within the chapters has features unique to the phase, but common from chapter to chapter—creating a familiar pattern of instruction, application, and mastery throughout.

An Integrated Learning System

The **Preview Chapter** highlights learning tools for student success, including an overview of learning styles, a review of scientific literacy, and tips and expectations for how to prepare before, during, and after class.

Foundations for Success

Theme: Cause and Effect

A thorough understanding of how to use this textbook will allow you to effectively study for this course.

How to Learn

Pay attention. It is a beautiful day. You can't help but stare wistfully out the window, the scent of spring blooms and sound of birds making it difficult to concentrate on what your teacher is saying. Gradually the lecture fades as you become aware of your own breathing, the beating of your heart, and the sweat that breaks out on your forehead in response to the radiant heat from the glorious day. Suddenly your reverie is cut short—a classmate has dropped a human anatomy and physiology textbook on the floor. You jump. Your heart hammers and a flash of fear grips your chest, but you soon realize what has happened and recover.

The message is clear: pay attention. So you do, tuning out the great outdoors and focusing on the class. In this course, you will learn all about the events that you have just experienced, including your response to the sudden stimulation. This is a good reason to stay focused.

This Preview Chapter will provide you with the foundation to do well in this anatomy and physiology course. In the pages ahead, you can identify your individual learning style, review the importance of scientific literacy, and plan for success. Take time to review these important concepts before diving in to the rest of this text, so that you will be fully prepared to take on all you will learn in this exciting course.

PREVIEW CHAPTER P

Chapter Contents

- P.1 Introduction
- P.2 Science Literacy Skills
- P.3 Strategies for Your Success

Learning Outcomes pinpoint the key takeaways of the section and are closely linked to the Chapter Assessment Critical Thinking and Clinical Application questions.

P.1 Introduction

Learning Outcomes

1. Explain the importance of an individualized approach to learning.

Studying the human body can be overwhelming at times. The new terminology, used to describe body parts and how they work, can make it seem as if you are studying a foreign language. Learning all the parts of the body, along with the composition of each part, and how each part fits with the other parts to make the whole requires memorization. Understanding the way each body part works individually, as well as body parts working together, requires a higher level of knowledge, comprehension, and application.

Identifying underlying structural similarities, from the macroscopic to the microscopic levels of body organization, taps more subtle critical thinking skills. This chapter will catalyze success in this active process of learning. Remember that although the skills and tips discussed in this chapter relate to learning anatomy and physiology, they can be applied to other subjects.

Learning occurs in different ways or modes. Most students use several modes (multimodal), but use more effectively one or two, often referred to as learning styles. Some students prefer to read the written word, or to actually write the words; others learn best by looking at visual representations, such as photographs and drawings. Still others learn most effectively by hearing the information or explaining it to someone else. For some learners, true understanding remains elusive until a principle is revealed in a laboratory or clinical setting that provides a memorable context and engages all of the senses. This text accommodates the range of learning styles. Read-write learners will appreciate the lists, definitions (glossary), and tables. Visual learners will discover many diagrams, flow charts, and figures, all with consistent and purposeful use of color. For example, a particular bone is always the same color in figures where bones are color-coded. Auditory learners will find pronunciations for new scientific terms to help sound them out, and kinesthetic learners can relate real-life examples and applications to their own activities.

 Practice



LEARN, PRACTICE, ASSESS

The chapter openers include several learning aids and provide context for the topic of study addressed in the chapter.

Vignettes lead into the chapter content. They connect to many areas of health care, including technology, physiology, medical conditions, historical perspectives, and careers.

Anatomy & Physiology REVEALED® (APR) icons at the beginning of each chapter indicates which module in APR applies to this chapter.

Aids to Understanding Words helps students decode scientific terminology by examining root words, stems, prefixes, suffixes, and pronunciations to help build a solid anatomy and physiology vocabulary and support ELL development.

CHAPTER 6

Integumentary System

Theme: Scale, Proportion, and Quantity

The integumentary system protects the body from bacteria and other external threats, and composes the largest organ system in the body.

Tattoos

With their dramatic rise in popularity and being more socially acceptable than ever, you probably know someone with a tattoo. Often referred to as body art, the canvas for these illustrations is your skin.

The outer layer of the skin, the epidermis, is what we usually see. But the ink used for tattooing resides in the deeper layer called the dermis. Initially, the ink is injected into the region between the epidermis and dermis. The damaged epidermis is shed. Trapped by white blood cells as part of an immune response, the pigments remain in the upper part of the dermis. This becomes the long-term image, or art, that is visible. The fading of a tattoo over time is the result of the pigments migrating into deeper layers of the dermis.

Tools for tattooing recovered from some archeological sites are as old as 12,000 years. This long history of tattoos reveals ancient knowledge of anatomy and the healing arts.

Contemporary tattoos are usually decorative, and most often are a form of self-expression. They exhibit a wide range of images in various categories. Others are known as “functional tattoos.” Alzheimer’s patients often get them to recall important information such as their names and home address. Tattoos have also been used to mark criminals and prisoners of war. The most notorious was the tattooing of prisoners in Nazi concentration camps during the Second World War.

The American Academy of Dermatology warns against tattoos due to the possibility of infection, scarring, and the desire to have a tattoo removed later in one’s life. To minimize potential danger, they recommend employing only certified and licensed tattoo artists.

Chapter Contents

- 6.1 Introduction
- 6.2 Layers of the Skin
- 6.3 Accessory Structures of the Skin: Epidermal Derivatives
- 6.4 Skin Function



Module 4: Integumentary System

Aids To Understanding Words (Appendix A has a complete list of Aids to Understanding Words.)

cut- [skin]	subcutaneous: beneath the skin.	kerat- [horn]	keratin: protein produced as epidermal cells die and harden.
derm- [skin]	dermis: inner layer of the skin.	melan- [black]	melanin: dark pigment produced by certain cells.
epi- [upon]	epidermis: outer layer of the skin.	seb- [grease]	sebaceous gland: gland that secretes an oily substance.
folic- [small bag]	hair follicle: tubelike depression in which a hair develops.	sudor- [sweat]	sudoriferous glands: exocrine glands that secrete sweat.



LEARN, PRACTICE, ASSESS

The practice features in the text allow students to frequently check their understanding through engaging, real-life applications including how the chapter relates to various fields of study and/or science and engineering careers.

Practice questions appear after major sections and assess student understanding of the material.

Vocabulary is an important part of the anatomy & physiology course, and is bolded in the text to support ELL instruction. In addition to the clickable glossary definition in the eBook, **eFlashcards** and **Vocabulary Focus Activities** are available online.



Practice

1. List the layers of the skin.
2. Name the tissues in the outer and inner layers of the skin.
3. Name the tissues in the subcutaneous layer beneath the skin.
4. What are the functions of the subcutaneous layer?

Epidermis

The epidermis lacks blood vessels because it is composed entirely of stratified squamous epithelium. However, the deepest layer of epidermal cells, called the **stratum basale** (stra'tum ba'sal), or stratum germinativum, is close to the dermis and is nourished by dermal blood vessels (fig. 6.1a). As the cells (basal cells) of this layer divide and grow, the older epidermal cells (keratinocytes) are pushed away from the dermis toward the skin surface. The farther the cells move away from the dermis toward the skin surface, the poorer their nutrient supply becomes, and in time they die.

The keratinocytes harden in a process called **keratinization** (ker"ah-tin'i-zā'shun). The cytoplasm fills with strands of tough, fibrous, waterproof **keratin** proteins. As a result, many layers of tough, tightly packed dead cells accumulate in the outermost layer of the epidermis, called the **stratum corneum** (kor'nē-um). These dead cells are eventually shed.

The thickness of the epidermis varies among different body regions. In most areas, only four layers can be distinguished (from deepest layer to superficial layer): the *stratum basale*, *stratum spinosum* (spi-no'sum), *stratum granulosum* (gran"u-lo'sum), and *stratum corneum*. An additional layer, the *stratum lucidum* (loo'sid-um), is in the thickened and hairless (glabrous) skin of the palms and soles (FIG. 6.2).

Healthy skin does not completely wear away, because the production of epidermal cells in the stratum basale closely balances the loss of dead cells from the stratum corneum. However, the rate of cell division increases where the skin is rubbed or pressed regularly. This action causes growth of thickened areas called **calluses** on the palms and soles, and keratinized conical masses on the toes called **corns**.

The epidermis has important protective functions. It shields the moist underlying tissues against excess water loss, mechanical injury, and the effects of harmful chemicals. Intact epidermis also keeps out disease-causing microorganisms (pathogens).



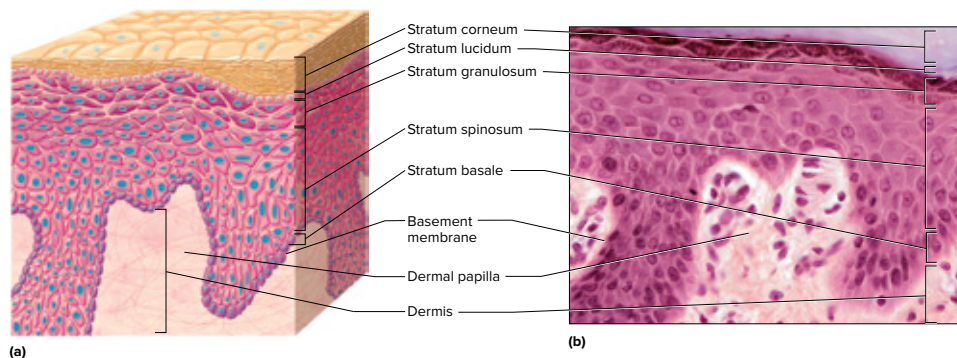
Case Study Connection

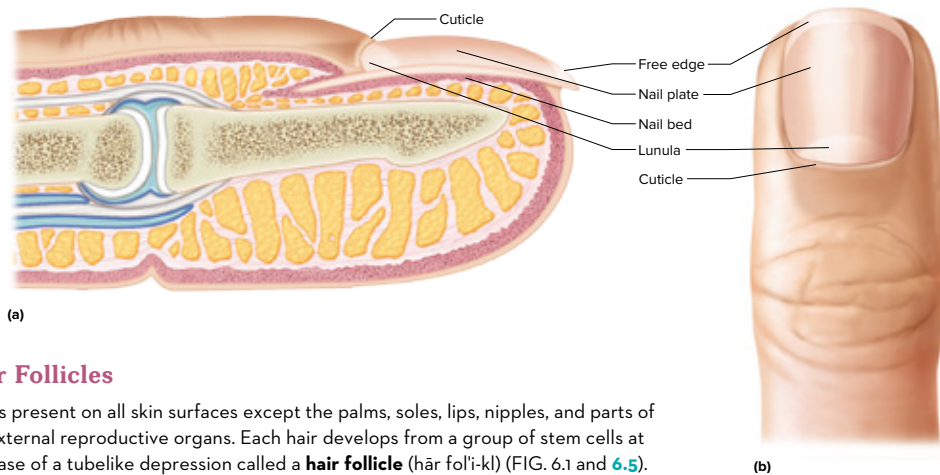
As the tattooist's needle is inserted, is it likely to cause much bleeding? Why or why not? Will a tattooist require a different length of needle when tattooing the bottom of a customer's foot than they would require when tattooing the skin of the forearm?

FIGURE 6.2 Epidermis of thick skin. (a) The layers of the epidermis are distinguished by changes in cells as they are pushed toward the surface of the skin. (b) Light micrograph of skin (500x). **APR**

Where is thick skin found on the body?

Go online to check your understanding of the structure of the epidermis by completing the Focus Activity.





Hair Follicles

Hair is present on all skin surfaces except the palms, soles, lips, nipples, and parts of the external reproductive organs. Each hair develops from a group of stem cells at the base of a tubelike depression called a **hair follicle** (hār fol'i-kl) (FIG. 6.1 and 6.5). These stem cells originate from a region near the bottom of the hair follicle known as the *hair bulge*, and migrate downward. The follicle contains the *hair root*, which can extend from the surface through the dermis into the subcutaneous layer. The deepest portion of the *hair root*, located at the base of the hair follicle, is the *hair bulb*. It is composed of epithelial cells that are nourished from dermal blood vessels in a projection of connective tissue (hair papilla). As these epithelial cells divide and

FIGURE 6.4 Nail. (a) Longitudinal section and (b) dorsal view of nail exterior. **APR**

What is the most actively growing region of the nail?

FIGURE 6.5 Hair follicle. (a) A hair grows from the base of a hair follicle when epithelial cells divide and older cells move outward and become keratinized. (b) Light micrograph of a hair follicle (175 \times).

Go online to check your understanding of the structure of hair follicles by completing the Focus Activity.

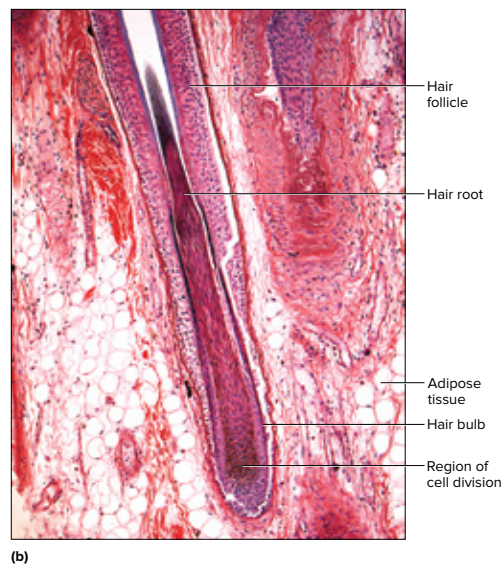
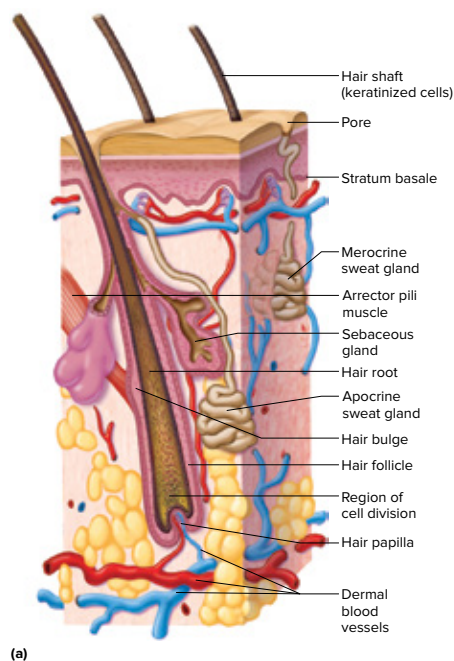


Figure Captions are included to clarify complex processes and steps in a process and are illustrated sequentially.

Figure Questions allow an additional assessment and are on key figures throughout the chapter.

Key figures within the chapter have a corresponding **Labeling Focus Activity** found online. These activities provide an opportunity to check student understanding of structures of the human body.

(b): Al Teiser/McGraw-Hill Education



LEARN, PRACTICE, ASSESS

Chapter level summaries provide an opportunity for students to refresh and reinforce their learning and assessments allow them to demonstrate mastery.



Chapter 6 Summary and Assessment

Study Strategy

Clarifying Use this summary to set up an outline. Add additional notes during class discussions and while you read.

Summary Outline

6.1 Introduction

1. An **organ** is formed by two or more tissue types grouped together and performing specialized functions.
2. The skin, the largest organ in the body by weight, is part of the **integumentary system**.

6.2 Layers of the Skin

1. The **epidermis** is stratified squamous epithelium that lacks blood vessels.
 - a. The outermost layer, called the stratum corneum, is composed of dead epidermal cells.
 - b. The epidermis protects underlying tissues against water loss, mechanical injury, and the effects of harmful chemicals.
 - c. **Melanin**, a pigment that provides skin color, protects underlying cells from the effects of ultraviolet light.
 - (1) All people have about the same number of melanocytes.
 - (2) Skin color is due largely to the amount of melanin and the distribution and size of pigment granules in the epidermis.
2. The **dermis** binds the epidermis to underlying tissues.
 - a. Dermal blood vessels supply nutrients to all skin cells and help regulate body temperature.
 - b. Nerve cell processes are scattered throughout the dermis.

2. Hairs develop from epidermal cells at the base of a tubelike **hair follicle**.

- a. As newly formed cells develop and grow, older cells are pushed toward the surface and undergo keratinization.
- b. Hair color is determined by genes that direct the amount of eumelanin or pheomelanin produced by melanocytes associated with hair follicles.

3. Skin glands

- a. **Sebaceous glands** are usually associated with hair follicles.
- b. Each **sweat gland** is a coiled tube.

6.4 Skin Functions

1. The skin is a protective covering, slows water loss, and houses sensory receptors.
2. The skin produces vitamin D precursor.
3. The skin helps regulate body temperature.
 - a. When body temperature rises above the normal set point, dermal blood vessels dilate and sweat glands secrete sweat.
 - b. When body temperature drops below the normal set point, dermal blood vessels constrict and sweat glands become inactive.

- The **Summary Outline** reviews the key content in each chapter. An expanded summary is available online

The **Chapter Assessment** checks student understanding of the chapter's learning outcomes.

All multiple-choice and short-answer questions in the Chapter Assessment are **new to this edition**.

Chapter Assessment

Chapter Review Questions

Multiple Choice

1. The largest organ in the body by weight is the
 - a. liver.
 - b. skin.
 - c. large intestine.
 - d. brain.
2. Which of the following is considered a true layer of skin?
 - a. epidermis (outer layer)
 - b. dermis (inner layer)
 - c. hypodermis (subcutaneous layer)
 - d. both a and b
3. Which of the following correctly matches skin tones to its cause?
 - a. Bluish skin tone can be caused by a liver malfunction.
 - b. Orange-yellow skin tone can be caused by a diet high in carrots and sweet potatoes.
 - c. Pinkish skin tone can be caused by oxygen-rich jaundice in blood vessels.
 - d. Yellowish skin tone can be caused by cyanosis.
4. Which of the following statements is *false* regarding the pigment melanin?
 - a. All people have the same number of melanocytes in their skin.
 - b. Cytocrine secretion transfers melanin granules into cells neighboring melanocytes.
 - c. Melanin is produced by keratinocytes.
 - d. Melanin is produced by melanocytes.
5. Which of the following is *not* a function of the skin?
 - a. protection
 - b. regulation of body temperature
 - c. production of vitamin D
 - d. production of collagen
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 - b. regulation of body temperature
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7. Which of the following is *not* a function of the skin?
 - a. protection
 - b. regulation of body temperature
 - c. production of vitamin D
 - d. production of collagen
8. What is the term used for the tissue's response to stress that includes pain, warmth, redness, and swelling?
 - a. healing
 - b. inflammation
 - c. homeostasis
 - d. none of these
9. Which of the following most closely lists the steps to healing a skin wound in the correct chronological order?
 - a. fibroblasts produce collagen fibers; scar tissue develops; a blood clot forms; a scab forms and protects
 - b. fibroblasts produce collagen fibers; a scab forms and protects; a blood clot forms; scar tissue develops
 - c. a blood clot forms; fibroblasts produce collagen fibers; a scab forms and protects; scar tissue develops
 - d. a blood clot forms; scar tissue develops; a scab forms and protects; fibroblasts produce collagen fibers
10. Suturing (stitching) or otherwise closing a large break in the skin speeds the process of
 - a. the provision of nutrients and oxygen to the wound.
 - b. the extension of blood vessels into the area beneath the scab.
 - c. the formation of scar tissue.
 - d. collagen fibers binding the edges of the wound.

Short Answer



LEARN, PRACTICE, ASSESS

13. How do sweat glands help regulate body temperature?

14. What is the function of the arrector pili muscle?

15. Describe the structure of a nail. How does the structure of a nail relate to its function?

16. Distinguish between first, second, and third-degree burns.

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Critical Thinking and Clinical Applications

1. **WRITING Connection** Explain why it is painful to pull a hair out your head, but not when your hair is cut.

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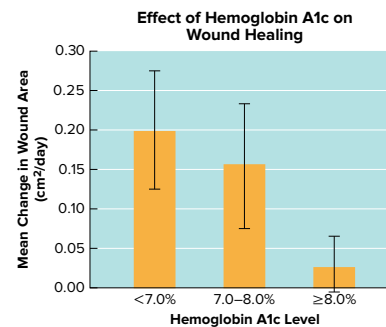
• The **Critical Thinking and Clinical Applications** section provides students with the opportunity to further refine cross-curricular skills including writing, clinical, and reading skills.

Lab Data Analysis: Wound Healing Rates

The integumentary system maintains a barrier between the body and the outside world, which can prevent infection. Wound healing repairs this barrier when it is compromised. Some diseases—such as diabetes—impair proper wound healing, thus increasing the risk of infection.

Data and Observations

The graph to the right displays the rate of wound healing in square centimeters per day (y-axis). Three groups of patients with different Hemoglobin A1c levels (HbA1c) are listed along the x-axis. The higher the A1c level, the more severe a patient's diabetes.



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Think Critically

1. Which HbA1c category of patients has the fastest wound healing? The slowest?
2. Which HbA1c category likely includes patients with severe diabetes?
3. Which group of patients would you most want to counsel on the risks of eventually developing severe diabetes?



Case Study Wrap-up

Recall the Case Study at the beginning of this chapter (pg. 163). You read about some the structure and function of the integumentary system. Now it is time to revisit your claim, summarize your evidence and analyze what you have learned.

Claim Evidence Reasoning

Revisit your Claim: Review your CER chart where you recorded your claim about which part or parts of the skin are involved in the tattooing process.

Summarize your Evidence: Summarize the evidence gathered from your investigations and research and finalize your Summary Table.

Explain your Reasoning: Does your evidence support your claim? Explain why your evidence supports your claim. If it does not, revise your claim.

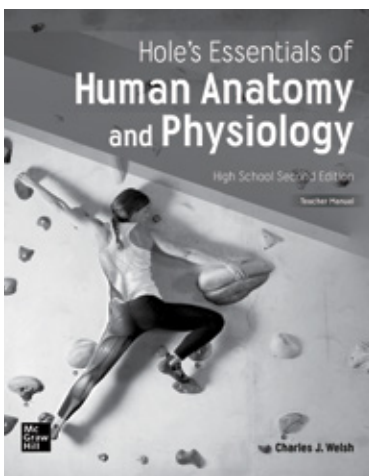
SUPPLEMENTARY RESOURCES

Hole's Essentials of Human Anatomy & Physiology, High School is supported by a variety of robust resources that help students not only grow in their understanding of anatomy and physiology, but also in their understanding of the relationship between the course material and the science and engineering practices.



High School Laboratory Manual for Human Anatomy & Physiology, Second Edition

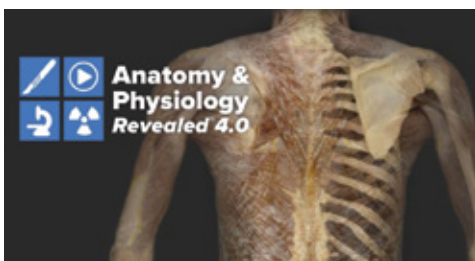
The *High School Laboratory Manual for Human Anatomy & Physiology* by Terry R. Martin is a streamlined lab manual ideal for the high school classroom. It contains 34 hands-on laboratory activities to complement any anatomy and physiology course.



Hole's Essentials of Anatomy & Physiology Teacher Manual


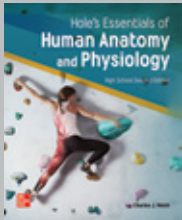
The Teacher Manual, available in print and online, will help create and deliver an anatomy and physiology course that engages students in the content and supports success in concept application and mastery. The manual provides:

- A chapter-level theme activity.
- Pacing for each chapter, including guidance on the most effective timing for labs and activities.
- Differentiated instruction support to address a variety of learning styles and needs.
- Answers to all student edition questions.




Anatomy & Physiology Revealed 4.0 is the ultimate online interactive cadaver dissection experience. This state-of-the-art program uses cadaver photos combined with a layering technique that allows the student to peel away layers of the human body to reveal structures beneath the surface. This program covers important topics from chemistry to organ systems, with animations, audio pronunciations, and comprehensive quizzing along the way.

LAB MANUAL CORRELATION


 <p>High School Laboratory Manual for Anatomy & Physiology, Second Edition</p>	 <p>Hole's Essentials of Human Anatomy & Physiology, High School Edition</p>
LAB 1 Scientific Method and Measurements	Chapter 1 / Appendix A
LAB 2 Body Organization, Membranes, and Terminology	Chapter 1
LAB 3 Chemistry of Life	Chapter 2
LAB 4 Cell Structure and Function	Chapter 3
LAB 5 Movements Through Membranes	Chapter 3
LAB 6 Muscle and Nervous Tissues	Chapter 5
LAB 7 Integumentary System	Chapter 6
LAB 8 Organization of the Skeleton	Chapter 7
LAB 9 Vertebral Column and Thoracic Cage	Chapter 7
LAB 10 Pectoral Girdle and Upper Limb	Chapter 7
LAB 11 Pelvic Girdle and Lower Limb	Chapter 7
LAB 12 Skeletal Muscle Structure and Function	Chapter 8
LAB 13 Muscle Fatigue and Force Variance	Chapter 8
LAB 14 Muscles of the Head and Neck	Chapter 8
LAB 15 Muscles of the Chest, Shoulder, and Upper Limb	Chapter 8
LAB 16 Muscles of the Hip and Lower Limb	Chapter 8
LAB 17 Nervous Tissue and Nerves	Chapter 9
LAB 18 Spinal Cord, Spinal Nerves, and Meninges	Chapter 9
LAB 19 Reflex Arc and Reflexes	Chapter 9
LAB 20 Reaction Rates and Practice	Chapter 9
LAB 21 Brain and Cranial Nerves	Chapter 9
LAB 22 General Senses	Chapter 10
LAB 23 Smell and Taste	Chapter 10
LAB 24 Ear and Equilibrium	Chapter 10
LAB 25 Endocrine Structure and Function	Chapter 11
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LAB 32 Action of a Digestive Enzyme	Chapter 15
LAB 33 Urinary Organs	Chapter 17
LAB 34 Urinalysis	Chapter 17

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P.2 Science Literacy Strategies	P3
P.3 Strategies for Your Success	P4

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CHAPTER 8

Muscular System

Theme: Structure and Function

The structure of muscles allows them to move body parts.

Too Much Muscle?

Mutations in the genes that control myostatin production can result in individuals with more muscle mass than normal. This occurs in humans as well as other species.

Other species with myostatin mutations are well known. Naturally “double-muscled” cattle and sheep are valued for their high weights early in life. Chicken breeders lower myostatin production to yield meatier birds, and “mighty mice” with silenced myostatin genes are used in basic research to study muscle overgrowth. In clinical applications, researchers are investigating ways to block myostatin activity to stimulate muscle growth to reverse muscle-wasting from AIDS, cancer, and muscular dystrophy. Myostatin could also be abused to enhance athletic performance.

Apart from double-muscle mutations, resistance (weight) training can increase the ratio of muscle to fat in our bodies, which offers several benefits. Weight training increases muscle strength and bone density; lowers blood pressure; decreases the risks of developing arthritis, osteoporosis, and diabetes mellitus; and is even associated with improved self-esteem and fewer sick days.

Chapter Contents

- 8.1 Introduction
- 8.2 Structure of a Skeletal Muscle
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- 8.4 Muscular Responses
- 8.5 Smooth Muscle
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- 8.7 Skeletal Muscle Actions
- 8.8 Major Skeletal Muscles



Module 6: Muscular System

Aids To Understanding Words (Appendix A has a complete list of Aids to Understanding Words.)

calat- [something inserted]

erg- [work]

hyper- [over, more]

inter- [between]

laten- [hidden]

intercalated disc: dense band that connects cardiac muscle cells.

synergist: muscle that works with an agonist to produce a movement.

muscular hypertrophy: enlargement of muscle fibers.

intercalated disc: dense band that connects cardiac muscle cells.

latent period: time between application of a stimulus and the beginning of a muscle contraction.

myo- [muscle]

sarco- [flesh]

syn- [together]

tetan- [stiff]

troph- [well fed]

myofibril: contractile structure within a muscle cell.

sarcoplasm: material (cytoplasm) within a muscle fiber.

synergist: muscle that works with an agonist to produce a movement.

tetanic contraction: sustained muscular contraction.

muscular hypertrophy: enlargement of muscle fibers.



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Case Study

You are spending your summer shadowing a pediatrician. Today your first patient is a five-year-old boy. The pediatrician explains the boy's history to you. As a newborn, the child had an astonishing appearance – his prominent arm and thigh muscles looked as if he'd been weightlifting in the womb. Now at five years of age, his muscles were twice normal size, and he could lift weights heavier than many adults. He also had half the normal amount of body fat.

The boy's muscle cells cannot produce a protein called myostatin, which normally stops stem cells from developing into muscle cells. In this boy, a mutation turned off this genetic brake, and as a result his muscles bulged, their cells both larger and more numerous than those in the muscles of an unaffected child. The boy is healthy so far, but because myostatin is also normally made in cardiac muscle, he may develop heart problems.

Because muscles burn calories at three times the rate of fat cells, changes in the proportion of fat and muscle have significant metabolic impacts. The pediatrician asks you to research myostatin mutations and explain how the child's muscle anatomy and physiology will differ from his older siblings who do not carry this mutation.

Claim, Evidence, Reasoning

Make Your Claim: Use your CER chart to make a claim about how the child's muscle anatomy and physiology will differ from his older siblings who do not carry this mutation.

Collect Evidence: Use the information in this chapter to collect evidence to support your claim. Record your evidence as you move through the chapter.

Explain Your Reasoning: You will revisit your claim and explain your reasoning at the end of this chapter.

Regular resistance training (weight training) can strengthen muscles.

8.1 Introduction

Study Strategy

Comprehending Vocabulary Before you begin reading the chapter, study the Aid to Understanding Words feature at the beginning of the chapter. Knowing the meanings of these prefixes and suffixes will help you understand and remember the meanings of the vocabulary words.



Learning Outcomes

1. List various outcomes of muscle actions.

Muscles are organs composed of specialized cells that generate forces, allowing all types of movement. These actions include walking, speaking, breathing, pumping blood, and moving food through the digestive tract.

Muscle is of three types—skeletal, smooth, and cardiac, as described in section 5.5, Muscle Tissues. This chapter focuses mostly on skeletal muscle, which attaches to bones and is mostly under conscious or voluntary control. It also functions to maintain posture and balance, as well as generate heat through “shivering.” Smooth muscle and cardiac muscle are discussed briefly.

Use the Practices

Analyzing Data We often use the 2-D models or tissue specimens to identify structures. Determine what a cross section of a skeletal muscle fiber would look like. Identify three different places where a fiber could be sectioned to reveal different structures.



CAREER CORNER

Physical Therapy Assistant

The man has joined a basketball league, and he cannot keep up. He lies on the gym floor, in pain, after an overambitious jump shot. He felt a sudden twinge in his knee, and now the area is red and swelling.

At the nearest hospital, the man receives an MRI scan, which reveals a small tear in the anterior cruciate ligament (ACL). The man doesn't want surgery, so he sees a physical therapist twice a week for a month. A physical therapy assistant works with the man, leading him through a series of exercises that may restore full mobility.

The therapy begins with stepping, squats, and using a single-leg bicycle that isolates and builds up the muscles of the injured limb. Therapy progresses to further build up muscles around the injured joint. The PT assistant gives her patient exercises to do daily at home. The therapy builds the muscles around the knee to compensate for the hurt ACL, restoring full range of motion.

A physical therapy assistant must complete a two-year college program and pass a certification exam. PT assistants work in hospitals, skilled nursing facilities, private homes, schools, fitness centers, and workplaces.

Consider This: Of the 3 muscle types, with which type do you think a physical therapy assistant is most concerned?

8.2 Structure of a Skeletal Muscle



Learning Outcomes

1. Identify the structures that make up a skeletal muscle.
2. Identify the major parts of a skeletal muscle fiber, and the function of each.
3. Discuss nervous stimulation of a skeletal muscle.

The human body has more than 600 distinct skeletal muscles. The face alone includes 60 muscles, more than 40 of which are used to frown, and 20 to smile. Thinner than a thread and barely visible, the stapedius in the middle ear is the body's smallest muscle. In contrast is the gluteus maximus, the largest muscle, located in the buttock. Averaging about 18 inches in length, the sartorius, found in the thigh, is the longest muscle in the body. However, at the microscopic level, all skeletal muscles are built from the same tissues.

Connective Tissue Coverings

Layers of connective tissue enclose and separate all parts of a skeletal muscle. Dense connective tissue called **fascia** (fash'e-ah) separates an individual skeletal muscle from adjacent muscles and holds it in position (**FIG. 8.1**). Fascia blends with the **epimysium** (ep'i-mis'ē-um), a layer of connective tissue that closely surrounds each skeletal muscle (fig. 8.1). Other layers of connective tissue, called **perimysium** (per'i-mis'ē-um), extend inward from the epimysium and separate the muscle tissue into small sections called **fascicles** (fas'ī-k'lz). Fascicles are bundles of skeletal muscle fibers. Each muscle fiber within a fascicle lies within a layer of connective tissue in the form of a thin covering called **endomysium** (en'do-mis'ē-um). This organization allows the parts to move somewhat independently. Many blood vessels and nerves pass through these layers.

The connective tissue layers may project beyond the muscle's end to form a cordlike tendon. Fibers in a tendon may intertwine with those in a bone's periosteum, attaching the muscle to the bone. In other cases, the connective tissue forms broad fibrous sheets called **aponeuroses** (ap'o-nū-rōsēz), which may attach to bone, skin, or to the connective tissue of adjacent muscles.

In *tendinitis*, a tendon (the attachment of a muscle to a bone) becomes painfully inflamed and swollen following injury or the repeated stress of athletic activity. If rest, physical therapy, and anti-inflammatory drugs do not alleviate tendinitis, then ultrasound can be applied to break up scar tissue. In *tenosynovitis*, the connective tissue sheath of the tendon (the tenosynovium) is inflamed. The tendons most commonly affected are those associated with the joint capsules of the shoulder, elbow, and hip, and those that move the hand, thigh, and foot.

Skeletal Muscle Fibers

A skeletal muscle fiber is a single cell that contracts (exerts a pulling force) in response to stimulation and then relaxes when the stimulation ends. Each skeletal muscle fiber is a long, thin, cylinder with rounded ends. It may extend the full length of the muscle. Just beneath its cell membrane (or *sarcolemma*), the cytoplasm (or *sarcoplasm*) of the fiber has many small, oval nuclei and mitochondria (fig. 8.1). The sarcoplasm also contains many threadlike **myofibrils** (mī'o-fi'brilz) that lie parallel to one another.



Case Study Connection

If these facial muscles were all the same size, which would require more caloric energy, smiling or frowning?

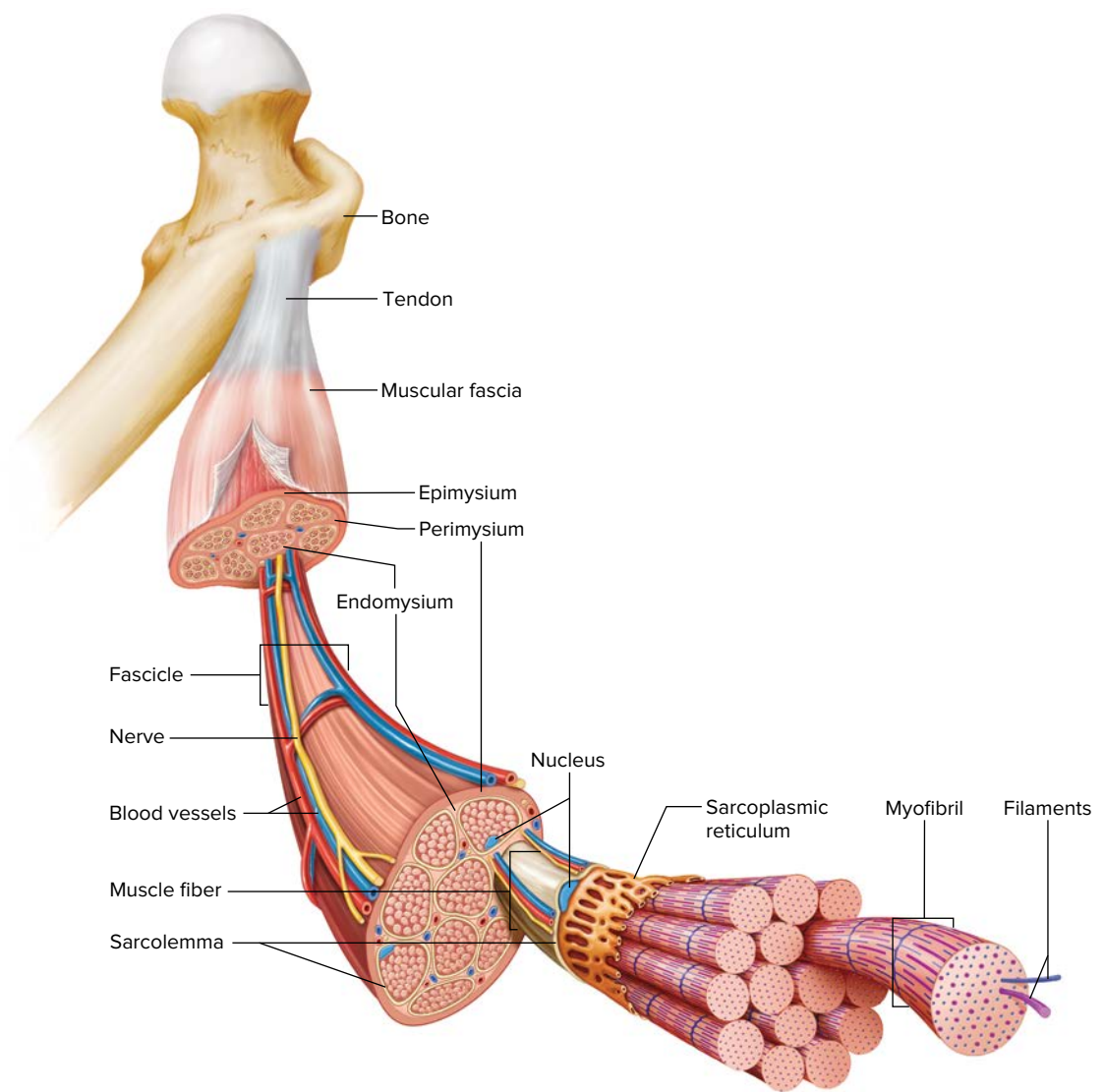


FIGURE 8.1 A skeletal muscle is composed of a variety of tissues, including layers of connective tissue. Fascia covers the surface of the muscle, epimysium lies beneath the fascia, and perimysium extends into the structure of the muscle where it groups muscle cells into fascicles. Endomysium separates individual muscle fibers within fascicles. **APR**

Myofibrils play a fundamental role in muscle contraction. They consist of two kinds of protein filaments (myofilaments)—thick filaments composed of the protein **myosin** (mī'o-sin) and thin filaments composed mainly of the protein **actin** (ak'tin) (**FIG. 8.2**). (Two other thin filament proteins, troponin and tropomyosin, are discussed later in section 8.3, Skeletal Muscle Contraction.) The organization of these filaments produces the characteristic alternating light and dark *striations*, or bands, of a skeletal muscle fiber.

The striations of skeletal muscle result from a repeating pattern of units called **sarcomeres** (sar'kō-měrz) within each muscle fiber. The myofibrils are essentially sarcomeres joined end-to-end (**FIGS. 8.2 and 8.3**). Muscle fibers, and in a way muscles themselves, may be thought of as a collection of sarcomeres. Sarcomeres are discussed later as the functional units of muscle contraction (section 8.3, Skeletal Muscle Contraction).

The striation pattern of skeletal muscle fibers has two main parts. The first, the *I bands* (the light bands), are composed of thin filaments directly attached to structures called *Z lines*. The second part of the striation pattern consists of the



Case Study Connection

Knowing that his muscles are functioning normally, will the child with a myostatin mutation have the same ratio of myosin to actin as his siblings without the mutation?

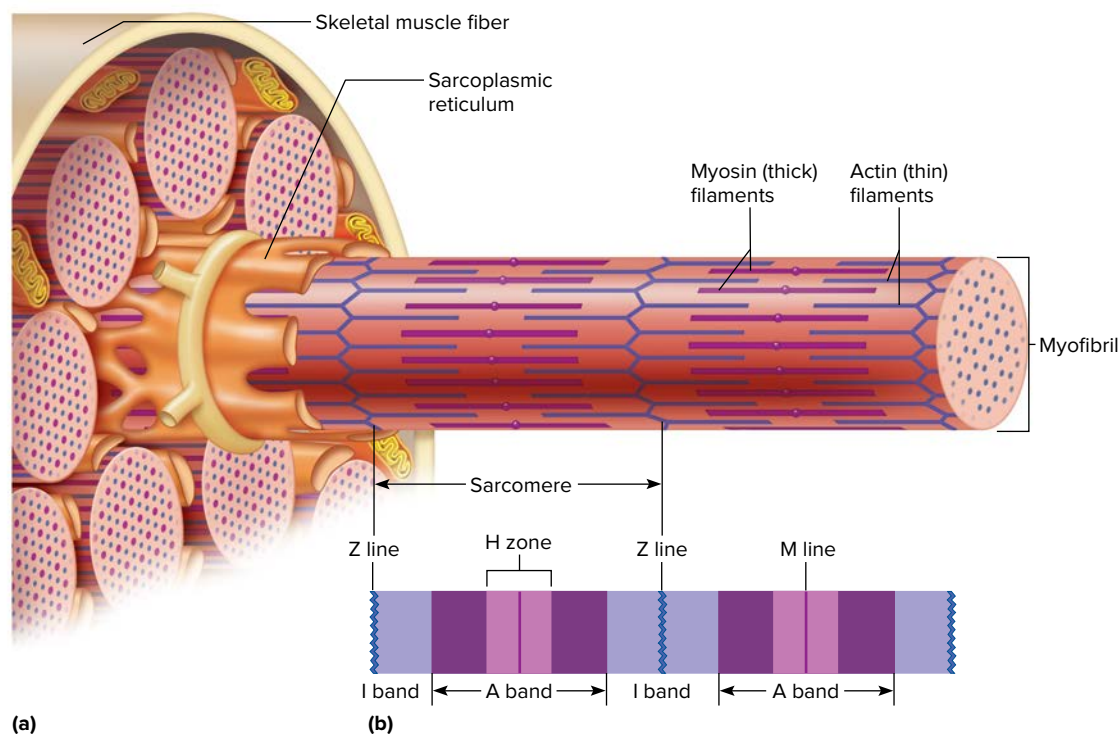


FIGURE 8.2 Skeletal muscle fiber. **(a)** A skeletal muscle fiber contains many myofibrils, each consisting of **(b)** repeating units called sarcomeres. The characteristic striations of a sarcomere reflect the organization of actin (thin) and myosin (thick) filaments.

Go online to demonstrate your understanding of the parts of a skeletal muscle fiber by completing the Focus Activity. **APR**

A bands (the dark bands), which extend the length of the thick filaments. The A bands have a central region (*H zone*), consisting only of thick filaments, located between two regions where the thick and thin filaments overlap. A thickening known as the *M line* is located down the center of the A band (see fig. 8.2). The *M line* consists of proteins that help hold the thick filaments in place. A sarcomere extends from one Z line to the next (see figs. 8.2 and 8.3).

Within the sarcoplasm of a muscle fiber is a network of membranous channels that surrounds each myofibril and runs parallel to it (FIG. 8.4). These membranes form the **sarcoplasmic reticulum**, which corresponds to the endoplasmic reticulum of other types of cells. Another set of membranous channels, called **transverse tubules** (T tubules), extends inward as invaginations from the fiber's membrane and passes all the way through the fiber. Thus, each transverse tubule opens to the outside of the muscle fiber and contains extracellular fluid. Furthermore, each transverse tubule lies between two enlarged portions of the sarcoplasmic reticulum called **cisternae**, near the region

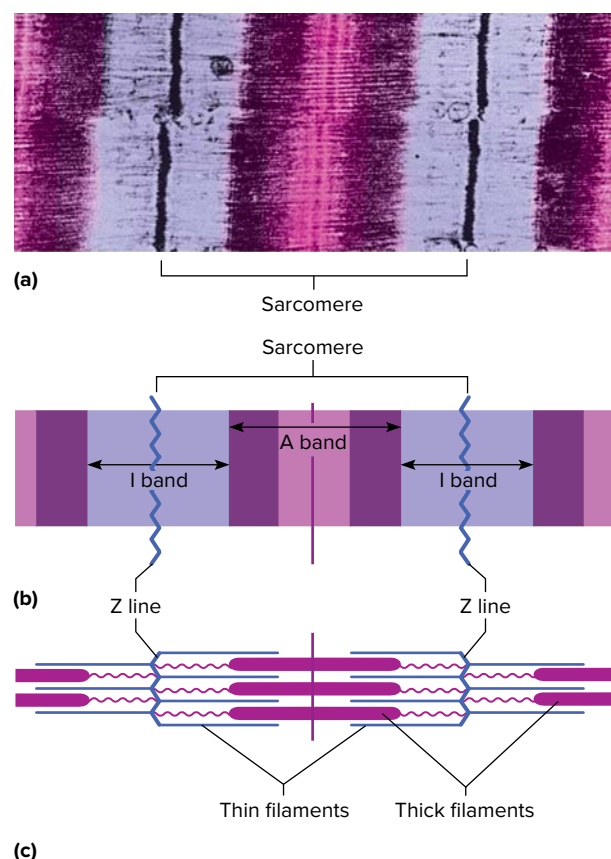


FIGURE 8.3 A sarcomere is the functional unit of muscle contraction. **(a)** Micrograph (16,000 \times). **(b, c)** The spatial relationship of thin and thick filaments in a sarcomere is the basis for the repeating pattern of striations in skeletal muscle. **APR**

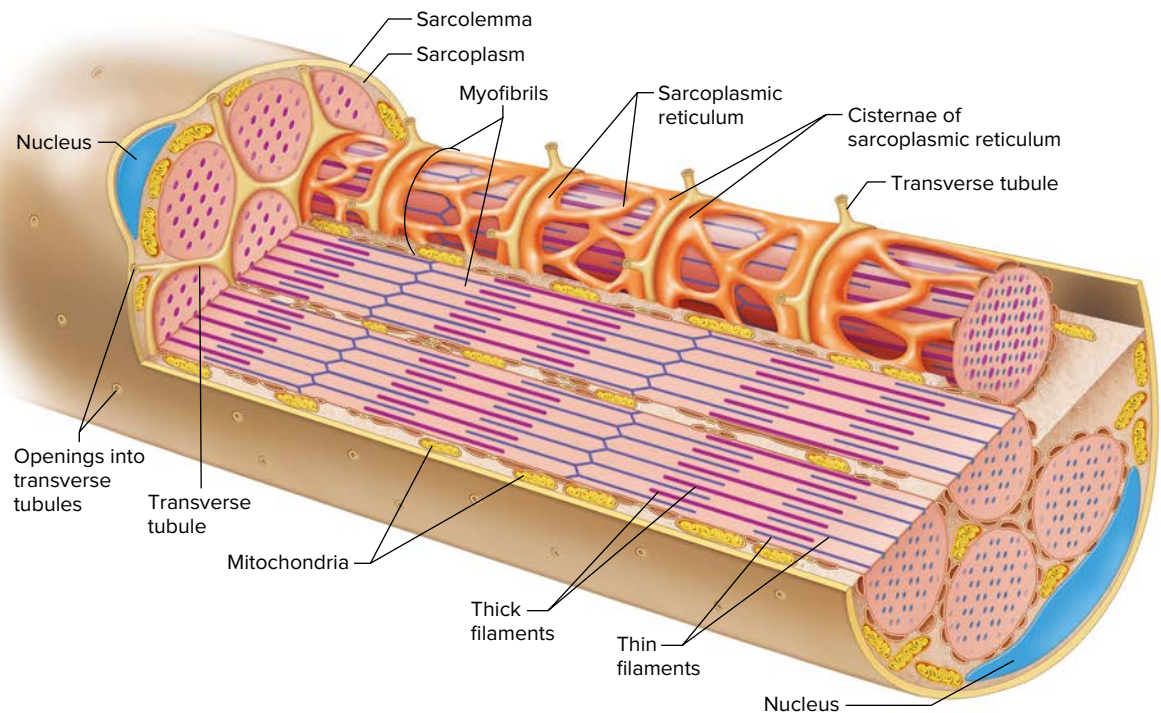


FIGURE 8.4 The sarcoplasm of a skeletal muscle fiber contains a network of sarcoplasmic reticulum and a system of transverse tubules.

Go online to demonstrate your understanding of the structures within a sarcomere by completing the Focus Activity.

where the thick and thin filaments overlap. The sarcoplasmic reticulum and transverse tubules play important roles in activating the contraction mechanism when the muscle fiber is stimulated.

Practice

1. Describe how connective tissue is part of a skeletal muscle.
2. Describe the general structure of a skeletal muscle fiber.
3. Explain why skeletal muscle fibers appear striated.
4. Explain the relationship between the sarcoplasmic reticulum and the transverse tubules.

Neuromuscular Junction

Recall from section 5.6, Nervous Tissues, that neurons (nerve cells) play a role in communication within the body by conducting electrical impulses. Neurons that control effectors (such as muscles) are called **motor neurons**. Normally, a skeletal muscle fiber contracts only when stimulated by a motor neuron. The opening vignette to chapter 3 describes amyotrophic lateral sclerosis (ALS, or Lou Gehrig's disease), which impairs the motor neurons that control skeletal muscles.

Each skeletal muscle fiber is functionally (but not physically) connected to the axon of a motor neuron that passes outward from the brain or the spinal cord. This is much like the functional connection whereby you can talk into a cell phone although your mouth is not in direct physical contact with it. The functional connection between a neuron and another cell is called a **synapse** (sin'aps). Neurons communicate with the cells that they control by releasing chemicals, called **neurotransmitters** (nu"ro-trans'mit-erz), at synapses.

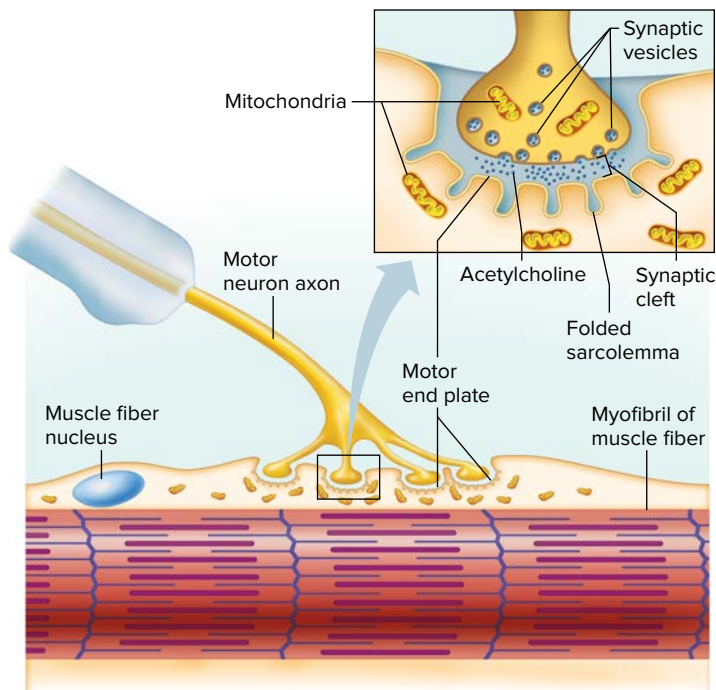


FIGURE 8.5 A neuromuscular junction includes the end of a motor neuron and the motor end plate of a muscle fiber. **APR**

? How does acetylcholine released into the synaptic cleft reach the muscle fiber membrane?

The synapse between a motor neuron and the muscle fiber that it controls is called a **neuromuscular junction**. Here, the muscle fiber membrane is specialized to form a **motor end plate**. At the motor end plate, nuclei and mitochondria are abundant. The sarcolemma has indentations and is extensively folded. The end of the motor neuron extends fine projections into the indentations of the muscle fiber membrane (**FIG. 8.5**).

A small gap called the **synaptic cleft** separates the membrane of the neuron and the membrane of the muscle fiber. The cytoplasm at the distal ends of these motor neuron axons is rich in mitochondria and contains many tiny vesicles (synaptic vesicles) that store neurotransmitter molecules (fig. 8.5).

Practice

5. Which two structures approach each other at a neuromuscular junction?
6. Describe a motor end plate.
7. What is the function of a neurotransmitter?

Use the Practices

Using Models A skeletal muscle is composed of a variety of tissues that are packaged together to make the organ. The structure of a muscle is similar to an orange. Create a model that demonstrates how an orange depicts the anatomy of a skeletal muscle.

8.3 Skeletal Muscle Contraction

Learning Outcomes

1. Identify the major events of skeletal muscle fiber contraction.
2. List the energy sources for muscle fiber contraction.
3. Describe how oxygen debt develops.
4. Describe how a muscle may become fatigued.
5. Distinguish between muscle fiber types.
6. Describe effects of skeletal muscle use and disuse.

A muscle fiber contraction involves an interaction of organelles and molecules in which myosin binds to actin and exerts a pulling force. The result is a movement within the myofibrils in which the filaments of actin and myosin slide past one another, increasing the area of overlap. This action shortens (contracts) the muscle fiber, which then pulls on the body part that it moves.

Role of Myosin and Actin

A myosin molecule is composed of two twisted protein strands with globular parts called heads projecting from one end. Many of these molecules together compose a thick filament. An actin molecule is a globular structure with a binding site to which the myosin heads can attach. Many actin molecules twist into a double strand (helix), forming a thin filament. The proteins **troponin** and **tropomyosin** are also part of the thin filament (**FIG. 8.6**).

The sarcomere is considered the functional unit of skeletal muscles because the contraction of an entire skeletal muscle can be described in terms of the shortening of the sarcomeres within its muscle fibers. The force that shortens the sarcomeres comes from the myosin heads pulling on the thin filaments. A myosin head can attach to an actin binding site, forming a *cross-bridge*, and bend slightly, pulling on the actin filament. Then the myosin head can release, straighten, combine with another binding site further down the actin filament, and pull again (**FIG. 8.7**).

The **sliding filament model** of muscle contraction includes all of these actin-myosin interactions and is named for how the sarcomeres shorten. Thick and thin filaments do not change length. Rather, they slide past one another, with the thin filaments moving toward the center of the sarcomere from both ends (**FIG. 8.8**).

The myosin heads contain an enzyme, **ATPase**, which catalyzes the breakdown of ATP to ADP and phosphate (see section 4.4, Energy for Metabolic Reactions). This reaction provides energy that straightens the myosin head into a “cocked” position, much like pulling back on the moving part of a spring-operated toy. The cocked myosin head stays in this position until it binds to actin, forming a cross-bridge.

When this happens, the “spring” is released and the cross-bridge pulls on the thin filament. Another ATP binding to the myosin breaks the cross-bridge, releasing the myosin head from the actin, but not breaking down the ATP. The ATPase then catalyzes the breakdown of ATP to ADP and phosphate, putting the myosin head in a “cocked” position again. This cycle repeats as long as ATP is available as an energy source and as long as the muscle fiber is stimulated to contract.

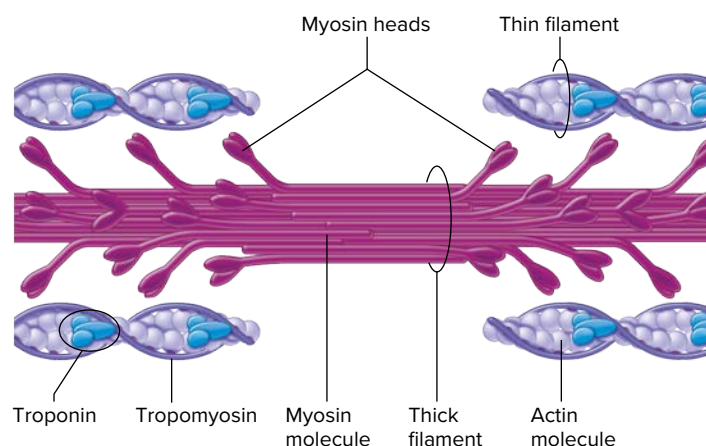


FIGURE 8.6 Thick filaments are composed of the protein myosin, and thin filaments are composed primarily of the protein actin. Myosin molecules have globular heads that extend toward nearby thin filaments.

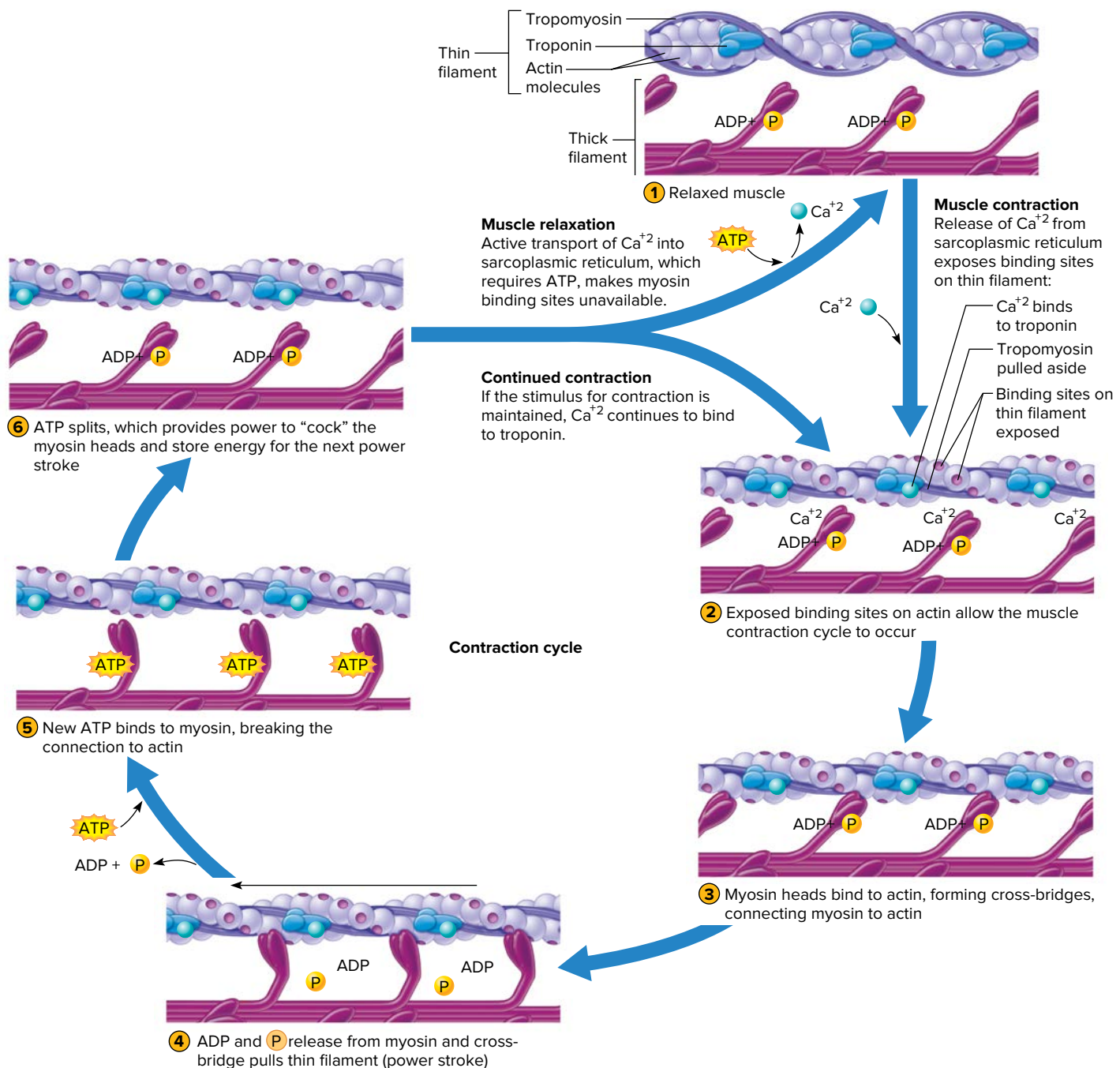
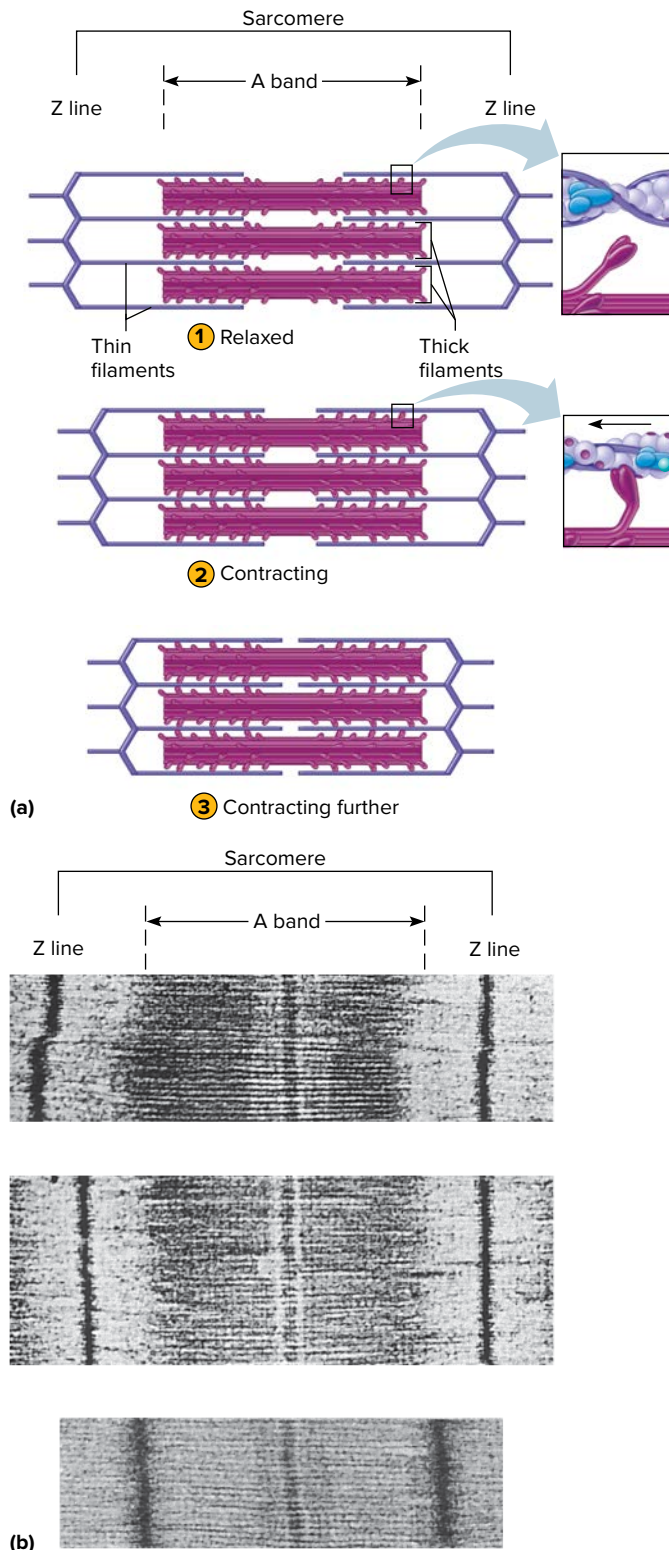


FIGURE 8.7 The sliding filament model. (1) Relaxed muscle. (2) When the calcium ion concentration in the cytosol rises, binding sites on thin filaments become exposed, and (3) myosin heads bind to the actin, forming cross-bridges. (4) Upon binding to actin, myosin heads spring from the cocked position and the cross-bridges pull on thin filaments. (5) ATP binds (but is not yet broken down), causing the myosin heads to release from the thin filament, thus breaking the cross-bridges. (6) ATP breakdown provides energy to again "cock" the unattached myosin heads. As long as ATP and calcium ions are present, the cycle continues. When the calcium ion concentration in the cytosol is low, the muscle is relaxed. **APR**

Several hours after death, skeletal muscles partially contract and become rigid, fixing the joints in place. This condition, *rigor mortis*, may continue for 72 hours or more. It results from an increase in membrane permeability to calcium ions, which allows cross-bridges to form, and a decrease in ATP in muscle fibers, which prevents relaxation. The actin and myosin filaments of the muscle fibers remain linked until the proteins begin to decompose.

FIGURE 8.8 When a skeletal muscle contracts, **(a)** individual sarcomeres shorten as thin filaments slide past thick filaments toward the center of the sarcomere. **(b)** This transmission electron micrograph shows a sarcomere shortening during muscle contraction (23,000 \times). **APR**

? What happens to the length of the thick and thin filaments during contraction?



Stimulus for Contraction

A skeletal muscle fiber normally does not contract until the neurotransmitter **acetylcholine** (as"ě-til-kō'llēn) stimulates it. This neurotransmitter is synthesized in the cytoplasm of the motor neuron and stored in vesicles at the distal end of the motor neuron axons. When an impulse (see section 9.5, Charges Inside a Cell, and section 9.6, Impulse Conduction) reaches the end of a motor neuron axon, some of the vesicles release their acetylcholine into the synaptic cleft, the space between the motor neuron axon and the motor end plate (see fig. 8.5).

Acetylcholine diffuses rapidly across the synaptic cleft and binds to specific protein molecules (acetylcholine receptors) in the muscle fiber membrane at the motor end plate, increasing membrane permeability to sodium ions. Entry of these charged particles into the muscle cell stimulates an electrical impulse much like the impulse on the motor neuron. The impulse passes in all directions over the surface of the muscle fiber membrane and travels through the transverse tubules, deep into the fiber, until it reaches the sarcoplasmic reticulum (see fig. 8.4).

The sarcoplasmic reticulum contains a high concentration of calcium ions. In response to a muscle impulse, the membranes of the sarcoplasmic reticulum become more permeable to these ions, and the calcium ions diffuse into the cytosol of the muscle fiber.

When a high concentration of calcium ions is in the cytosol, troponin and tropomyosin interact in a way that exposes binding sites on actin where myosin heads can attach. As a result, cross-bridge linkages form between the thick and thin filaments, and the muscle fiber contracts (see figs. 8.7 and 8.8). The contraction, which requires ATP, continues as long as the motor neuron releases acetylcholine.

When nervous stimulation ceases, three events lead to muscle relaxation. First, the acetylcholine that stimulated the muscle fiber is rapidly decomposed by the enzyme **acetylcholinesterase** (as'ee-til-kō"lin-es'ter-ās). This enzyme is present at the neuromuscular junction on the membrane of the motor end plate. Without acetylcholine binding to its receptors, the impulse on the muscle fiber ceases.

The second event in muscle relaxation takes place once acetylcholine is broken down and the stimulus to the muscle fiber ceases. Using ATP as an energy source, calcium ions are actively transported back into the sarcoplasmic reticulum, which decreases the calcium ion concentration of the cytosol. The third event involves ATP binding to myosin, breaking the cross-bridge linkages between thin and thick filaments, and consequently relaxing the muscle fiber. **TABLE 8.1** summarizes the major events leading to muscle contraction and relaxation.



Practice

1. Explain how an impulse on a motor neuron can trigger a muscle contraction.
2. Explain how the filaments of a myofibril interact during muscle contraction.

Energy Sources for Contraction

ATP molecules supply the energy for muscle fiber contraction. However, when a contraction starts, a muscle fiber has only enough ATP to enable it to contract for a very short time. Therefore, when a fiber is active, ATP must be regenerated from ADP and phosphate. The molecule that initially makes this possible is **creatine phosphate** (krē'ah-tin fos'fāt).

Like ATP, creatine phosphate contains high-energy phosphate bonds. When ATP supply is sufficient, an enzyme in the mitochondria (creatine phosphokinase) catalyzes the synthesis of creatine phosphate, which stores excess energy in its phosphate bonds (**FIG. 8.9**).

Creatine phosphate is four to six times more abundant in muscle fibers than ATP, but it cannot directly supply energy to a cell's energy-utilizing reactions. Instead, as ATP decomposes, the phosphate from creatine phosphate can be transferred to ADP molecules, converting them back into ATP. Active muscle fibers, however,

TABLE 8.1 Major Events of Muscle Contraction and Relaxation

Muscle Fiber Contraction	
1.	An impulse travels down a motor neuron axon.
2.	The motor neuron releases the neurotransmitter acetylcholine (ACh).
3.	ACh binds to ACh receptors in the muscle fiber membrane.
4.	The sarcolemma is stimulated. An impulse travels over the surface of the muscle fiber and deep into the fiber through the transverse tubules.
5.	The impulse reaches the sarcoplasmic reticulum, and calcium channels open.
6.	Calcium ions diffuse from the sarcoplasmic reticulum into the cytosol and bind to troponin molecules.
7.	Tropomyosin molecules move and expose specific sites on actin where myosin heads can bind.
8.	Cross-bridges form, linking thin and thick filaments.
9.	Thin filaments are pulled toward the center of the sarcomere by pulling of the cross-bridges.
10.	The muscle fiber exerts a pulling force on its attachments as a contraction occurs.
Muscle Fiber Relaxation	
1.	Acetylcholinesterase decomposes acetylcholine, and the muscle fiber membrane is no longer stimulated.
2.	Calcium ions are actively transported into the sarcoplasmic reticulum.
3.	ATP breaks cross-bridge linkages between actin and myosin filaments without breakdown of the ATP itself.
4.	Breakdown of ATP “cocks” the myosin heads.
5.	Troponin and tropomyosin molecules block the interaction between myosin and actin filaments.
6.	The muscle fiber remains relaxed, yet ready, until stimulated again.

rapidly exhaust the supply of creatine phosphate. When this happens, the muscle fibers use cellular respiration of glucose as an energy source for synthesizing ATP.

Oxygen Supply and Cellular Respiration

Glycolysis can take place in the cytosol in the absence of oxygen (anaerobic), as discussed in section 4.4, Energy for Metabolic Reactions. The more complete breakdown of glucose occurs in the mitochondria and requires oxygen. The blood carries the oxygen from the lungs to body cells to support this aerobic respiration. Red blood cells carry the oxygen, loosely bound to molecules of **hemoglobin**, the protein responsible for the red color of blood.

Another protein, **myoglobin**, is synthesized in muscle cells and imparts the reddish-brown color of skeletal muscle tissue. Like hemoglobin, myoglobin can combine loosely with oxygen. Myoglobin’s ability to temporarily store oxygen increases the amount of oxygen available in the muscle cells to support aerobic respiration (**FIG. 8.10**).

Oxygen Debt

When a person is resting or is moderately active, the respiratory and cardiovascular systems can usually supply sufficient oxygen to skeletal muscles to support aerobic respiration. This may not be the case when skeletal muscles are used strenuously for even a minute or two. In this situation, muscle fibers increasingly rely on anaerobic respiration to obtain energy.

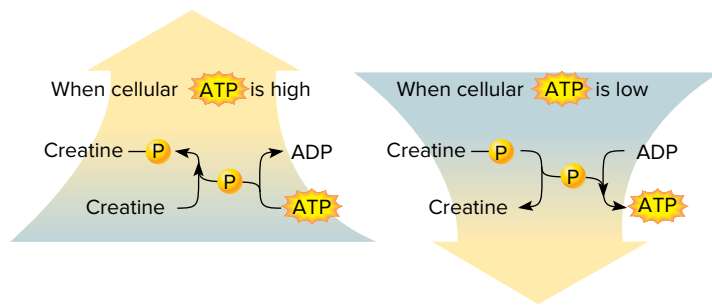


FIGURE 8.9 Creatine phosphate is synthesized when ATP levels in a muscle cell are high. Creatine phosphate may be used to replenish ATP when ATP levels in a muscle cell are low.

In anaerobic respiration, glucose molecules are broken down by glycolysis, yielding *pyruvic acid*, which would enter the citric acid cycle under aerobic conditions (see section 4.4, Energy for Metabolic Reactions). Because the oxygen supply is low, however, the pyruvic acid reacts to produce **lactic acid** (fig. 8.10). Lactic acid dissociates rapidly to form lactate ion (lactate) and hydrogen ion. Lactate leaves muscle cells by facilitated diffusion, enters the bloodstream, and eventually reaches the liver. In liver cells, reactions requiring ATP synthesize glucose from lactate.

During strenuous exercise, available oxygen is used primarily to synthesize the ATP the muscle fiber requires to contract, rather than to make ATP for synthesizing glucose from lactate. Consequently, as lactate accumulates, a person develops an oxygen debt that must be repaid. **Oxygen debt** (also called *excess post-exercise oxygen consumption*, or EPOC) equals the amount of oxygen that liver cells require to convert the accumulated lactate into glucose, plus the amount muscle cells require to restore ATP and creatine phosphate to their original concentrations and to return blood and tissue oxygen levels to normal. The conversion of lactate back into glucose is slow. Repaying an oxygen debt following vigorous exercise may take several hours.

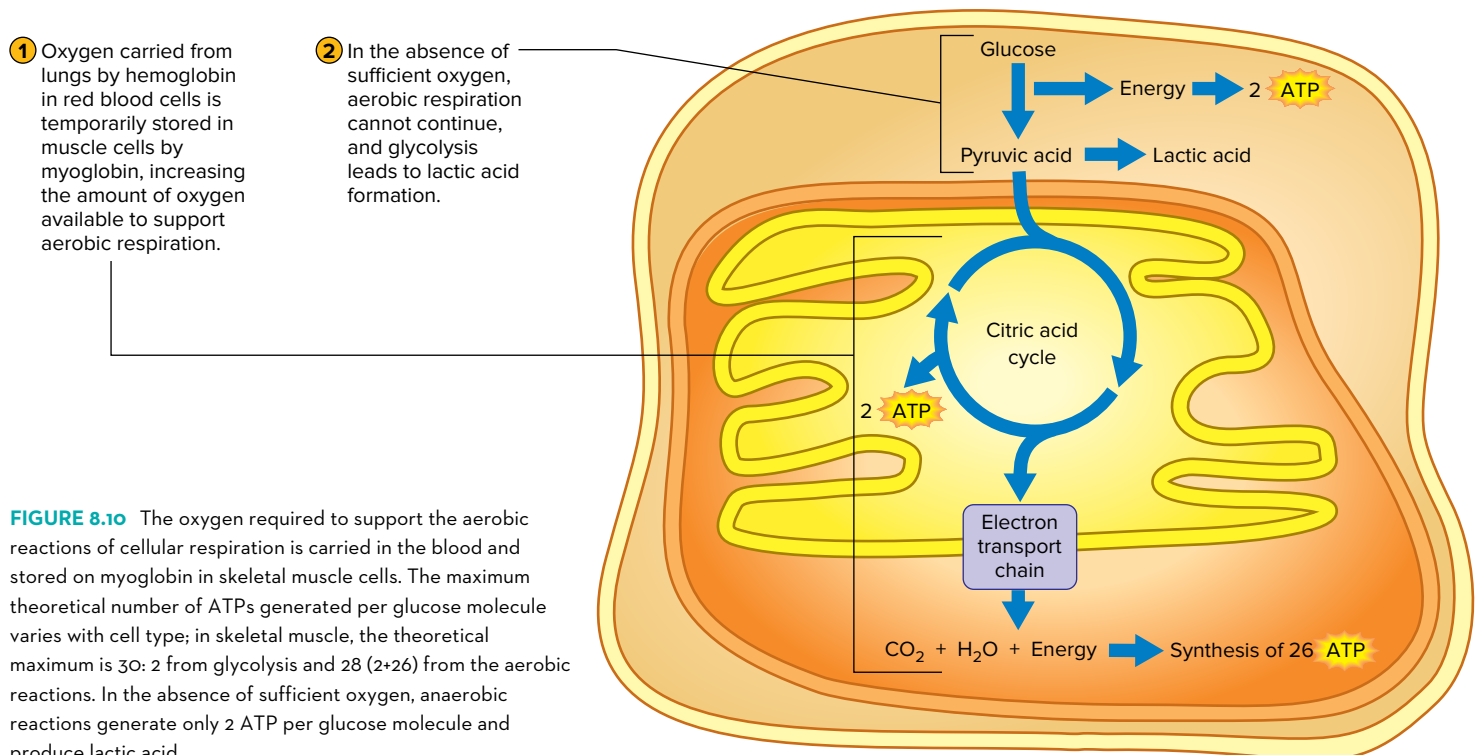


FIGURE 8.10 The oxygen required to support the aerobic reactions of cellular respiration is carried in the blood and stored on myoglobin in skeletal muscle cells. The maximum theoretical number of ATPs generated per glucose molecule varies with cell type; in skeletal muscle, the theoretical maximum is 30: 2 from glycolysis and 28 (2+26) from the aerobic reactions. In the absence of sufficient oxygen, anaerobic reactions generate only 2 ATP per glucose molecule and produce lactic acid.

Table 8.2 Muscle Metabolism

Type of Exercise	Pathway Used	ATP Production	Waste Product
Low to moderate intensity: Blood flow provides sufficient oxygen for cellular requirements	Glycolysis, leading to pyruvic acid formation and aerobic respiration	30 ATP per glucose for skeletal muscle	Carbon dioxide is exhaled
High intensity: Oxygen supply is not sufficient for cellular requirements	Glycolysis, leading to lactic acid formation	2 ATP per glucose	Lactic acid accumulates

The metabolic capacity of a muscle may change with physical training. With high-intensity exercise, which depends more on glycolysis for ATP, a muscle synthesizes more glycolytic enzymes, and its capacity for glycolysis increases. With aerobic exercise, more capillaries and mitochondria form, and the muscle's capacity for aerobic respiration increases. **TABLE 8.2** summarizes muscle metabolism, and The Healthy Lifestyle Choices feature on the next page discusses abuse of steroid drugs to enhance muscle performance.

Heat Production

Less than half of the energy released in cellular respiration is transferred to ATP, and the rest becomes heat. Although all active cells generate heat, muscle tissue is a major heat source because muscle is such a large proportion of the total body mass. Blood transports heat generated in muscle to other tissues, which helps maintain body temperature. In cold temperatures, skeletal muscles can also generate body heat through involuntary contractions commonly called shivering.

Muscle Fatigue

A muscle exercised strenuously for a prolonged period may have a decreased ability to contract, a condition called *fatigue*. The obvious cause of muscle fatigue is the depletion of the energy source, ATP. Although not completely understood, fatigue more than likely involves a complex combination of other factors, including a drop in pH due to a buildup of lactic acid. Fluctuations in pH can have adverse effects on the physiology of a muscle fiber. Electrolyte imbalance and central nervous system exhaustion have also been proposed as potential factors.

Occasionally, a muscle becomes fatigued and cramps at the same time. A cramp is a painful condition in which a muscle undergoes a sustained involuntary contraction. Cramps are thought to occur when changes in the extracellular fluid surrounding the muscle fibers and their motor neurons somehow trigger uncontrolled stimulation of the muscle.

Types of Muscle Fibers and Muscle Use

Not all muscle fibers are the same. *Fast fibers* are built for rapid movements, whereas *slow fibers* allow for endurance activities. All whole muscles are comprised of a unique combination of these two fiber types.

Fast Fibers Fast fibers make up the majority of muscle fibers in the body. They are called fast fibers because they are able to generate their maximum force rapidly. Large in diameter, they also provide fairly powerful contractions. They contain a



Case Study Connection

Because he has more muscle mass, will the child with the myostatin mutation need more blood volume and more blood vessels?



Case Study Connection

This child has significantly more muscle mass than his peers. Last week in his Kindergarten class, the school's heat system broke and the classroom was cold. How do you think this child felt in the cold room compared to his classmates?

Healthy Lifestyle Choices

Steroids and Athletes—An Unhealthy Combination

It seems that not a year goes by without a few famous athletes confessing to, or being caught using, steroid hormones to bulk up their muscles to improve performance. High school and college athletes have abused steroids too. Athletes who abuse steroids seek the hormone's ability to increase muscular strength. They are caught when the steroids or their breakdown products are detected in urine or when natural testosterone levels plummet in a negative feedback response to the outside hormone supply (**FIG. 8A**).

Improved performance today due to steroid use may have consequences tomorrow. Steroids hasten adulthood, stunting height and causing early hair loss. In males, excess steroid hormones lead to breast development, and in females to a deepened voice, hairiness, and a male physique. The drugs may damage the kidneys, liver, and heart. Atherosclerosis may develop because steroids raise LDL cholesterol. In males, the body mistakes the synthetic steroids for the natural hormone and lowers its own production of testosterone. Infertility may result. Steroids can also cause psychiatric symptoms, including delusions, depression, and violence.

Anabolic steroids have been used for medical purposes since the 1930s, to treat underdevelopment of the testes and the resulting testosterone deficiency, anemia, and muscle-wasting disorders. Today, they are used to treat wasting associated with AIDS.



FIGURE 8A Sprinter Ben Johnson ran away with the gold medal in the 100-meter race at the 1988 Summer Olympics—but then had to return the award when traces of a steroid drug showed up in his urine. Drug abuse continues to be a problem among amateur as well as professional athletes.

Concept Connection

1. Explain what happens to the levels of testosterone in a male athlete who abuses steroids and how this explains the signs and symptoms of steroid abuse (hint: think about negative feedback loops).
2. Describe how the metabolic capacity of a muscle changes with physical exercise.

large amount of glycogen and relatively few mitochondria, making them mostly dependent on anaerobic energy production (glycolysis). Therefore, they are not ideal for prolonged activities. Whole skeletal muscles constructed primarily from fast fibers are known as white muscles. Examples include most of the muscles in the hand, the biceps brachii in the arm, and those that move the eyeball. Chicken breast is called “white meat” because it is mostly made of fast fibers for quick, short bursts of flight.

Slow Fibers Slow fibers are small in diameter. Taking longer to reach peak tension, slow fibers have the ability to provide contraction for prolonged periods. Densely packed with mitochondria, capillaries, and myosin, they are custom built for aerobic energy production. Therefore, they are much more resistant to fatigue than fast fibers. Skeletal muscles with a high percentage of slow fibers are often called red muscles because of the high concentration of myoglobin. Examples include the muscles of the back and vertebral column that maintain posture and many of the muscles in the legs for standing and walking. “Dark meat” in chicken is found in the legs and thighs where the muscles contain mostly slow, red fibers.

Exercise and Muscle Use Skeletal muscles are very responsive to an increase or decrease in activity. Forcefully exercised muscles enlarge, which is called *muscular hypertrophy*. Conversely, an unused muscle undergoes *atrophy*, decreasing in size and strength.

The way a muscle responds to use also depends on the type of exercise. A muscle contracting with lower intensity, during swimming or running, activates slow fibers. With use, these specialized muscle fibers develop more mitochondria, and more extensive capillary networks envelop them. Such changes increase the slow fibers' ability to resist fatigue during prolonged exercise, although their sizes and strengths may remain unchanged.

Forceful exercise, such as weightlifting, in which a muscle exerts more than 75% of its maximum tension, utilizes fast fibers. In response to strenuous exercise, these fibers produce new filaments of actin and myosin, the diameters of the muscle fibers increase, and the entire muscle enlarges. That is, there is no increase in the number of muscle fibers; the existing fibers become larger.

The strength of a muscular contraction is directly proportional to the diameter of the activated muscle fibers. Consequently, an enlarged muscle can produce stronger contractions than before. Such a change, however, does not increase the muscle's ability to resist fatigue during activities like swimming or running.

If regular exercise stops, the capillary networks shrink, and the number of mitochondria within the muscle fibers drops. The number of actin and myosin filaments decreases, and the entire muscle atrophies. Such atrophy commonly occurs when accidents or diseases block motor impulses from reaching muscle fibers. An unused muscle may shrink to less than half its usual size within a few weeks.

The fibers of muscles whose motor neurons are severed not only shrink, but also may fragment and, in time, be replaced by fat or fibrous connective tissue. However, reinnervation within the first few months following an injury may restore muscle function.

Astronauts experience muscle atrophy and impaired performance with long-term exposure to the microgravity environment of space. Customized workouts using special resistance equipment can minimize the changes in muscle structure and function.



Case Study Connection

Muscle atrophy is common in AIDS and other diseases. What might occur in AIDS patients if a myostatin inhibitor (a drug that could stop the action of myostatin) was given?



Practice

3. Which chemicals provide the energy to regenerate ATP?
4. What are the sources of oxygen for aerobic respiration?
5. How are lactic acid and oxygen debt related?
6. What is the relationship between cellular respiration and heat production?
7. What are the causes of skeletal muscle fatigue?
8. How do fast fibers and slow fibers differ?
9. How does skeletal muscle respond to different types of exercise and to no exercise?

Use the Practices

Arguing from Evidence In idiopathic dilated cardiomyopathy (a genetic disorder), actin is unable to anchor to the Z lines in cardiac muscle cells. Provide reasoning based on the mechanism of muscle contraction why this results in heart failure.

8.4 Muscular Responses

Learning Outcomes

1. Distinguish among a twitch, recruitment, and a sustained contraction.
2. Explain how muscular contractions move body parts and help maintain posture.
3. Distinguish between the types of contractions.

One way to observe muscle contraction is to remove a single muscle fiber from a skeletal muscle and connect it to a device that records changes in the fiber's length. Such experiments usually require an electrical device that can produce stimuli of varying strengths and frequencies.

Threshold Stimulus

When an isolated muscle fiber in the laboratory is exposed to a series of stimuli of increasing strength, the fiber remains unresponsive until a certain strength of stimulation called the *threshold stimulus* is applied. Once threshold is reached, an electrical impulse is generated that spreads throughout the muscle fiber, releasing enough calcium ions from the sarcoplasmic reticulum to activate cross-bridge binding and contract that fiber. In the body, a single impulse in a motor neuron normally releases enough ACh at the neuromuscular junction to bring a muscle fiber to threshold.

Recording of a Muscle Contraction

The contractile response of a single muscle fiber to a single impulse is called a **twitch**. A twitch consists of a period of contraction, during which pulling force increases, followed by a period of relaxation, during which the pulling force declines. These events can be recorded in a pattern called a *myogram* (FIG. 8.11). Note that a twitch has a brief delay between the time of stimulation and the beginning of contraction. This is the **latent period**, which in human muscle is approximately 2 milliseconds. During this time, calcium ions, actin, and myosin are preparing to interact as described in section 8.3.

A muscle fiber brought to threshold under a given set of conditions tends to contract completely, such that each twitch generates the maximum force of a single muscle fiber. This phenomenon has been termed an *all-or-none* response: either the muscle fiber contracts or it does not. There is no partial contraction of a single muscle fiber.

The myogram of twitch contractions allows us to understand and visualize the various phases of muscle contraction. However, a twitch contraction of a single fiber is of no use in the overall action of a whole muscle.

Contractions of whole muscles enable us to perform everyday activities, but the force generated by those contractions must be controlled. For example, holding a paper coffee cup

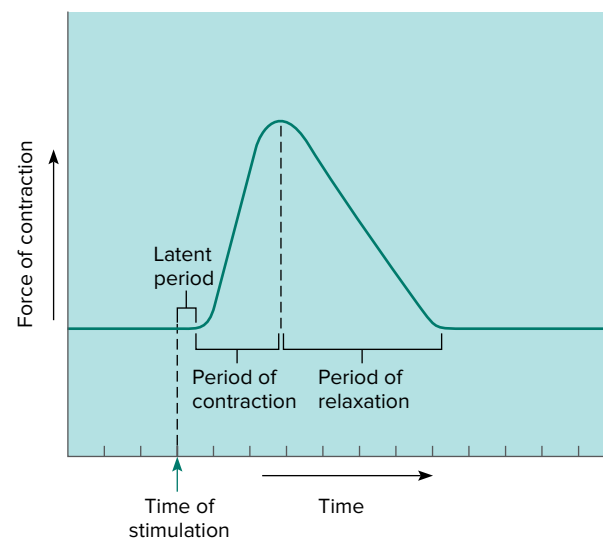


FIGURE 8.11 A myogram of a single muscle twitch.

firmly enough that it does not slip through our fingers, but not so forcefully as to crush it, requires precise control of contractile force. In the whole muscle, the degree of tension developed reflects (1) the frequency at which individual muscle fibers are stimulated and (2) how many fibers take part in the overall contraction of the muscle.

Summation

A muscle fiber exposed to a series of stimuli of increasing frequency reaches a point when it is unable to completely relax before the next stimulus in the series arrives. When this happens, the force of individual twitches combines through the process of **summation**.

At higher frequencies of stimulation, the time spent in relaxation becomes very brief. A condition called partial tetany results. If the frequency of contraction is so rapid that the fiber doesn't relax at all, it is called a complete tetanic (tě-tan'ik) contraction, or tetanus (**FIG. 8.12**). Partial tetanic contractions occur frequently in skeletal muscles during everyday activities. Complete tetany does not occur in the body, but can be demonstrated in the laboratory.

Recruitment of Motor Units

Summation increases the force of contraction of a single muscle fiber, but a whole muscle can generate more force if more muscle fibers participate in the contraction. A muscle fiber typically has a single motor end plate. The axons of motor neurons, however, are densely branched, which enables one such axon to control many muscle fibers. A motor neuron and the muscle fibers that it controls constitute a **motor unit** (mō'tor ū'nit) (**FIG. 8.13**). Each motor unit is a functional unit because an impulse in its motor neuron will cause all of the muscle fibers in that motor unit to contract at the same time.

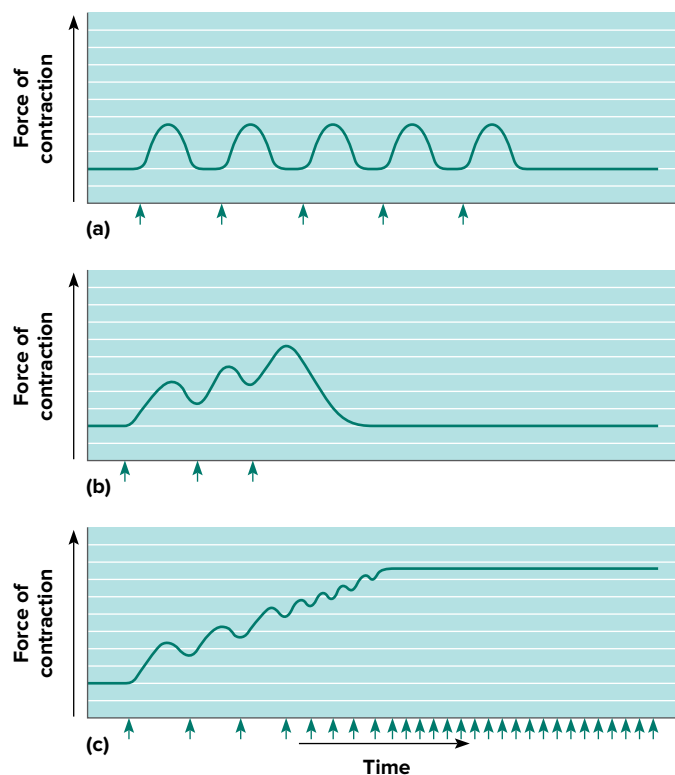


FIGURE 8.12 Myograms of (a) a series of twitches, (b) summation, and (c) a tetanic contraction. Note that stimulation frequency increases from one myogram to the next.

A whole muscle is composed of many motor units controlled by different motor neurons. Like muscle fibers, motor neurons must be brought to threshold before an impulse is generated. It turns out that some motor neurons are more easily brought to threshold than others. If only the more sensitive motor neurons reach threshold, few motor units contract. At higher intensities of stimulation, other motor neurons are brought to threshold, and more motor units are activated. An increase in the number of motor units activated during a contraction is called **recruitment**. As the intensity of stimulation increases, recruitment of motor units continues until, finally, all motor units in that muscle are activated and the muscle contracts with maximal tension.

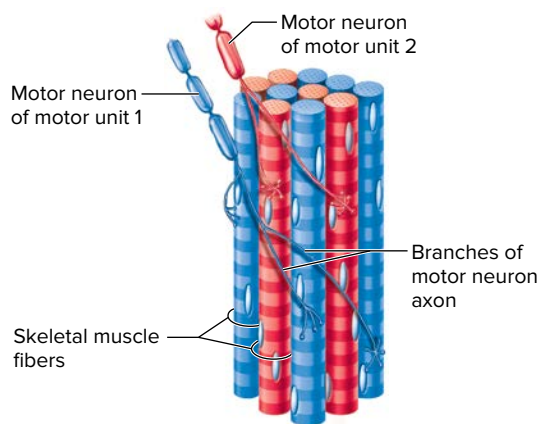


FIGURE 8.13 Portions of two motor units. Muscle fibers within a motor unit are innervated by a single neuron and may be distributed throughout the muscle.

Sustained Contractions and Muscle Tone

Summation and recruitment together can produce a *sustained contraction* of increasing strength. Sustained contractions of whole muscles enable us to perform everyday activities. Such contractions are responses to a rapid series of impulses transmitted from the brain and spinal cord on motor neuron axons.

Even when a muscle appears to be at rest, its fibers undergo some sustained contraction. This is called **muscle tone**. Muscle tone is a response to nervous stimulation that originates repeatedly from the spinal cord and stimulates only a few muscle fibers at a time. Muscle tone is particularly important in maintaining posture. If muscle tone is suddenly lost, as happens when a person loses consciousness, the body collapses.

Types of Contractions

The term “contraction” can be misleading. Muscles do not have to “shorten” to generate a force. The type of contraction associated with movement that actually involves the shortening of the muscle is called an **isotonic contraction**. As the muscle shortens and generates a force, the tension throughout the movement remains the same. An example would be going to the gym and using a ten-pound weight for the “bicep curl.” You start with the weight at your side and then lift it up to your shoulder. You can see and feel your bicep become short and squat. In an **isometric contraction**, the muscle generates a force without shortening. This occurs when holding a weight at your side. The muscles have to generate enough force to resist overstretching and oppose the gravitational pull of the weight. Although the muscle does not shorten, the tension increases as time passes and the weight appears to get heavier. Most movements employ various combinations of isotonic and isometric contractions.



Practice

1. Define threshold stimulus.
2. Distinguish between a twitch and a sustained contraction.
3. How is muscle tone maintained?
4. How do isotonic and isometric contractions differ?

Use the Practices

Conducting Investigations Allison hypothesizes that the force generated by a muscle is directly related to the number of muscle fibers contracting within the muscle. Research whether or not there is evidence to support Allison's hypothesis.

8.5 Smooth Muscle



Learning Outcomes

1. Distinguish between the structures and functions of multiunit smooth muscle and visceral smooth muscle.
2. Compare the contraction mechanisms of skeletal and smooth muscle

The contractile mechanism of smooth muscle is essentially the same as for skeletal muscle. The cells of smooth muscle, however, have some important structural and functional differences from the other types of muscle.

Smooth Muscle Cells

Recall from section 5.5, Muscle Tissues, that smooth muscle cells are elongated, with tapering ends. Smooth muscle cells contain thick and thin filaments, but these filaments are organized differently and more randomly than those in skeletal muscle. Therefore, smooth muscle cells lack striations (and appear “smooth” under the microscope). The sarcoplasmic reticulum in these cells is not well developed.

The two major types of smooth muscle are multiunit and visceral. In **multiunit smooth muscle**, the muscle cells are separate rather than organized into sheets. Smooth muscle of this type is found in the irises of the eyes and in the walls of blood vessels. Typically, multiunit smooth muscle tissue contracts only in response to stimulation by neurons or certain hormones.

Visceral smooth muscle is composed of sheets of spindle-shaped cells in close contact with one another (see fig. 5.23). This more common type of smooth muscle is found in the walls of hollow organs, such as the stomach, intestines, urinary bladder, and uterus.

Visceral smooth muscle displays *rhythmicity*, a pattern of repeated contractions. Rhythmicity is due to self-exciting cells that deliver spontaneous impulses periodically into surrounding muscle tissue. When one cell is stimulated, the impulse may excite adjacent cells, which in turn stimulate still others. These two features—rhythmicity and transmission of impulses from cell to cell—are largely responsible for the wavelike motion, called **peristalsis** (per"ĩ-stal'sis), that helps force the contents of certain tubular organs along their lengths. Peristalsis occurs, for example, in the intestines.

Smooth Muscle Contraction

Smooth muscle contraction resembles skeletal muscle contraction in a number of ways. Both mechanisms include reactions of actin and myosin, both are triggered by membrane impulses and an increase in intracellular calcium ions, and both use energy from ATP. However, these two types of muscle tissue also have significant differences.

Recall that acetylcholine is the neurotransmitter in skeletal muscle. Two neurotransmitters commonly affect smooth muscle—acetylcholine and norepinephrine. Each of

these neurotransmitters stimulates contractions in some smooth muscle and inhibits contractions in other smooth muscle (see section 9.16, Autonomic Nervous System). Also, a number of hormones affect smooth muscle, stimulating contractions in some cases and altering the degree of response to neurotransmitters in others.

Smooth muscle is slower to contract and to relax than skeletal muscle. On the other hand, smooth muscle can maintain a forceful contraction longer with a given amount of ATP. Also, unlike skeletal muscle, smooth muscle cells can change length without changing tautness. As a result, smooth muscle in the stomach and intestinal walls can stretch as these organs fill, yet maintain a constant pressure inside these organs.

Practice

1. Describe two major types of smooth muscle.
2. What special characteristics of visceral smooth muscle make peristalsis possible?
3. How does smooth muscle contraction differ from skeletal muscle contraction?

Use the Practices

Asking Questions Develop a question about why peristalsis is found only in smooth muscle.

8.6 Cardiac Muscle

Learning Outcomes

1. Compare the contraction mechanisms of cardiac and skeletal muscle.

Cardiac muscle is found only in the heart. Its mechanism of contraction is essentially the same as that of skeletal and smooth muscle, but with some important differences.

Cardiac Muscle Cells and Contraction

Cardiac muscle is composed of branching, striated cells interconnected in three-dimensional networks (see fig. 5.24). Each cell has many filaments of actin and myosin, organized similarly to those in skeletal muscle. A cardiac muscle cell also has a sarcoplasmic reticulum, many mitochondria, and a system of transverse tubules. However, the sarcoplasmic reticulum of cardiac muscle cells is less well developed and stores less calcium than that of skeletal muscle, and the transverse tubules of cardiac muscle are larger. Many calcium ions released into the cytosol in response to muscle impulses come from the extracellular fluid through these large transverse tubules. This mechanism causes cardiac muscle twitches to last longer than skeletal muscle twitches.

The opposing ends of cardiac muscle cells are connected by structures called **intercalated discs**. These are elaborate junctions between cardiac muscle cell membranes. Intercalated discs allow impulses to pass freely so that they travel rapidly from cell to cell, triggering contraction. The discs help to join cells and to transmit the force of contraction from cell to cell. Thus, when one portion of the cardiac muscle network is stimulated, the resulting impulse passes to the other parts of the network, and the whole structure contracts as a functional unit.

Cardiac muscle is also self-exciting and rhythmic. Consequently, a pattern of contraction and relaxation repeats, causing the rhythmic contractions of the heart.

Table 8.3 Types of Muscle Tissue

	Skeletal	Smooth	Cardiac
<i>Major Location</i>	Skeletal muscles	Walls of hollow viscera, blood vessels	Wall of the heart
<i>Major Function</i>	Movement of bones at joints, maintenance of posture	Movement of viscera, peristalsis, vasoconstriction	Pumping action of the heart
<i>Cellular Characteristics</i>			
Striations	Present	Absent	Present
Nucleus	Many nuclei	Single nucleus	Single nucleus
Special features	Well-developed transverse tubule system	Lacks transverse tubules	Well-developed transverse tubule system; intercalated discs separating adjacent cells
<i>Mode of Control</i>	Voluntary	Involuntary	Involuntary
<i>Contraction Characteristics</i>	Contracts and relaxes rapidly when stimulated by a motor neuron	Contracts and relaxes slowly; single unit type is self-exciting; rhythmic	Network of cells contracts as a unit; self-exciting; rhythmic

TABLE 8.3 summarizes the characteristics of the three types of muscle tissue. The Genetic Engineering feature on p. 263 considers several inherited diseases that affect the muscular system.



Practice

1. How is cardiac muscle similar to smooth muscle?
2. How is cardiac muscle similar to skeletal muscle?
3. What is the function of intercalated discs?
4. What characteristic of cardiac muscle contracts the heart as a unit?

Use the Practices

Constructing Explanations Using what you have learned about muscle contraction, describe how the structure of cardiac muscle allows it to produce rhythmic, synchronized contractions.

8.7 Skeletal Muscle Actions



Learning Outcomes

1. Explain how the attachments, locations, and interactions of skeletal muscles make different movements possible.

Skeletal muscles provide a variety of body movements, as described in section 7.13, Joints. Each muscle's movement depends largely on the kind of joint it is associated with and the way the muscle attaches on either side of that joint.

Origin and Insertion

One end of a skeletal muscle usually attaches to a relatively immovable or fixed part on one side of a movable joint, and the other end attaches to a movable part

on the other side of that joint, such that the muscle crosses the joint. The less movable end of the muscle is called its **origin** (or'i-jin), and the more movable end is its **insertion** (in-ser'shun). When a muscle contracts, its insertion is pulled toward its origin.

Some muscles have more than one origin or insertion. *Biceps brachii* in the arm, for example, has two origins. This is reflected in the name *biceps*, which means “two heads.” (Note: The head of a muscle is the part nearest its origin.) One head of *biceps brachii* attaches to the coracoid process of the scapula, and the other head arises from a tubercle above the glenoid cavity of the scapula. The muscle runs along the anterior surface of the humerus and is inserted by means of a tendon on the radial tuberosity of the radius. When *biceps brachii* contracts, its insertion is pulled toward its origin, and the forearm flexes at the elbow (**FIG. 8.14**).

Muscle Movements

Whenever limbs or other body parts move, bones and muscles interact as simple mechanical devices called **levers** (lev'erz). A lever has four basic components: (1) a rigid bar or rod, (2) a fulcrum or pivot on which the bar turns, (3) an object moved against resistance, and (4) a force that supplies energy for the movement of the bar. The actions of bending and straightening the upper limb at the elbow illustrate bones and muscles functioning as levers.

When the upper limb bends, the forearm bones represent the rigid bar, the elbow joint is the fulcrum, the hand is moved against the resistance provided by the weight, and the force is supplied by muscles on the anterior side of the arm (**FIG. 8.15a**). One of these muscles, the *biceps brachii*, is attached by a tendon to a projection on a bone (radius) in the forearm, a short distance distal to the elbow.

When the upper limb straightens at the elbow, the forearm bones again serve as the rigid bar, the elbow joint serves as the fulcrum, and the hand moves against the resistance by pulling on the rope to raise the weight (**FIG. 8.15b**). However, in this case the *triceps brachii*, a muscle located on the posterior side of the arm, supplies the force. A tendon of this muscle attaches to a projection on a forearm bone (ulna) at the point of the elbow.

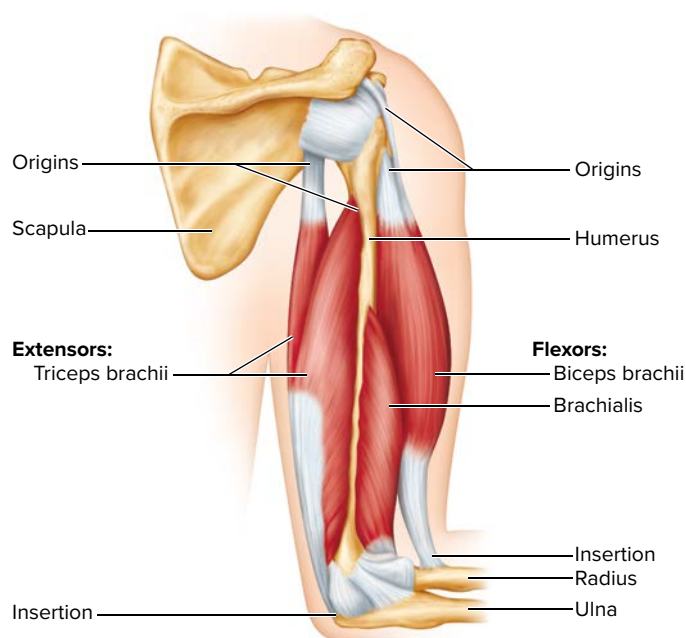


FIGURE 8.14 The biceps brachii has two heads that originate on the scapula. A tendon inserts this muscle on the radius.


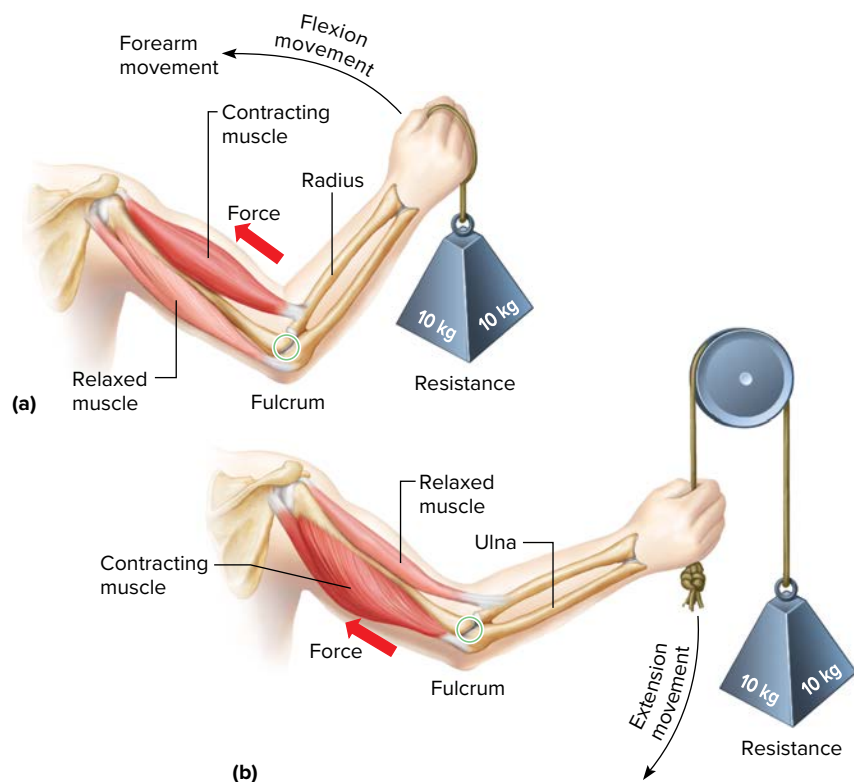
 Go online to check your understanding of the structures involved in biceps contraction by completing the Focus Activity.

FIGURE 8.15 Levers and movement. **(a)** When the upper limb bends at the elbow or **(b)** when the upper limb straightens at the elbow, the bones and muscles function as levers.



Sometimes the less movable and more movable bones are reversed based upon the action of the muscle in question. Therefore, an alternate way to describe muscle attachments is to use the directional terms *proximal* and *distal* for the attachments of appendicular muscles and the terms *superior* and *inferior* for axial muscles. Thus, the proximal attachments of biceps brachii are on the coracoid process and the tubercle above the glenoid cavity of the scapula. The distal attachment is on the radial tuberosity (see table 8.9). Similarly, the superior attachment of rectus abdominis is on the costal cartilage and xiphoid process of the sternum, and the inferior attachment is on the pubic crest and pubic symphysis (see table 8.11). The tables throughout this chapter that describe muscle actions identify the traditional origin and insertions, but the alternative terms described here can be easily determined from that information.

Muscle Relationships

The terms **flexion** and **extension** describe opposing movements and changes in the angle between bones that meet at a joint. For example, flexion of the elbow refers to a movement of the forearm that bends the elbow, or decreases the angle. In general, flexion refers to bringing the bones closer together (fig 8.15a). Extension of the elbow widens the angle, increasing the distance between the bones (fig. 8.15b).

Skeletal muscles almost always function in groups. A number of terms describe the roles of muscles in performing particular actions. The **prime mover**, or **agonist**, generates the majority of the force during a desired action (fig. 8.14). A **synergist** aids the prime mover in the desired action or by inhibiting the opposing action. In the example of elbow flexion, the biceps brachii is the prime mover for flexion, and the synergist is the brachialis. The triceps brachii is the **antagonist** to the biceps brachii and brachialis because it brings about the opposite action, extension. Note that the role of a muscle is dependent on the movement; in the example of elbow extension, triceps brachii is the prime mover and biceps brachii and brachialis are the antagonists.

Genetic Engineering

Inherited Diseases of Muscle

Several inherited conditions affect muscle tissue. These disorders differ in the nature of the genetic defect, the type of protein that is abnormal in form or function, and the muscles that are impaired.

The Muscular Dystrophies—Missing Proteins

A muscle cell is packed with filaments of actin and myosin. Much less abundant, but no less important, is a protein called dystrophin. It holds skeletal muscle cells together by linking actin in the cell to glycoproteins in the cell membrane, which helps attach the cell to the extracellular matrix. Missing or abnormal dystrophin or the glycoproteins cause muscular dystrophies. These illnesses vary in severity and age of onset, but in all cases, muscles weaken and degenerate. Eventually fat and connective tissue replace muscle.

Duchenne muscular dystrophy (DMD) is the most severe type of the illness (**FIG. 8B**). Symptoms begin by age five and affect only boys. By age thirteen, the person cannot walk, and by early adulthood he usually dies from failure of the respiratory muscles. In DMD, dystrophin is absent or shortened. In Becker muscular dystrophy, symptoms begin in early adulthood, are less severe, and result from underproduction of dystrophin. An experimental genetic therapy produces nearly full-length dystrophin by skipping over the part of the gene that includes the mutation.

Charcot-Marie-Tooth Disease—A Duplicate Gene

Charcot-Marie-Tooth disease causes a slowly progressing weakness in the muscles of the hands and feet and a decrease in tendon reflexes in these parts. In this illness, an extra gene impairs the insulating sheath around affected nerve cells, so that nerve cells cannot adequately stimulate muscles. Physicians perform two tests—electromyography and nerve conduction velocity—to diagnose Charcot-Marie-Tooth disease. It is also possible to test for gene mutations to confirm a diagnosis based on symptoms.



FIGURE 8.B These twins are both affected with Duchenne muscular dystrophy because it is an inherited genetic disease.

Hereditary Idiopathic Dilated Cardiomyopathy—A Tiny Glitch

This very rare inherited form of heart failure usually begins in a person's forties and is lethal in 50% of cases within five years of diagnosis, unless a heart transplant can be performed. The condition is caused by a mutation in a gene that encodes a form of actin found only in cardiac muscle. The mutation disturbs actin's ability to anchor to the Z lines in heart muscle cells, preventing actin from effectively transferring the force of contraction. As a result, the heart chambers enlarge and eventually fail.

Concept Connections

1. Describe how hereditary idiopathic dilated cardiomyopathy disrupts the rhythm of cardiac muscle.
2. Describe how the protein dystrophin differs in Duchenne and Becker muscular dystrophies, and why this difference results in one type being more severe than the other.

Relationships between muscles depend on the action in question and can be complex. For example, pectoralis major, a chest muscle, and latissimus dorsi, a back muscle, are synergistic for medial rotation of the arm. However, they are antagonistic to each other for flexion and extension of the shoulder. Similarly, two muscles on the lateral forearm, flexor carpi radialis and extensor carpi radialis longus, are synergistic for abduction of the hand, yet they are antagonistic for flexion and extension of the wrist. Thus, any role of a muscle must be learned in the context of a particular movement.

Because students (and patients) often find it helpful to think of movements in terms of the specific actions of the muscles involved, we may also describe flexion and extension in these terms. Thus, the action of biceps brachii may be described as

“flexion of the forearm at the elbow,” and the action of the quadriceps group as “extension of the leg at the knee.” We believe this occasional departure from strict anatomical terminology may facilitate learning.



Practice

1. Distinguish between the origin and the insertion of a muscle.
2. Define *agonist*.
3. What is the function of a synergist? an antagonist?

Use the Practices

Using Models In literature, the protagonist is the main character, and the antagonist is the chief opponent. Use this structure to describe skeletal muscle actions.

8.8 Major Skeletal Muscles



Learning Outcomes

1. Identify and locate the major skeletal muscles of each body region.
2. Identify the actions of the major skeletal muscles of each body region.

This section discusses the locations, actions, and attachments of some of the major skeletal muscles. (**FIGS. 8.16** and **8.17** and reference plates 1 and 2 show the locations of the superficial skeletal muscles—those near the surface.)

Naming Muscles

The names of these muscles often describe them. A name may indicate a muscle’s relative size, shape, location, action, or number of attachments, or the direction of its fibers, as in the following examples:

pectoralis major Large (major) and located in the pectoral region (chest).

deltoid Shaped like a delta or triangle.

extensor digitorum Extends the digits (fingers or toes).

biceps brachii Having two heads (biceps) or points of origin and located in the brachium (arm).

sternocleidomastoid Attached to the sternum, clavicle, and mastoid process.

external oblique Located near the outside, with fibers that run obliquely (in a slanting direction).

Note that in the anatomical position some actions have already occurred, such as supination of the forearm and hand, extension of the elbow, and extension of the knee. The muscle actions described in the following section consider the entire range of movement at each joint, and do not presume that the starting point is the anatomical position.

Some muscles have more than one origin or more than one insertion. The wide range of attachments of some of the larger muscles has the effect of giving those muscles different, sometimes opposing actions, depending on which portion of the muscle is active. Many of these cases are identified in the appropriate sections and tables.

You may have noticed some discrepancies between anatomical terminology and the terms the general public uses when referring to body parts. For example, someone

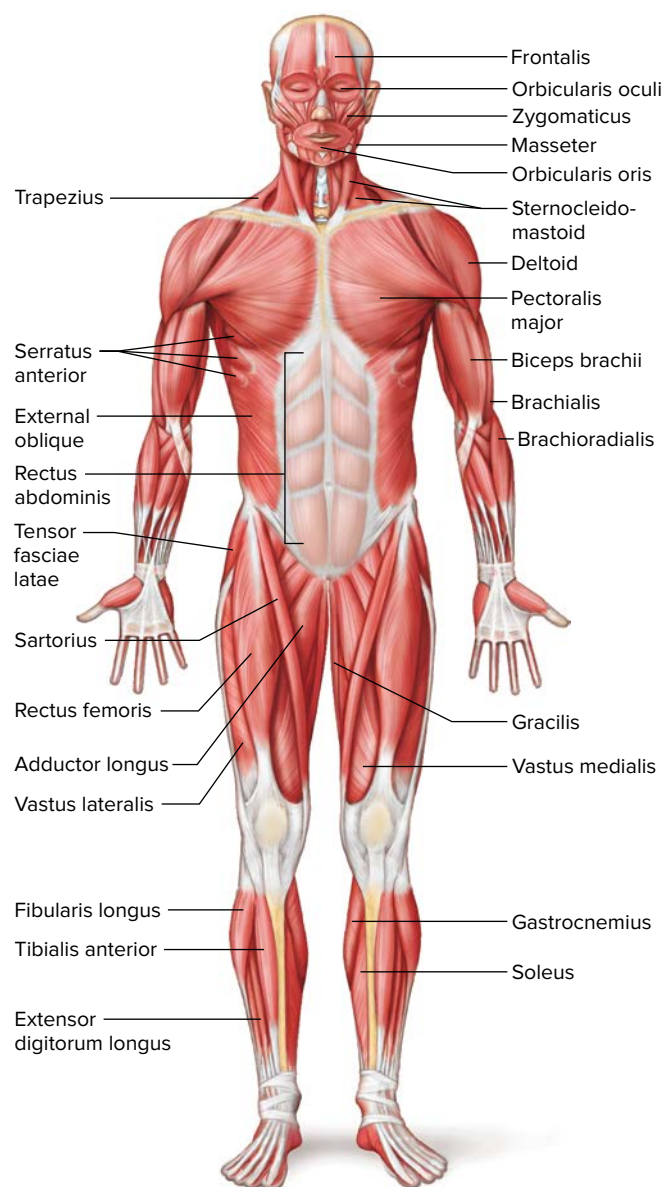


FIGURE 8.16 Anterior view of superficial skeletal muscles.

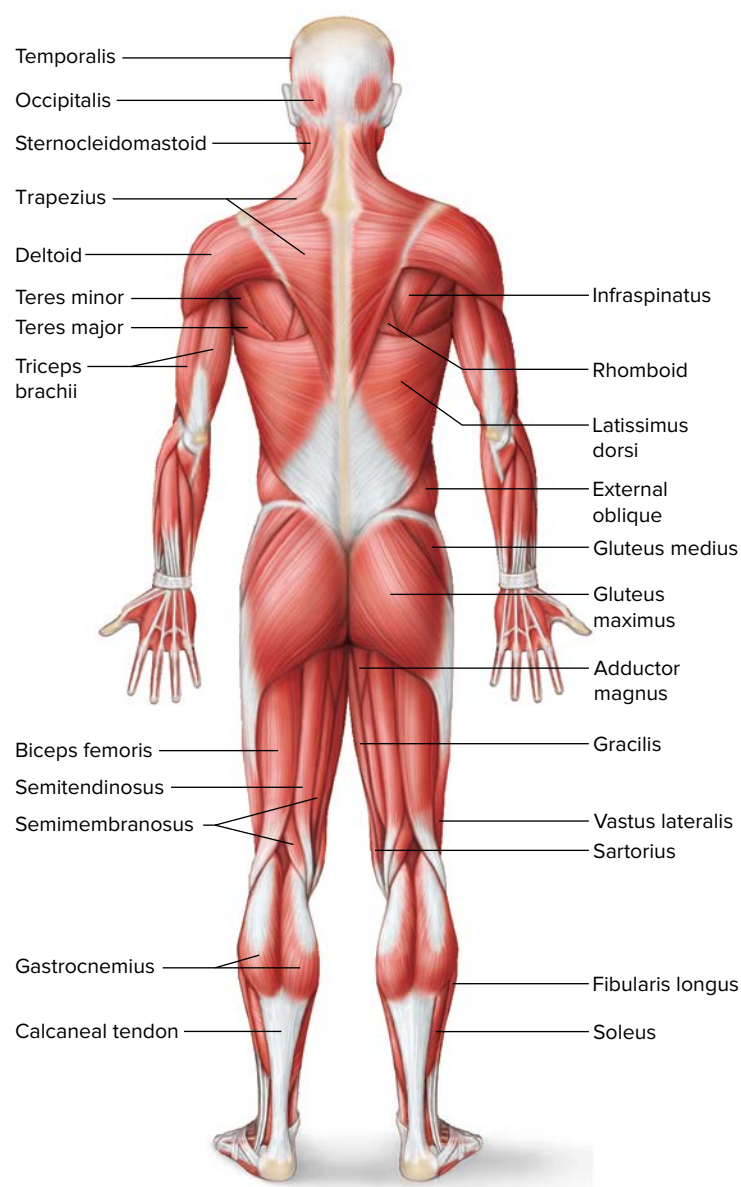


FIGURE 8.17 Posterior view of superficial skeletal muscles.

with a bruised thigh may complain of a sore leg, instead of correctly referring to the thigh. In this book, we have used accepted anatomical terminology when referring to body parts. On the other hand, you will likely be dealing not only with colleagues (who rely on the precision of correct terminology when communicating) but also with patients (who simply, sometimes desperately, want to communicate). You must become a master of both ways of communicating. The bottom line is being able to communicate accurately with colleagues and effectively with patients.

Muscles of Facial Expression

A number of small muscles that lie beneath the skin of the face and scalp enable us to communicate feelings through facial expression (**FIG. 8.18a**). Many of these muscles, located around the eyes and mouth, are responsible for such expressions as surprise, sadness, anger, fear, disgust, and pain.

Some of the muscles of facial expression join the bones of the skull to connective tissue in various regions of the overlying skin. They include:

epicranius (ep"i-krā'nē-us) Composed of two parts, *frontalis* (frun-ta'lis) and *occipitalis* (ok-sip"i-ta'lis)

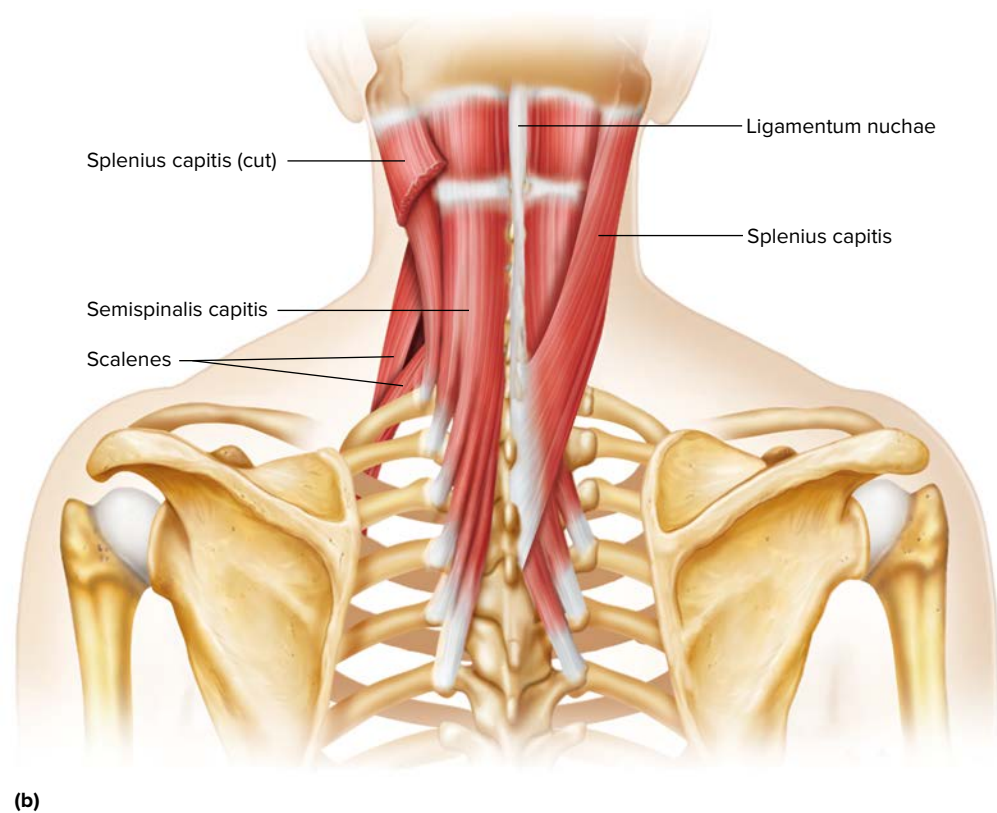
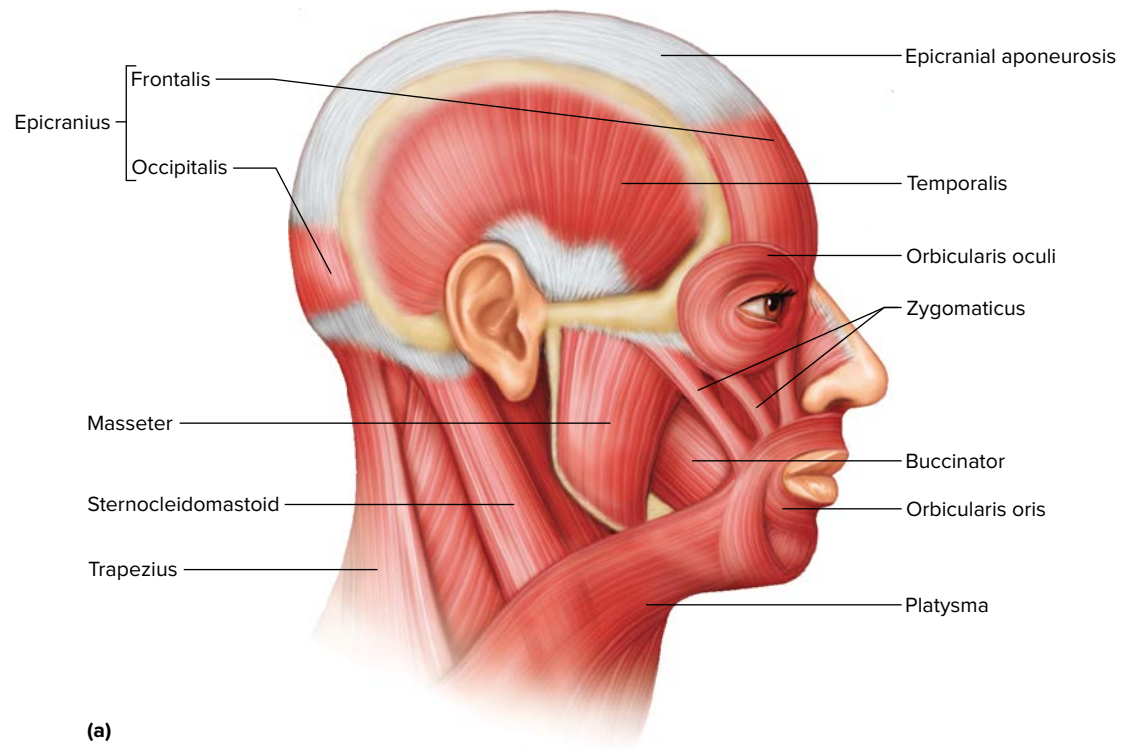


FIGURE 8.18 Muscles of the face and neck. **(a)** Lateral view including muscles of facial expression and mastication.

(b) Posterior view of muscles that move the head. **APR**

Go online to demonstrate your understanding of the muscles of the head by completing the Focus Activity.

orbicularis oculi (or-bik'u-la-rus ok'u-li)
orbicularis oris (or-bik'u-la-rus o'ris)
buccinator (buk'sī-nā"tor)
zygomaticus (zī"gō-mat'ik-us)
platysma (plah-tiz'mah)

TABLE 8.4 lists the origins, insertions, and actions of the muscles of facial expression. Section 10.9, Sense of Sight, describes the muscles that move the eyes.

Muscles of Mastication

Muscles attached to the mandible produce chewing movements. Two pairs of these muscles elevate the mandible, a motion used in biting. These muscles are the *masseter* (mas-se'ter) and the *temporalis* (tem-po-ra'lis) (fig. 8.18a). **TABLE 8.5** lists the origins, insertions, and actions of the muscles of mastication.

Grinding the teeth, a common response to stress, may strain the temporomandibular joint through the excessive force generated by the masseter and temporalis muscles. This condition, called temporomandibular joint syndrome (TMJ syndrome), may produce headache, earache, and pain in the jaw, neck, or shoulder.

Muscles that Move the Head

Head movements result from the actions of paired muscles in the neck and upper back. These muscles flex, extend, and rotate the head. They are aided by an elastic ligament (*ligamentum nuchae*), which limits flexion of the neck and helps to hold the head upright. They include (see **FIGS. 8.18b, 8.19, and 8.20**):

sternocleidomastoid (ster"nō-kli"do-mas'toid)
splenius capitis (sple'nē-us kap'ī-tis)
semispinalis capitis (sem"ē-spi-na'lis kap'ī-tis)
scalenes (skā'lēnz)

TABLE 8.6 lists the origins, insertions, and actions of muscles that move the head.

Table 8.4 Muscles of Facial Expression			
Muscle	Origin	Insertion	Action
Epicranius	Occipital bone	Skin around eye	Elevates eyebrow
Orbicularis oculi	Maxilla and frontal bone	Skin around eye	Closes eye
Orbicularis oris	Muscles near the mouth	Skin of lips	Closes and protrudes lips
Buccinator	Alveolar processes of maxilla and mandible	Orbicularis oris	Compresses cheeks
Zygomaticus	Zygomatic bone	Skin and muscle at corner of mouth	Elevates corner of mouth
Platysma	Fascia in upper chest	Skin and muscles below mouth	Depresses lower lip and angle of mouth

Table 8.5 Muscles of Mastication			
Muscle	Origin	Insertion	Action
Masseter	Zygomatic arch	Posterior lateral surface of mandible	Elevates and protracts mandible
Temporalis	Temporal bone	Coronoid process of mandible	Elevates and retracts mandible

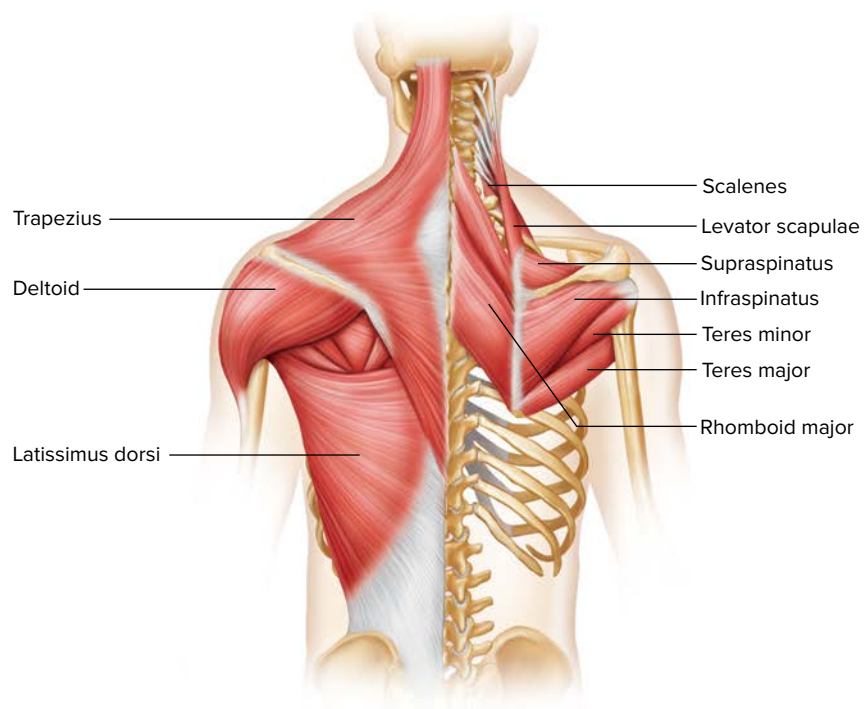


FIGURE 8.19 Muscles of the posterior shoulder. The right trapezius is removed to show underlying muscles.

Go online to demonstrate your mastery of the muscles of the shoulder and back by completing the Focus Activity. **APR**

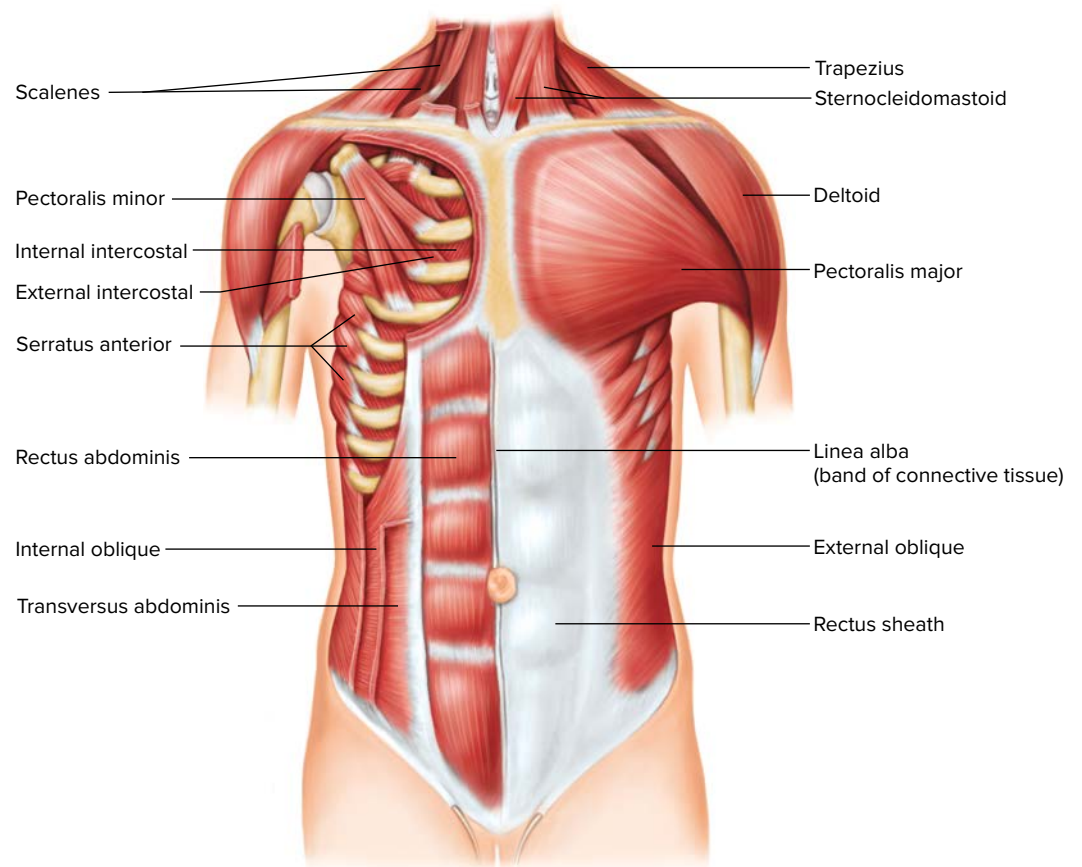


FIGURE 8.20 Muscles of the anterior chest and abdominal wall. The right pectoralis major is removed to show the pectoralis minor. **APR**

Table 8.6 Muscles that Move the Head **APR**

Muscle	Origin	Insertion	Action
Sternocleidomastoid	Manubrium of sternum and medial clavicle	Mastoid process of temporal bone	Individually: laterally flexes head and neck to the same side, rotates head to the opposite side. Together: pull the head forward and down; also aid in forceful inhalation by elevating sternum and first ribs.
Splenius capitis	Ligamentum nuchae; spinous processes of 7th cervical and upper thoracic vertebrae	Occipital bone and mastoid process of temporal bone	Individually: rotates head to the same side Together: bring head into an upright position
Semispinalis capitis	Below the articular facets of lower cervical vertebrae; transverse processes of upper thoracic vertebrae	Occipital bone	Individually: rotates head to the opposite side Together: extend head and neck
Scalenes	Transverse processes of cervical vertebrae	Superior and lateral surfaces of first two ribs	Individually: laterally flexes head and neck to the same side Together: elevate first two ribs during forceful inhalation

Muscles that Move the Pectoral Girdle

The muscles that move the pectoral girdle are closely associated with those that move the arm. A number of these chest and shoulder muscles attach from the scapula to nearby bones and move the scapula in various directions. They include (figs. 8.19 and 8.20):

trapezius (trah-pē'zē-us)
rhomboid (rom-boid') major
levator scapulae (le-va'tor scap'u-lē)
serratus anterior (ser-ra'tus an-te'rē-or)
pectoralis (pek"to-ra'lis) *minor*

TABLE 8.7 lists the origins, insertions, and actions of the muscles that move the pectoral girdle.

Muscles that Move the Arm

The arm is one of the more freely movable parts of the body. Muscles that attach from the humerus to various regions of the pectoral girdle, ribs, and vertebral column make these movements possible (**FIGS.** 8.19, 8.20, **8.21**, and **8.22**). These muscles can be grouped according to their primary actions—flexion, extension, abduction, and rotation—as follows:

Flexors *coracobrachialis* (kor"ah-kō-brā'kē-al-is)
pectoralis (pek"to-ra'lis) *major*

Extensors *teres* (te'rēz) *major*
latissimus dorsi (lah-tis'ī-mus dor'sī)

Abductors *supraspinatus* (sū"prah-spī'nā-tus)
deltoid (del'toid)

Table 8.7 Muscles that Move the Pectoral Girdle **APR**

Muscle	Origin	Insertion	Action
Trapezius	Occipital bone, ligamentum nuchae, and spinous processes of 7th cervical and all thoracic vertebrae	Clavicle; spine and acromion process of scapula	Rotates and retracts scapula Superior portion elevates scapula Inferior portion depresses scapula
Rhomboid major	Spinous processes of upper thoracic vertebrae	Medial border of scapula	Elevates and retracts scapula
Levator scapulae	Transverse processes of cervical vertebrae	Superior angle and medial border of scapula	Elevates scapula
Serratus anterior	Anterior surfaces of ribs 1-10	Medial border of scapula	Protracts and rotates scapula
Pectoralis minor	Anterior surfaces of ribs 3-5	Coracoid process of scapula	Depresses and protracts scapula, elevates ribs during forceful inhalation

Rotators *subscapularis* (sub-scap'u-lar-is)
infraspinatus (in'frah-spi'na-tus)
teres (te'rēz) *minor*

The movements of flexion and extension of the shoulder may be less obvious than at other joints. Movements of the arm forward and upward flex the shoulder, and the opposite movements extend it.

TABLE 8.8 lists the origins, insertions, and actions of muscles that move the arm.

Muscles that Move the Forearm

Muscles that attach from the radius or ulna to the humerus or pectoral girdle produce most of the forearm movements. A group of muscles located along the anterior surface of the humerus flexes the elbow, and a single posterior muscle extends this joint. Other muscles move the radioulnar joint and rotate the forearm.

FIGURE 8.21 Muscles of the posterior surface of the scapula and arm. (Note: the medial head of triceps brachii is not visible.) **APR**

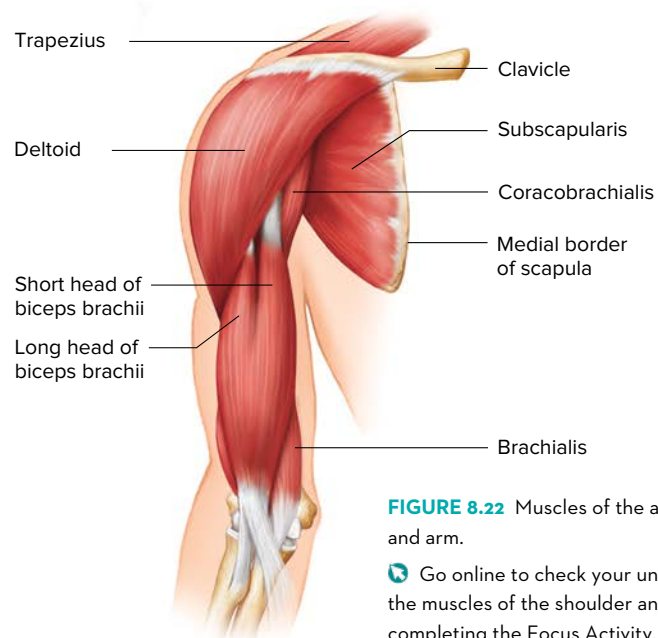
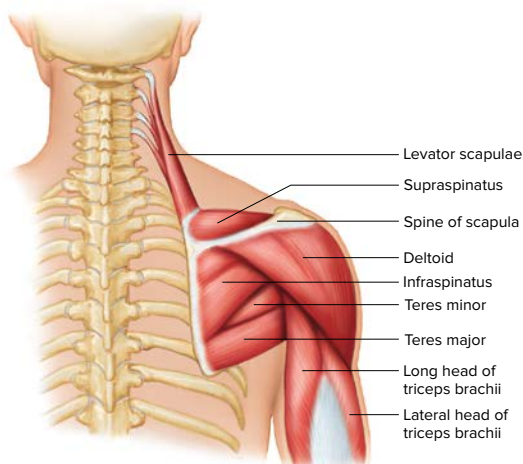


FIGURE 8.22 Muscles of the anterior shoulder and arm.

Go online to check your understanding of the muscles of the shoulder and arm by completing the Focus Activity. **APR**

Table 8.8 Muscles that Move the Arm

Muscle	Origin	Insertion	Action
Coracobrachialis	Coracoid process of scapula	Medial midshaft of humerus	Flexes arm at shoulder, adducts arm
Pectoralis major	Clavicle, sternum, and costal cartilages of upper ribs	Intertubercular sulcus of humerus	Flexes arm at shoulder, adducts and medially rotates arm
Teres major	Lateral border of scapula	Intertubercular sulcus of humerus	Extends arm at shoulder, adducts and medially rotates arm
Latissimus dorsi	Spinous processes of lower thoracic and lumbar vertebrae, iliac crest, and lower ribs	Intertubercular sulcus of humerus	Extends arm at shoulder, adducts and medially rotates arm
Supraspinatus	Supraspinous fossa of scapula	Greater tubercle of humerus	Abducts arm
Deltoid	Acromion process, spine of scapula, and clavicle	Deltoid tuberosity of humerus	Lateral portion abducts arm Anterior portion flexes arm at shoulder Posterior portion extends arm at shoulder
Subscapularis	Anterior surface of scapula	Lesser tubercle of humerus	Medially rotates arm
Infraspinatus	Infraspinous fossa of scapula	Greater tubercle of humerus	Laterally rotates arm
Teres minor	Lateral border of scapula	Greater tubercle of humerus	Laterally rotates arm

Muscles that move the forearm include (FIGS. 8.21, 8.22, and 8.23):

Flexors *biceps brachii* (bī'seps brā'kē-ī)

brachialis (brā'kē-al-is)

brachioradialis (brā'kē-o-rā'dē-a'lis)

Extensor *triceps brachii* (tri'seps brā'kē-i)

Rotators *supinator* (su'pī-nā-tor) (Note: This deep muscle is not shown in these figures, but can be found in APR.)

pronator teres (pro-nā'tor te'rēz)

pronator quadratus (pro-nā'tor kwod-ra'tus)

TABLE 8.9 lists the origins, insertions, and actions of muscles that move the forearm.

Muscles that Move the Hand

Many muscles move the hand. They originate from the distal end of the humerus and from the radius and ulna. The two major groups of these muscles are flexors on the anterior side of the forearm and extensors on the posterior side. These muscles include (FIGS. 8.23 and 8.24):

Flexors *flexor carpi radialis* (flex'sor kar-pī' rā'dē-a'lis)

flexor carpi ulnaris (flex'sor kar-pī' ul-na'ris)

palmaris longus (pal-ma'ris long'gus)

flexor digitorum profundus (flex'sor dij'ī-to'rum pro-fun'dus)

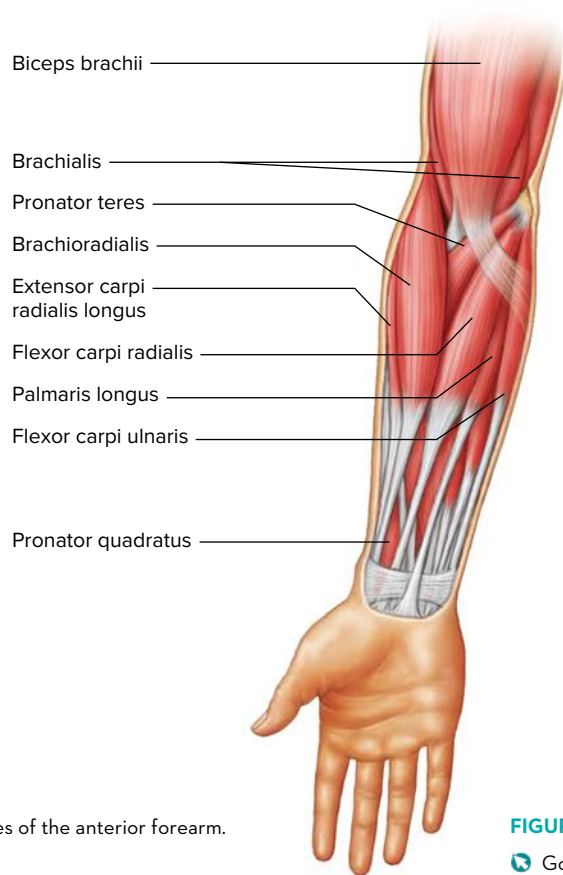


FIGURE 8.23 Muscles of the anterior forearm.

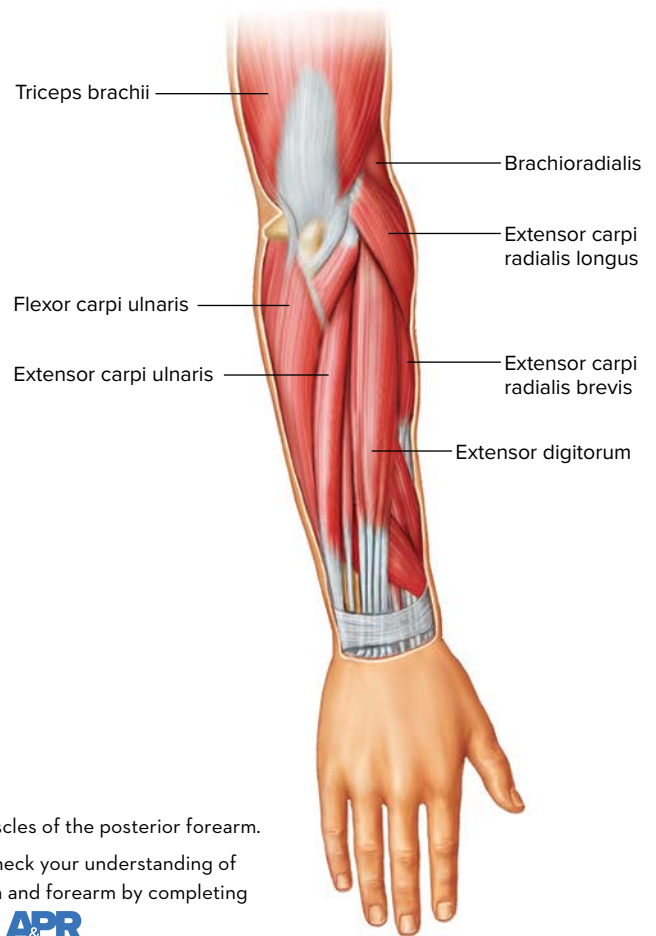


FIGURE 8.24 Muscles of the posterior forearm.

Go online to check your understanding of muscles of the arm and forearm by completing the Focus Activity.



Extensors *extensor carpi radialis longus* (eks-ten'sor kar-pī' rā"dē-a'lis long'gus)
extensor carpi radialis brevis (eks-ten'sor kar-pī' rā"dē-a'lis brev'is)
extensor carpi ulnaris (eks-ten'sor kar-pī' ul-na'ris)
extensor digitorum (eks-ten'sor dij'ī-to'rum)

TABLE 8.10 lists the origins, insertions, and actions of muscles that move the hand.

Table 8.9 Muscles that Move the Forearm

Muscle	Origin	Insertion	Action
Biceps brachii	Coracoid process (short head); tubercle above glenoid cavity of scapula (long head)	Radial tuberosity	Flexes forearm at elbow, supinates forearm and hand
Brachialis	Anterior surface of humerus	Coronoid process of ulna	Flexes forearm at elbow
Brachioradialis	Distal lateral end of humerus	Lateral surface of radius above styloid process	Flexes forearm at elbow
Triceps brachii	Tubercle below glenoid cavity of scapula (long head); lateral surface of humerus (lateral head); posterior surface of humerus (lateral and medial heads)	Olecranon process of ulna	Extends forearm at elbow
Supinator	Lateral epicondyle of humerus and proximal ulna	Anterior and lateral surface of radius	Supinates forearm and hand
Pronator teres	Medial epicondyle of humerus and coronoid process of ulna	Lateral surface of radius	Pronates forearm and hand
Pronator quadratus	Anterior distal end of ulna	Anterior distal end of radius	Pronates forearm and hand

Table 8.10 Muscles that Move the Hand

Muscle	Origin	Insertion	Action
Flexor carpi radialis	Medial epicondyle of humerus	Base of second and third metacarpals	Flexes wrist, abducts hand
Flexor carpi ulnaris	Medial epicondyle of humerus and olecranon process of ulna	Carpal bones and fifth metacarpal bone	Flexes wrist, adducts hand
Palmaris longus	Medial epicondyle of humerus	Fascia of palm	Flexes wrist
Flexor digitorum profundus	Anterior and medial surface of ulna	Distal phalanges of fingers 2-5	Flexes wrist and joints of fingers
Extensor carpi radialis longus	Lateral distal end of humerus	Base of second metacarpal	Extends wrist, abducts hand
Extensor carpi radialis brevis	Lateral epicondyle of humerus	Base of third metacarpal	Extends wrist, abducts hand
Extensor carpi ulnaris	Lateral epicondyle of humerus and proximal, posterior ulna	Base of fifth metacarpal	Extends wrist, adducts hand
Extensor digitorum	Lateral epicondyle of humerus	Posterior surface of phalanges in fingers 2-5	Extends wrist and joints of fingers

Muscles of the Abdominal Wall

Bone supports the walls of the chest and pelvic regions, but not those of the abdomen. Instead, the anterior and lateral walls of the abdomen are composed of layers of broad, flattened muscles. These muscles connect the rib cage and vertebral column to the pelvic girdle. A band of tough connective tissue called the **linea alba** extends from the xiphoid process of the sternum to the pubic symphysis (see fig. 8.20). It is an attachment for some of the abdominal wall muscles. Another important attachment is the inguinal ligament, which extends from the anterior superior iliac spine to the pubis near the pubic symphysis.

Contraction of these muscles decreases the size of the abdominal cavity and increases the pressure inside. These actions help press air out of the lungs during forceful exhalation and aid in the movements of defecation, urination, vomiting, and childbirth.

The abdominal wall muscles include (see fig. 8.20):

external oblique (eks-ter'nal o-blēk')

internal oblique (in-ter'nal o-blēk')

transversus abdominis (trans-ver'sus ab-dom'i-nis)

rectus abdominis (rek'tus ab-dom'i-nis)

TABLE 8.11 lists the origins, insertions, and actions of muscles of the abdominal wall.

Muscles of the Pelvic Floor

The inferior outlet of the pelvis is closed off by two muscular sheets—a deeper **pelvic diaphragm** and a more superficial **urogenital diaphragm**. Together they form the floor of the pelvis. The pelvic diaphragm spans the outlet of the pelvic cavity, and the urogenital diaphragm fills the space within the pubic arch (see fig. 7.28). Just anterior to the anal canal, a deep central tendon serves as an attachment for a number of these muscles. The muscles of the male and female pelvic floors include (**FIG. 8.25**):

Pelvic diaphragm *levator ani* (le-va'tor ah-ni')

coccygeus (kok-sij'e-us)

Urogenital diaphragm *superficial transversus perinei* (su'per-fish'al trans-ver'sus per'i-ne'i)

bulbospongiosus (bul'bo-spon'je-o'sus)

ischiocavernosus (is'ke-o-kav'er-no'sus)

Table 8.11 Muscles of the Abdominal Wall

Muscle	Origin	Insertion	Action
External oblique	Outer surfaces of lower 8 ribs	Outer lip of iliac crest and linea alba	Compresses abdomen, flexes and rotates vertebral column
Internal oblique	Iliac crest and inguinal ligament	Lower 3–4 ribs, linea alba, and crest of pubis	Compresses abdomen, flexes and rotates vertebral column
Transversus abdominis	Costal cartilages of lower 6 ribs, processes of lumbar vertebrae, lip of iliac crest, and inguinal ligament	Linea alba and crest of pubis	Compresses abdomen
Rectus abdominis	Crest of pubis and pubic symphysis	Xiphoid process of sternum and costal cartilages of ribs 5–7	Compresses abdomen, flexes vertebral column

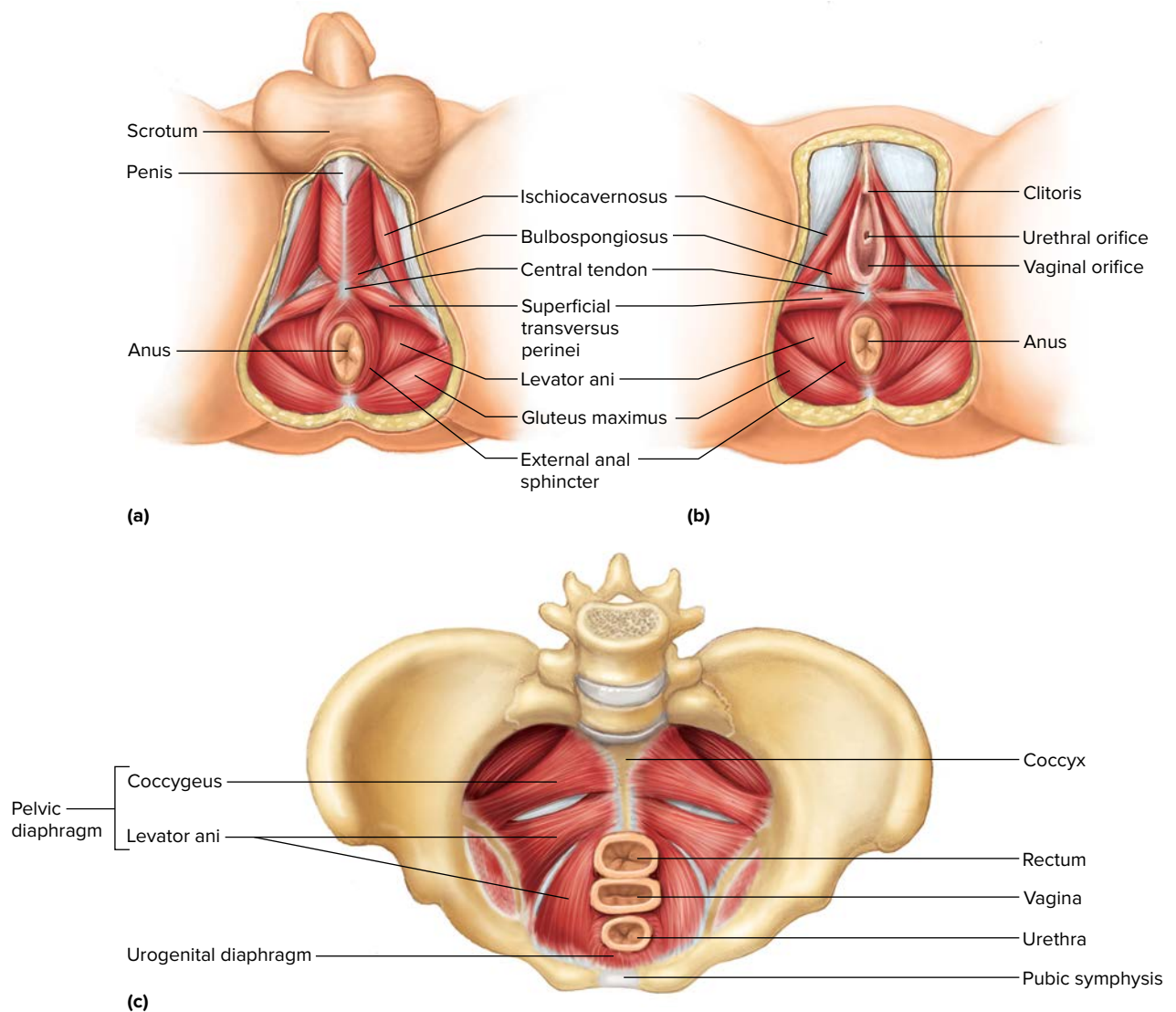


FIGURE 8.25 External view of (a) the male pelvic floor and (b) the female pelvic floor. (c) Internal view of the female pelvic and urogenital diaphragms. **APR**

Table 8.12 Muscles of the Pelvic Floor

Muscle	Origin	Insertion	Action
Levator ani	Pubis and ischial spine	Coccyx	Supports pelvic viscera, compresses anal canal
Coccygeus	Ischial spine	Sacrum and coccyx	Supports pelvic viscera, compresses anal canal
Superficial transversus perinei	Ischial tuberosity	Central tendon	Supports pelvic viscera
Bulbospongiosus	Central tendon	Males: Corpus cavernosa of penis Females: Corpus cavernosa of clitoris	Males: Assists emptying of urethra, assists erection of penis Females: Constricts vagina, assists erection of clitoris
Ischiocavernosus	Ischial tuberosity	Males: Corpus cavernosa of penis Females: Corpus cavernosa of clitoris	Males: Contributes to erection of the penis Females: Contributes to erection of the clitoris

TABLE 8.12 lists the origins, insertions, and actions of muscles of the pelvic floor.

Muscles that Move the Thigh

Muscles that move the thigh are attached to the femur and to some part of the pelvic girdle. These muscles are in anterior, medial, and posterior groups. Muscles of the anterior group primarily flex the hip; those of the medial group adduct the thigh; those of the posterior group extend the hip, abduct the thigh, or rotate the thigh. The muscles in these groups include (**FIGS. 8.26, 8.27, and 8.28**):

Anterior group *psoas* (so'as) major
iliacus (il'i-ak-us)

Posterior group *gluteus maximus* (gloo'tē-us mak'si-mus)
gluteus medius (gloo'tē-us me'de-us)
gluteus minimus (gloo'tē-us min'ī-mus)
tensor fasciae latae (ten'sor fash'ē-e lah-tē)

Medial Group *adductor longus* (ah-duk'tor long'gus)
adductor magnus (ah-duk'tor mag'nus)
gracilis (gras'il-is)

TABLE 8.13 lists the origins, insertions, and actions of muscles that move the thigh.

Muscles that Move the Leg

Muscles that move the leg attach from the tibia or fibula to the femur or to the pelvic girdle. They can be separated into two major groups—those that flex the knee and those that extend the knee. Muscles that move the leg include the hamstring group and the quadriceps femoris group (see **figs. 8.26, 8.27, and 8.28**):

Flexors *hamstring group*
biceps femoris (bī'seps fem'or-is)
semitendinosus (sem"ē-ten'dī-nō-sus)
semimembranosus (sem"ē-mem'brah-nō-sus)
sartorius (sar-to'rē-us)

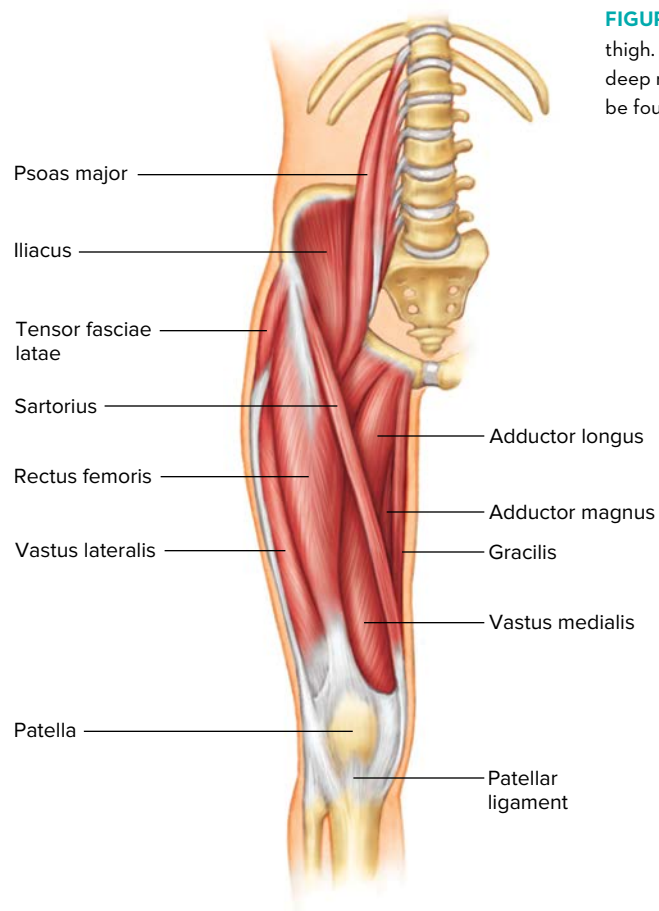


FIGURE 8.26 Muscles of the anterior right thigh. (Note that the vastus intermedius is a deep muscle not visible in this view, but it can be found in APR.) **APR**

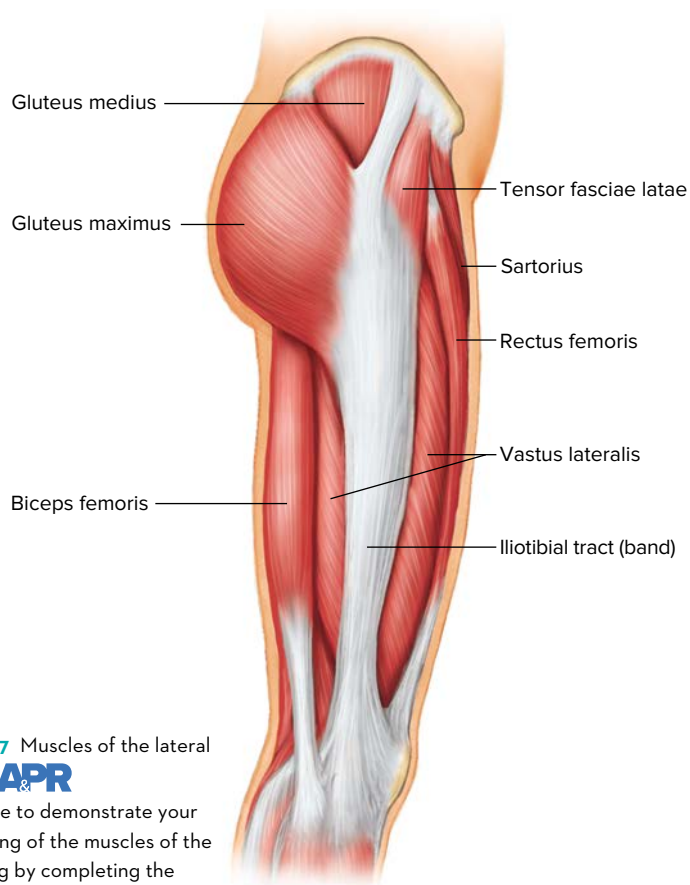


FIGURE 8.27 Muscles of the lateral right thigh. **APR**

Go online to demonstrate your understanding of the muscles of the thigh and leg by completing the Focus Activity.

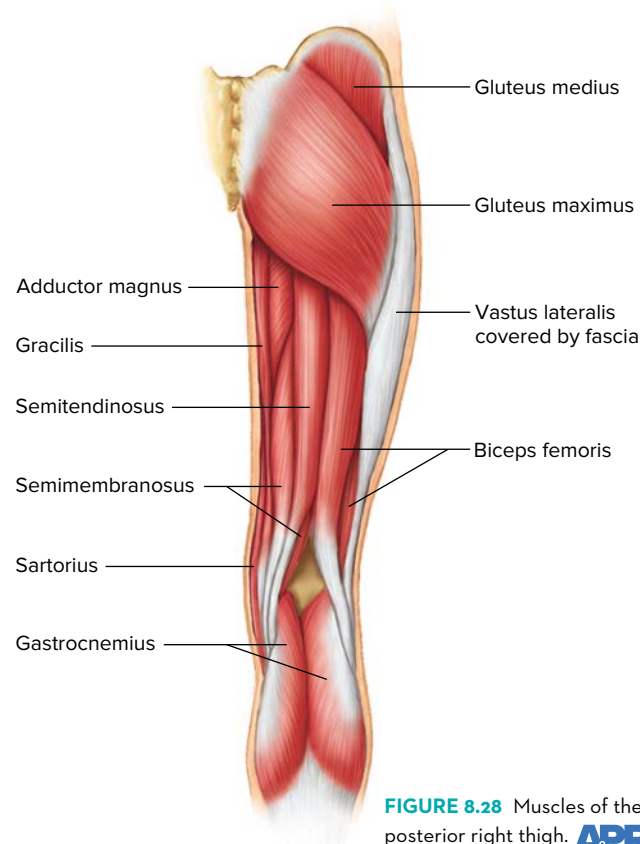


FIGURE 8.28 Muscles of the posterior right thigh. **APR**

Table 8.13 Muscles that Move the Thigh

Muscle	Origin	Insertion	Action
Psoas major	Bodies and transverse processes of lumbar vertebrae	Lesser trochanter of femur	Flexes thigh at hip
Iliacus	Iliac fossa of ilium	Lesser trochanter of femur	Flexes thigh at hip
Gluteus maximus	Sacrum, coccyx, and posterior surface of ilium	Posterior surface of femur and fascia of thigh	Extends thigh at hip, laterally rotates thigh
Gluteus medius	Lateral surface of ilium	Greater trochanter of femur	Abducts thigh, medially rotates thigh
Gluteus minimus	Lateral surface of ilium	Greater trochanter of femur	Abducts thigh, medially rotates thigh
Tensor fasciae latae	Anterior iliac crest	Fascia of thigh	Abducts thigh, medially rotates thigh
Adductor longus	Pubic bone near pubic symphysis	Posterior surface of femur	Adducts thigh, flexes thigh at hip
Adductor magnus	Pubis and ischial tuberosity	Posterior surface of femur	Adducts thigh, extends thigh at hip
Gracilis	Lower edge of pubis	Proximal medial surface of tibia	Adducts thigh, flexes thigh at hip, medially rotates thigh and leg

Extensors *quadriceps femoris group* (kwod'rĭ-seps fem'or-is)

rectus femoris (rek'tus fem'or-is)

vastus lateralis (vas'tus lat'er-a'lis)

vastus medialis (vas'tus mē'de-a'lis)

vastus intermedius (vas'tus in'ter-mē'dē-us)

TABLE 8.14 lists the origins, insertions, and actions of muscles that move the leg.

Muscles that Move the Foot

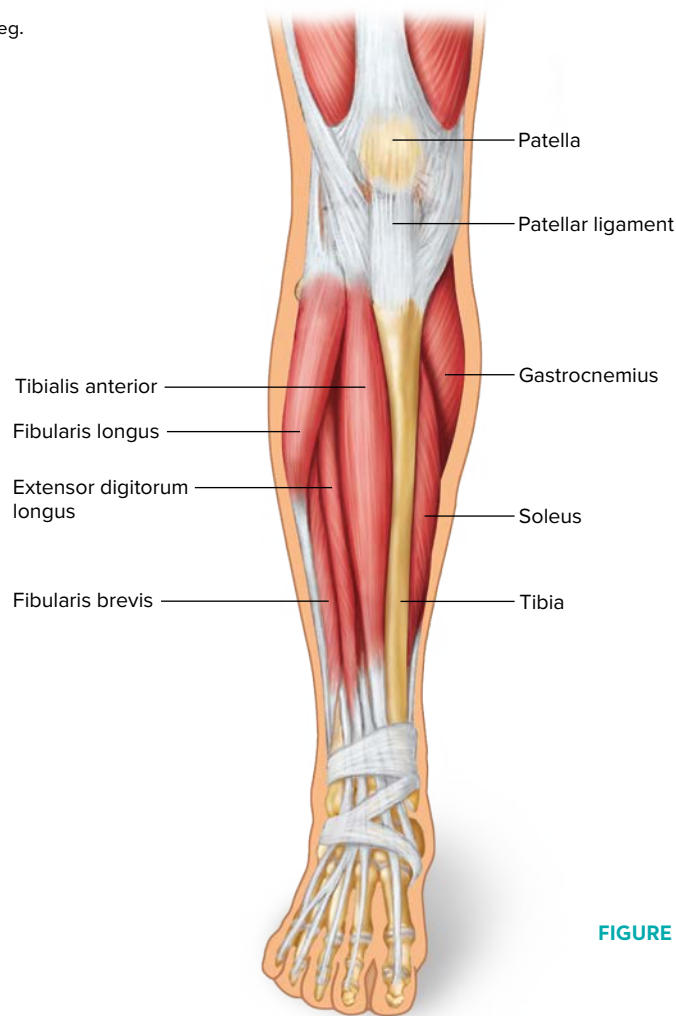
A number of muscles that move the foot are in the leg. They attach from the femur, tibia, and fibula to bones of the foot, move the foot upward (dorsiflexion) or downward (plantar flexion), and turn the sole of the foot medial (inversion) or lateral (eversion).

These muscles include (**FIGS. 8.29, 8.30, and 8.31**):

Table 8.14 Muscles that Move the Leg

Muscle	Origin	Insertion	Action
Sartorius	Anterior superior iliac spine	Proximal medial surface of tibia	Flexes leg at knee, flexes thigh at hip, abducts thigh, laterally rotates thigh, medially rotates leg
Hamstring group			
Biceps femoris	Ischial tuberosity and posterior surface of femur	Head of fibula	Flexes leg at knee, extends thigh at hip
Semitendinosus	Ischial tuberosity	Proximal medial surface of tibia	Flexes leg at knee, extends thigh at hip
Semimembranosus	Ischial tuberosity	Medial condyle of tibia	Flexes leg at knee, extends thigh at hip
Quadriceps femoris group			
Rectus femoris	Anterior inferior iliac spine and margin of acetabulum	Patella, by the tendon which continues as patellar ligament to tibial tuberosity	Extends leg at knee, flexes thigh at hip
Vastus lateralis	Greater trochanter and posterior surface of femur	Patella, by the tendon which continues as patellar ligament to tibial tuberosity	Extends leg at knee
Vastus medialis	Medial surface of femur	Patella, by the tendon which continues as patellar ligament to tibial tuberosity	Extends leg at knee
Vastus intermedius	Anterior and lateral surfaces of femur	Patella, by the tendon which continues as patellar ligament to tibial tuberosity	Extends leg at knee

FIGURE 8.29 Muscles of the anterior right leg.



Dorsiflexors

tibialis anterior (tib"ē-a'lis an-te'rē-or)
fibularis (peroneus) tertius (fib"ū-la'ris ter'shus)
extensor digitorum longus (eks-ten'sor dij"ī-tō'rum long'gus)

Plantar

flexors *gastrocnemius* (gas"trok-nē'mē-us)
soleus (sō'lē-us)
flexor digitorum longus (flek'sor dij"ī-tō'rum long'gus)

Invertor *tibialis posterior* (tib"ē-a'lis pos-tēr'ē-or)

Evertor *fibularis (peroneus) longus* (fib"ū-la'ris long'gus)
fibularis (peroneus) brevis (fib"ū-la'ris bre'vis)

FIGURE 8.30 Muscles of the lateral right leg. (Note that the tibialis posterior is a deep muscle not visible in this view.)

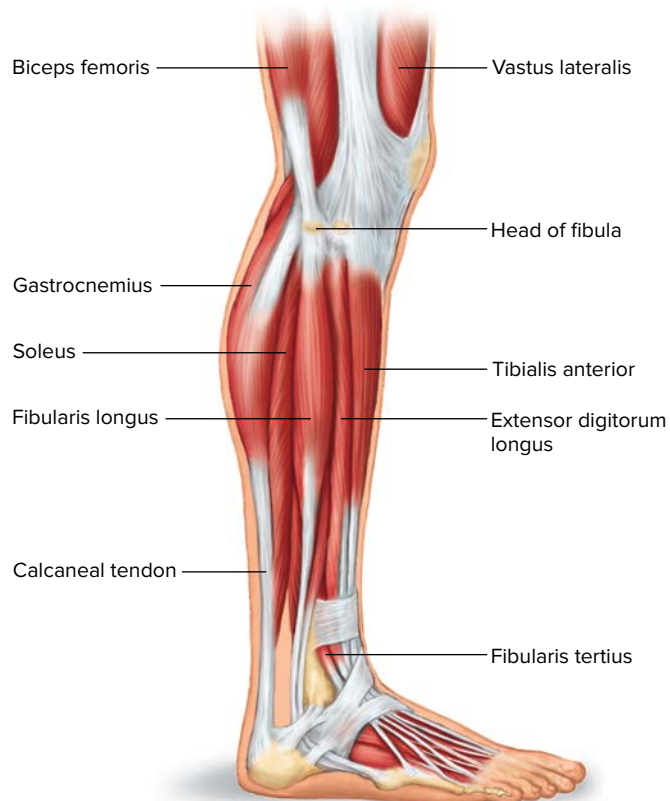


FIGURE 8.31 Muscles of the posterior right leg.

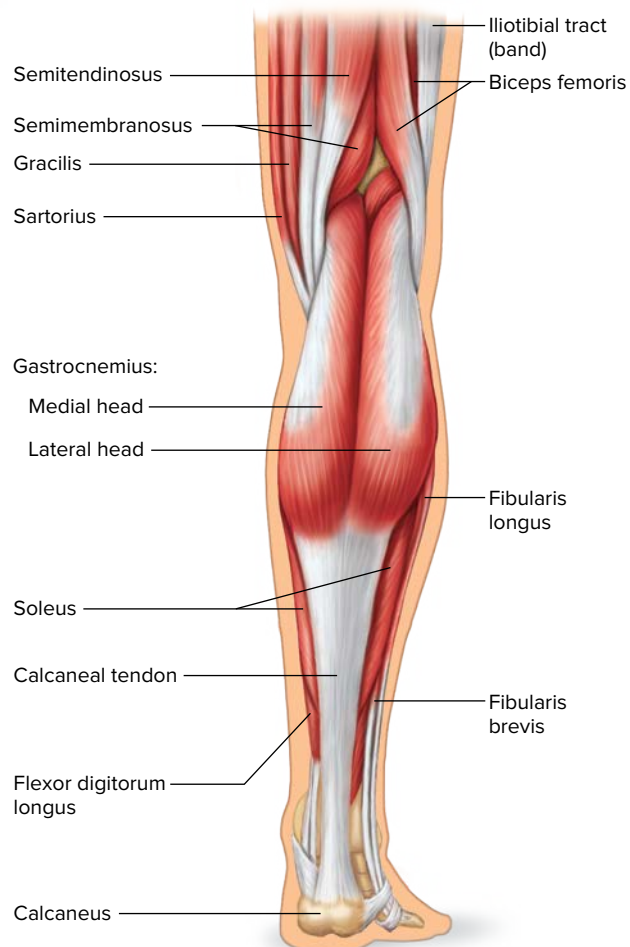


Table 8.15 Muscles That Move the Foot

Muscle	Origin	Insertion	Action
Tibialis anterior	Lateral condyle and lateral surface of tibia	Tarsal bone (medial cuneiform) and first metatarsal	Dorsiflexion and inversion of foot
Fibularis tertius	Anterior surface of fibula	Dorsal surface of fifth metatarsal	Dorsiflexion and eversion of foot
Extensor digitorum longus	Lateral condyle of tibia and anterior surface of fibula	Dorsal surfaces of middle and distal phalanges of the four lateral toes	Dorsiflexion of foot, extension of four lateral toes
Gastrocnemius	Lateral and medial condyles of femur	Posterior surface of calcaneus	Plantar flexion of foot, flexion of leg at knee
Soleus	Head and shaft of fibula and posterior surface of tibia	Posterior surface of calcaneus	Plantar flexion of foot
Flexor digitorum longus	Posterior surface of tibia	Distal phalanges of the four lateral toes	Flexion of the four lateral toes
Tibialis posterior	Lateral condyle and posterior surface of tibia, and posterior surface of fibula	Tarsal and metatarsal bones	Inversion and plantar flexion of foot
Fibularis longus	Lateral condyle of tibia and head and shaft of fibula	Tarsal bone (medial cuneiform) and first metatarsal	Eversion and plantar flexion of foot; also supports arch
Fibularis brevis	Lower lateral surface of fibula	Base of fifth metatarsal	Eversion and plantar flexion of foot

TABLE 8.15 lists the origins, insertions, and actions of muscles that move the foot.



Practice

1. What information is imparted in a muscle's name?
2. Which muscles provide facial expressions? The ability to chew? Head movements?
3. Which muscles move the pectoral girdle? Abdominal wall? Pelvic outlet? The arm, forearm, and hand? The thigh, leg, and foot?

Use the Practices

Using Mathematics The human skeleton has 206 bones, but the muscular system contains more than 600 muscles. Explain the benefit of having more muscles than bones.

Organization

Muscular System

INTEGUMENTARY SYSTEM



The skin increases heat loss during skeletal muscle activity.

LYMPHATIC SYSTEM

Muscle action pumps lymph through lymphatic vessels.



SKELETAL SYSTEM



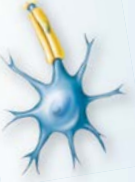
Bones provide attachments that allow skeletal muscles to cause movement.

DIGESTIVE SYSTEM

Skeletal muscles are important in swallowing. The digestive system absorbs nutrients needed for muscle contraction.



NERVOUS SYSTEM



Neurons control muscle contractions.

RESPIRATORY SYSTEM

Breathing depends on skeletal muscles. The lungs provide oxygen for body cells and excrete carbon dioxide.



ENDOCRINE SYSTEM



Hormones help increase blood flow to exercising skeletal muscles.

URINARY SYSTEM

Skeletal muscles help control expulsion of urine from the urinary bladder.



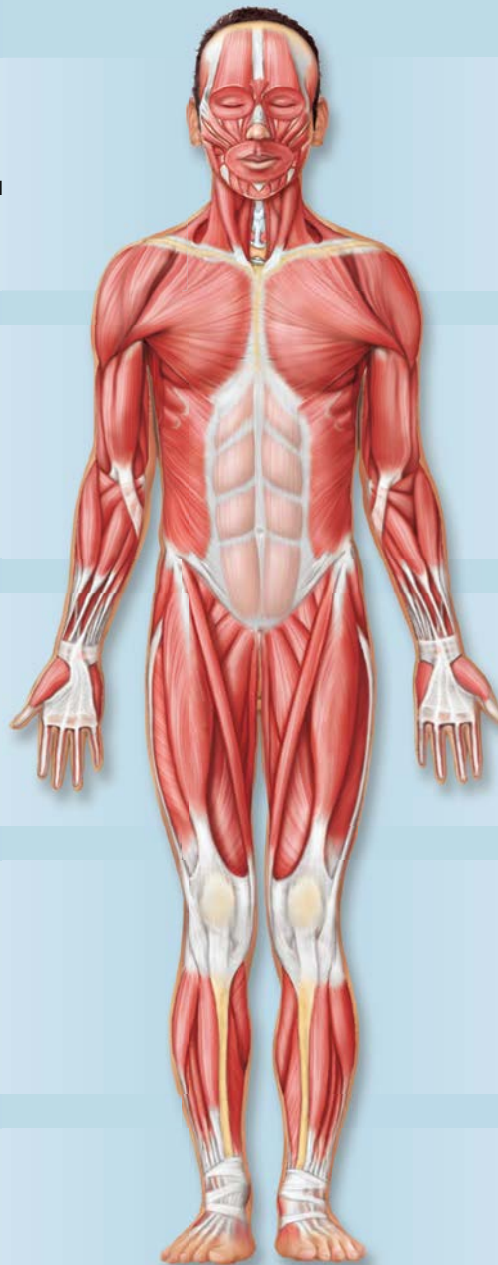
CARDIOVASCULAR SYSTEM



The heart pumps as a result of cardiac muscle contraction. Blood flow delivers oxygen and nutrients and removes wastes.

REPRODUCTIVE SYSTEM

Skeletal muscles are important in sexual activity.



Muscles provide the force for moving body parts.



Chapter 8 Summary and Assessment

Study Strategy

Clarifying Use this summary to set up an outline. Add additional notes during class discussions and while you read.

Summary Outline

8.1 Introduction

1. Muscles are composed of specialized cells that generate forces allowing for movement
2. The three types of muscle tissue are skeletal, smooth, and cardiac

8.2 Structure of a Skeletal Muscle

1. Connective tissue called **fascia** covers skeletal muscles
2. A network of connective tissue extends throughout the muscular system
3. Skeletal muscle fibers are single cells – the organization of **actin** and **myosin** filaments produces striations
4. **Neuromuscular junction: motor neurons** stimulate muscle fibers to contract
 - a. In response to an impulse, the end of a motor neuron axon secretes a **neurotransmitter**
 - b. This stimulates the muscle fiber to contract

8.3 Skeletal Muscle Contraction

1. Heads of myosin filaments form cross-bridge linkages with actin filaments
2. The reaction between actin and myosin filaments generates the force of contraction
3. **Acetylcholine** released from the distal end of a motor neuron axon stimulates a skeletal muscle fiber
 - a. Cross-bridge linkages form between actin and myosin, and the cross-bridges pull on actin filaments, shortening the fiber
 - b. **Acetylcholinesterase** breaks down acetylcholine
4. ATP supplies the energy for muscle fiber contraction, and **creatine phosphate** stores energy that can be used to synthesize ATP
5. Oxygen supply and cellular respiration
 - a. Aerobic respiration requires oxygen
 - b. **Myoglobin** in muscle cells helps maintain oxygen availability

c. Oxygen debt is the amount of oxygen required to convert lactate to glucose and to restore supplies of ATP and creatine phosphate.

6. A fatigued muscle loses its ability to contract.
 - a. Muscle fatigue may be due in part to increased production of lactic acid.
 - b. Muscle action is an important source of body heat.

8.4 Muscular Responses

1. Threshold stimulus is the minimal stimulus required to elicit a muscular contraction
2. A twitch is a single contraction reflecting stimulation of a muscle fiber
 - a. A myogram is a recording of an electrically stimulated isolated muscle
 - b. A rapid series of stimuli may produce **summation** of twitches
 - c. Very rapid stimulation can lead to partial or **complete tetanic contraction**
3. One neuron and the muscle fibers associated with it constitute a **motor unit**
 - a. All the muscle fibers of a motor unit contract together
 - b. Recruitment increases the number of motor units being activated in a whole muscle
 - c. At increasing intensities of stimulation, other motor units are recruited until the muscle contracts with maximal force
 - d. Even when a muscle is at rest, its fibers usually remain partially contracted, called **muscle tone**
4. **Types of contraction**
 - a. Isotonic contraction shortens the muscle
 - b. Isometric contraction increases the tension

8.5 Smooth Muscle

1. The contractile mechanism of smooth muscle is similar to that of skeletal muscle.
2. Smooth muscle cells contain filaments of actin and myosin, less organized than those in skeletal muscle.
 - a. Two neurotransmitters—acetylcholine and norepinephrine—and hormones affect smooth muscle function
 - b. Smooth muscle can maintain a contraction longer with a given amount of energy than can skeletal muscle

8.6 Cardiac Muscle

1. Like skeletal muscle cells, cardiac muscle cells have actin and myosin filaments that are well-organized and striated
2. Intercalated discs connect cardiac muscle cells
3. A network of cells contracts as a unit

8.7 Skeletal Muscle Actions

1. The type of movement a skeletal muscle produces depends on the way the muscle attaches on either side of a joint
2. The relatively immovable end of a skeletal muscle is its **origin**, and the relatively movable end is its **insertion**
3. Skeletal muscles function in groups
 - a. An **agonist** causes a movement
 - b. **Antagonists** are muscles that oppose a movement

8.8 Major Skeletal Muscles

1. Muscles of facial expression
 - a. These muscles lie beneath the skin of the face and scalp and are used to communicate feelings through facial expression
 - b. They include the epicranii, orbicularis oculi, orbicularis oris, buccinator, zygomaticus, and platysma
2. Muscles attach to the mandible are used in chewing — they include the masseter and temporalis

3. Muscles in the neck and upper back move the head — they include the sternocleidomastoid and splenius capitis
4. Muscles that move the pectoral girdle connect to the scapula — they include the trapezius, rhomboid major, levator scapulae, serratus anterior, and pectoralis minor
5. Muscles that move the arm connect to the humerus — they include the coracobrachialis, pectoralis major, teres major, and deltoid
6. Muscles that move the forearm connect to the radius and ulna — they include the biceps brachii, brachialis, brachioradialis, and triceps brachii
7. Muscles that move the hand connect to the humerus, radius, and ulna — they include the flexor carpi radialis, flexor carpi ulnaris, palmaris longus, and flexor digitorum profundus
8. Muscles of the abdominal wall connect to the rib cage and pelvic girdle — they include the external oblique, internal oblique, transversus abdominis, and rectus abdominis
9. Muscles of the pelvic floor — they include the levator ani, coccygeus, superficial transverse perineal, bulbospongiosus, and ischioanal
10. Muscles that move the thigh attach to the femur and pelvic girdle — they include the psoas major, iliacus, gluteus maximus, gluteus medius, gluteus minimus, tensor fasciae latae, adductor longus, adductor magnus, and gracilis
11. Muscles that move the leg attach to the tibia, fibula, and femur — they include the hamstring group (biceps femoris, semitendinosus, semimembranosus), sartorius, and the quadriceps femoris group (rectus femoris, vastus lateralis, vastus medialis, vastus intermedius)
12. Muscles that move the foot
 - a. These muscles attach the femur, tibia, and fibula to bones of the foot
 - b. They include the tibialis anterior, fibularis tertius, extensor digitorum longus, gastrocnemius, soleus, flexor digitorum longus, tibialis posterior, fibularis longus, and fibularis brevis

Chapter Assessment

Chapter Review Questions

Multiple Choice

1. Exercise that includes strength training offers all of the following benefits except
 - a. increases the body's energy efficiency
 - b. lowers blood pressure
 - c. decreases the risks of developing arthritis and osteoporosis
 - d. increases bone density and bone length
2. The sheet of dense connective tissue that separates individual muscles and helps hold them in position is called
 - a. fascicle.
 - b. fascia.
 - c. epimysium.
 - d. endomysium.

3. The cell membrane of a skeletal muscle fiber is called the
 - a. sarcolemma.
 - b. sarcoplasm.
 - c. sarcomere.
 - d. sarcoplasmic reticulum.
4. All of the following describe the sliding filament model of muscle contraction except:
 - a. ATPase catalyzes the breakdown of ATP to ADP and phosphate inside myosin heads.
 - b. Calcium binds to troponin, pulling tropomyosin aside to expose binding sites on actin.
 - c. The length of the thick myosin filaments shortens as thin actin filaments slide past.
 - d. When ATP binds to myosin, the connection between the two filaments is broken.
5. Which of the following muscle cell components aids in the ability to store the oxygen required for energy muscle cells, which utilize relatively large quantities of energy?
 - a. creatine phosphate
 - b. myoglobin
 - c. hemoglobin
 - d. lactic acid
6. Continuous, forceful muscular contraction without relaxation is called
 - a. latency.
 - b. summation.
 - c. complete tetany.
 - d. partial tetany.
7. Select the pair of words that completes the following sentence: *Peristalsis* describes the ___ waves of ___ smooth muscular contraction in the walls of certain tubular organs such as the stomach intestines.
 - a. rhythmic; visceral
 - b. rhythmic; multiunit
 - c. random; visceral
 - d. random; multiunit
8. Which of the following descriptions truly applies to cardiac muscle?
 - a. Cardiac muscle cells contain many nuclei.
 - b. Cardiac muscle cells contract and relax slowly.
 - c. Cardiac muscle cells lack transverse tubules.
 - d. Cardiac muscle cells junction at intercalated discs.
9. When a person extends their knee to straighten their leg, three muscles work together as prime movers: the rectus femoris, the vastus medialis, and the vastus lateralis (all quadriceps). What is the best term for these three muscles working together in leg extensions?
 - a. agonists
 - b. synergists
 - c. antagonists
 - d. origins
10. Which muscle functions to compress the cheeks with its origin at the alveolar processes of maxilla and mandible?
 - a. epicranium
 - b. buccinator
 - c. masseter
 - d. temporalis

Short Answer

1. Describe the functions of the muscular system.
2. What is fascia?
3. Describe a myofibril.
4. Distinguish between actin and myosin.
5. Describe the unique structure of a muscle cell.
6. What is a sarcomere?
7. Describe the sliding filament model of muscle contraction.
8. What is a motor unit?
9. What is recruitment?
10. What is the neuromuscular junction?
11. Distinguish between flexors and extensors.
12. Distinguish between origin and insertion.
13. What is the relationship between agonists, antagonists and synergists?
14. Distinguish between smooth muscle and cardiac muscle.
15. What is oxygen debt and fatigue?

Critical Thinking and Clinical Applications

1. **WRITING Connection** Discuss how connective tissue is part of the muscular system.
2. All muscles contain *fast* and *slow* muscle fibers in various ratios. This is controlled mostly genetically. What would be the difference between these ratios in a marathon runner and a sprinter?
3. The drug neostigmine inhibits the function of acetylcholinesterase. What do you predict will be the effects of this drug?
4. **CLINICAL Applications** The poison curare blocks ACh from binding to receptors in the neuromuscular junction. What would be the effects of this? How could this be used in a clinical/medical setting?
5. What steps might be taken to minimize atrophy of the skeletal muscles in patients confined to bed for prolonged times?

Lab Data Analysis: Mutations in a Giant Gene

The dystrophin gene is one of the longest known DNA sequences in the human genome and is located on the X chromosome. It codes for a protein (called dystrophin) that is important for a number of structural and biochemical processes within a muscle cell. A defect in this gene can result in different forms of a disease known as *muscular dystrophy*.

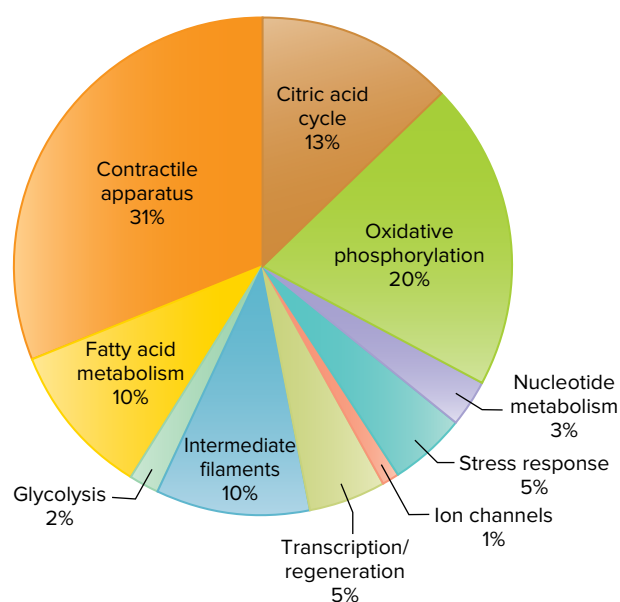
Data and Observations

The chart to the right identifies the different areas of activity of the dystrophin protein inside of a mouse heart muscle cell. The activity is reported in terms of percentage of all dystrophin-associated activity within the cell.

Think Critically

1. Based on the chart, describe the various roles of the dystrophin gene and protein.
2. Which cellular function is most dependent on the dystrophin gene?
3. Recall the *Genetic Engineering* feature “Inherited Diseases of Muscles” (page 263). Describe how the role of dystrophin in muscle cells explains some of the symptoms observed in muscular dystrophy.

Dystrophin Function in Murine Heart Muscle



Data obtained from: Lewis, Caroline, Jockusch, Harald, and Kay Ohlendieck. 2010. Proteomic Profiling of the Dystrophin-Deficient MDX Heart Reveals Drastically Altered Levels of Key Metabolic and Contractile Proteins. *Journal of Biomedicine and Biotechnology* 2010: 1–20.



Case Study Wrap-up

Recall the Case Study at the beginning of this chapter (pg. 239). You read about a child with a myostatin mutation. Throughout the chapter, you read about the structure and function of skeletal muscles. Now it is time to revisit your claim, summarize your evidence and analyze what you have learned.

Claim, Evidence, Reasoning

Revisit Your Claim: Review your CER chart where you recorded your claim about how the child's muscle anatomy and physiology will differ from his older siblings who do not carry this mutation.

Summarize Your Evidence: Summarize the evidence gathered from your investigations and research and finalize your Summary Table.

Explain Your Reasoning: Does your evidence support your claim? Explain why your evidence supports your claim. If it does not, revise your claim.

Chapter Project

Investigating How your Workout Affects your Muscles

From yoga to weight lifting to resistance training to high-intensity workouts, there are numerous exercises out there that have been touted as the best workout for your body. But what exactly do these exercises do? And how do they affect your muscles?

In this chapter, you learned all about how the metabolic capacity of a muscle changes with physical training. For this activity, you will pick a particular type of exercise that interests you and research how muscles respond to the exercise.

You will:

- Review current research related to the effect of your exercise on muscle development and/or activity
- Summarize empirical evidence from the research
- Evaluate evidence and defend in a presentation to your peers if you think this is a good exercise for individuals to undertake

CHAPTER 8

Muscular System

Section	Pacing (class periods)	Learning Outcomes
8.1 Introduction	—	1. List various outcomes of muscle actions.
8.2 Structure of a Skeletal Muscle	2	1. Identify the structures that make up a skeletal muscle. 2. Identify the major parts of a skeletal muscle fiber, and the function of each. 3. Discuss nervous stimulation of a skeletal muscle.
8.3 Skeletal Muscle Contraction	3	1. Identify the major events of skeletal muscle fiber contraction. 2. List the energy sources for muscle fiber contraction. 3. Describe how oxygen debt develops. 4. Describe how a muscle may become fatigued. 5. Distinguish between muscle fiber types. 6. Describe effects of skeletal muscle use and disuse.
8.4 Muscular Responses	1	1. Distinguish among a twitch, recruitment, and a sustained contraction. 2. Explain how muscular contractions move body parts and help maintain posture. 3. Distinguish between the types of contractions.
8.5 Smooth Muscle	1	1. Distinguish between the structures and functions of multiunit smooth muscle and visceral smooth muscle. 2. Compare the contraction mechanisms of skeletal and smooth muscle.
8.6 Cardiac Muscle	1	1. Compare the contraction mechanisms of cardiac and skeletal muscle.
8.7 Skeletal Muscle Actions	2	1. Explain how the attachments, locations, and interactions of skeletal muscles make different movements possible.
8.8 Major Skeletal Muscles	2	1. Identify and locate the major skeletal muscles of each body region. 2. Identify the actions of the major skeletal muscles of each body region.

Focus Activity Workbook
Focus Activities: Labeling (9)
Focus Activities: Vocabulary (7)
Chapter Resources
Extended Summary Review
Chapter 8 Test Bank
Chapter 8 Interactive Question Bank
Vocabulary Flashcards
APR Module 6: Muscular System
Laboratory Exercise 12: Skeletal Muscle Structure and Function
Laboratory Exercise 13: Muscle Fatigue and Force Variance
Laboratory Exercise 14: Muscles of the Head and Neck
Laboratory Exercise 15: Muscles of the Chest, Shoulder, and Upper Limb
Laboratory Exercise 16: Muscles of the Hip and Lower Limb

A Suggested Approach

The three muscle types (skeletal, smooth, and cardiac) were introduced in Chapter 5. In this chapter, students focus on skeletal muscle and learn about its microscopic structure and how that structure allows for muscle contraction. Students are introduced to the way the muscular and nervous systems are interrelated as they study muscular responses. As with the prior chapter, the anatomically correct names and functions of the major muscles of the body are presented.

In understanding the structure of the skeletal muscle, an orange is a good analogy. Just as an orange is divided into many sections, each with their own covering, so is skeletal muscle composed of both connective tissue and skeletal muscle tissue. Additionally, students can build models of sarcomeres out of a variety of materials. This modeling aids not only in the understanding of skeletal muscle structure, but also provides a visual model for the sliding filament theory of muscle contraction. There are also a variety of online tutorials to help students visualize the complex process in which our muscles contract.

Although students have already learned about energy sources and cellular respiration in cell (Chapter 4), the muscular system provides an opportunity to review this material.

While muscle and bones are separate systems in the body, learning about muscles draws on student knowledge of bones. Many of the muscles in our bodies are named after the bones they are attached to, such as the frontalis and bicep femoris. It is helpful to remind students of both the Latin roots of many of the anatomical names. Additionally, many muscles in our bodies are actually groups of muscles. For example, the hamstrings and quadriceps in our legs. In the same way knowing the anatomical names of the bones is important to health care professions, so is knowing the names of the muscles. Additionally, in order to understand the action of the muscle, it is helpful to know the origin and insertion of the muscle. Again, students can use an online resource to review the origin, insertion, and movement made by the muscles they have learned about.

This chapter is expected to take 12 class periods including Lab 12, Lab 13, Lab 14, Lab 15, and Lab 16.



Case Study

After reading the case study, students should access their online Claim, Evidence, Reasoning (CER) chart and make their claim. CER is a strategy used to teach students how to construct explanations and craft scientific arguments. A scientific claim answers a question or offers a solution to a problem. Give students time to reflect and brainstorm, then have each student take a clear stand and write a claim.

As students read the chapter and complete classroom and laboratory activities, they will collect evidence related to their claim. Scientific evidence is information that supports or contradicts a claim. This information can come from a variety of sources, such as research, experimentation, or data interpretation. It is important to have multiple pieces of evidence to support a claim. Encourage students to return to their claims and add evidence at multiple points in the chapter.

This mutation discussed in the case study is used to study muscle diseases, and could possibly be used in agriculture as well. Here is a link to an open-source article describing the induction of a myostatin mutation using the Crispr/CAS9 system to create lab animals: <https://www.nature.com/articles/srep25029>

Introduction to the Theme

Theme: *Structure and Function* The contraction and shortening of muscles is directly a result of the unique structure that sets muscles apart of all other body tissues.

Theme Activity: The Sliding Filament Model

This activity focuses on how muscle is able to contract and shorten, allowing muscles to move in the body. Begin by going over the sliding filament model with students. How do muscles move? What is causing the pull and release of a muscle? Be sure to go over what is actin and myosin.

Provide students with a variety of different model materials such as beads, rubber bands, pipe cleaners, glue, etc. Have students create their own sliding filament model. Be sure that they include a key with their model.

Section 8.1: Introduction



Learn

Classroom Activities

Section 8.1 sets the groundwork for activities in sections 8.2 and beyond.

Additional Discussion Questions

Ask students to develop a chart that compares and contrasts the structure and function of various muscles.

Responses will vary, but should include a discussion of examples of skeletal, smooth, and cardiac muscle.

Compare and contrast various muscle actions.

Responses may include a discussion of muscle tone, the movement of nutrients and fluids, the role of a heartbeat, and the production of heat through shivering.

Practice

Practice Questions

1. Name the three types of muscle tissue.

Muscle is of three types: skeletal, smooth, and cardiac.

Use the Practice 8.1

Analyzing Data Tissues are 3-D structures, but we often use the 2-D models or tissue specimens to identify structures. Determine what a cross section of a skeletal muscle fiber would look like. Identify three different places where a fiber could be sectioned to reveal different structures.

Answers will vary.

Section 8.2: Structure of Skeletal Muscle

Learn

Classroom Activities

EL Strategy: Summarizing

Beginning Review with students that a summary is a short explanation of a longer work. Provide students with an example of a summary of one paragraph of section 8.2. Have each student read a different paragraph and summarize the paragraph. Give them a graphic organizer to provide a visual of the skeletal muscle structure for their summary.

Writing Connection: Story Book Activity

Discuss with students how skeletal muscle is composed of a variety of fibers and layers. Students will create a flip book that represents the five different layers of skeletal muscle represented in Figure 8.1. Provide students with five sheets of paper, organized from large size to small. Students will draw or create the outer most layer of skeletal muscle on the largest paper. They should label the key components and list any important characteristics at the bottom. The second page of the book is smaller and represents the second internal layer of skeletal muscle. Repeat this until all five layers are represented with the smallest layer in the center. The students will have created a visual book of skeletal muscle that they can review when needed.

Differentiated Instruction

Student may prefer to make a digital presentation of the different layers of a skeletal muscle. Students could also be given the chance to present their illustrations to the class or to their families in an open house night.

Demonstration: Muscle Layers

For this activity, you will either need a photo of a power cord that has been cut in half or a power cord that you have cut in half. As you discuss the structure of skeletal muscle, show the photo or past the cut cord around. Just like a power cord, skeletal muscle is composed of different layers. Discuss the different functions of the layers. The power cord has a protective sheath, followed by layers of insulation, filler, and more PVC sheaths to protect the conductors within. Ask students what the equivalents are within a skeletal muscle. It may be helpful to show Fig. 8.1 or 8.2 side by side with the power cord.

Additional Discussion Questions

Provide students with a variety of microscope slides applicable to this chapter objective. Ask them to draw and label what they see.

The slides may illustrate myofibrils, sarcomeres, Z lines, actin, myosin, M lines, H zones, I bands, A bands, and sarcoplasm.

Discuss the meaning of the presence or absence of striations by comparing skeletal muscle, cardiac muscle, and smooth muscle.

The striated appearance of skeletal and cardiac muscle begins with an alternating configuration of light and dark bands of myofibrils. The myofibrils are actually chains of sarcomeres, which contain even smaller structures called myofilaments. It is the unique banding pattern of the myofilaments that produces a striated appearance. This banding pattern is absent in smooth muscle.



Practice

Practice Questions

1. Describe the general structure of a skeletal muscle fiber.

Each skeletal muscle fiber is a long, thin cylinder with rounded ends. Just beneath its cell membrane (sarcolemma) the cytoplasm (sarcoplasm) of the fiber has many small, oval nuclei and mitochondria. The sarcoplasm has myofibrils made of myosin and actin, which give the skeletal muscle its striated appearance. Repeating patterns of units called sarcomeres make up the functional units of skeletal muscle.

2. Explain why skeletal muscle fibers appear striated.

Myofibrils consist of two kinds of protein filaments, actin and myosin. The organization of these filaments produces the characteristic alternating light and dark striations, or bands, of a skeletal muscle fiber.

3. Which two structures approach each other at a neuromuscular junction?

Each skeletal muscle fiber is functionally (not physically) connected to the axon of a motor neuron that passes outward from the brain or spinal cord. This functional connection is called a synapse.

4. What is the function of a neurotransmitter?

Neurons communicate with the cells that they control by releasing chemicals called neurotransmitters at synapses.



Practice

Use the Practices 8.2

Using Models A skeletal muscle is composed of a variety of tissues that are packaged together to make the organ. The structure of a muscle is similar to an orange. Create a model that demonstrates how an orange depicts the anatomy of a skeletal muscle.

Outside peel = muscular fascia (epimysium)

Orange sections = fascicles surrounded by perimysium

Individual orange cells = muscle fibers surrounded by the endomysium



Figure Questions

Figure 8.5, page 245: How does acetylcholine released into the synaptic cleft reach the muscle fiber membrane?

Neurotransmitters cross the synaptic cleft by diffusion

Section 8.3: Skeletal Muscle Contraction



Learn

Classroom Activities

Visual Literacy: Storyboard Activity

Muscle contractions and relaxations take place because of specific steps involving molecules and organelles. Put students into groups and assign them an action in skeletal muscle. Each group must break down the steps that occur to make the action happen into storyboard boxes as if they were creating a step-by-step motion film or flip book. Each storyboard box the group creates should explain one step. Once each group completes their storyboard set, they should present it to the class as if they were the teachers. Allow for questions from the student audience.

Example actions that can be assigned to groups: muscle fiber contraction, muscle fiber relaxation, oxygen debt development, muscle fatigue.

Differentiated Instruction

Storyboard boxes can be created in different ways. Provide students options on how their group chooses to complete the activity and present. Some groups may need more guidance so the teacher should provide a storyboard template for the assigned muscle action. Some of the storyboard boxes may be filled in to give the students in the group more guidance.

Additional Discussion Questions

Application Questions

Ask students to develop a set of index cards, each of which has one or two key words that represents a major event of muscle contraction. Develop a second set in a similar manner for muscle relaxation. Have each student place the steps in the correct order, and then briefly present the major steps to the class in more detail.

Suggestions for key words in describing contraction are acetylcholine release, acetylcholine diffuses, membrane stimulated, calcium diffusion, linkages, cross-bridges, and fiber shortens. Suggestions for key words in describing relaxation are acetylcholinesterase, calcium transport, linkages, sliding, and fiber relaxes.

What causes muscle cramping? What may be done to treat muscle cramps?

Cramps may occur anywhere in the body. They are a sharp, involuntary muscle contraction that may be caused by fatigue, electrolyte imbalance, or dehydration. Muscle cramps are usually treated with fluid intake and gradual stretching of the muscle.

Discuss the connection between anaerobic respiration and aerobic respiration when describing how a muscle cell uses energy.

A muscle cell uses energy released in cellular respiration to synthesize ATP. ATP is then used to power muscle contraction or to synthesize creatine phosphate. Later, creatine phosphate may be used to synthesize ATP. The oxygen required to support aerobic respiration is carried in the blood and stored in myoglobin. In the absence of sufficient oxygen, pyruvic acid is converted to lactic acid. The maximum number of ATPs generated per glucose molecule varies with cell type.

Distinguish between a strain and a sprain.

A muscle strain is sometimes referred to as a pulled muscle. It is caused by tearing of muscle fibers or a tendon, resulting from an abnormally violent contraction. A sprain is caused by the tearing of a ligament, resulting from a sudden force such as a violent twisting motion of the ankle.



Practice

Practice Questions

1. **Explain how an impulse on a motor neuron can trigger a muscle contraction.**

A skeletal muscle fiber normally does not contract until stimulated by acetylcholine. When an impulse reaches the end of a motor neuron axon, some of the vesicles release their acetylcholine into the synaptic cleft. Acetylcholine diffuses rapidly across the synaptic cleft and binds to specific protein molecules in the muscle fiber membrane, increasing membrane permeability to sodium ions. Entry of these ions into the muscle cell stimulates an electrical impulse, which passes in all directions over the surface of the muscle fiber, and travels through the transverse tubules until it reaches the sarcoplasmic reticulum. The sarcoplasmic reticulum contains a high concentration of calcium ions, which diffuse into the cytosol of the muscle fiber. When a high concentration of calcium ions is in the cytosol, troponin and tropomyosin interact and the muscle fiber contracts.

2. **Explain how the filaments of a myofibril interact during muscle contraction.**

When a high concentration of calcium ions is in the cytosol, troponin and tropomyosin interact and expose binding sites on actin where myosin heads can attach. Cross-bridge linkages form between the thick and thin filaments and the muscle fiber contracts.

3. **Which chemicals provide the energy to regenerate ATP?**

Creatine phosphate, like ATP, it contains high-energy phosphate bonds.

4. **What are the sources of oxygen for aerobic respiration?**

The blood carries oxygen from the lungs to body cells to support aerobic respiration. Red blood cells carry the oxygen bound to hemoglobin. Another protein, myoglobin, can also combine with oxygen to assist in aerobic respiration.

5. How are lactic acid and oxygen debt related?

During strenuous exercise, available oxygen is used primarily to synthesize the ATP the muscle fiber requires to contract, rather than to make ATP for synthesizing glucose from lactate. Consequently, as lactate accumulates, a person develops an oxygen debt. Oxygen debt equals the amount of oxygen that liver cells require to convert the accumulated lactate into glucose, plus the amount muscle cells require to restore ATP and creatine phosphate to their original concentrations and to return blood and tissue oxygen levels to normal.

6. What is the relationship between cellular respiration and heat production?

Less than half of the energy released in cellular respiration is transferred to ATP, and the rest becomes heat. All active cells generate heat, with muscle tissue being a major source.

Use the Practices 8.3

Arguing from Evidence In idiopathic dilated cardiomyopathy (a genetic disorder) actin is unable to anchor to the Z lines in cardiac muscle cells. Provide reasoning based on the mechanism of muscle contraction why this results in heart failure.

The sarcomere is the functional unit of the muscle contraction. The interaction between the myosin heads and the actin filament causes the shortening of the muscle (or contraction). Without the actin molecules anchored to the Z-line the movement would not shorten the muscle, and therefore no contraction. With no contraction, no heartbeat.

? Figure Questions

Figure 8.8, page 248: What happens to the length of the thick and thin filaments during contraction?

Their lengths stay the same.

Section 8.4: Muscular Responses

Learn

Classroom Activities

Demonstration Activity: Lift it High

Divide students into small groups for discussion. Provide students with a picture of an action of somebody doing something. Actions could be lifting a box from the floor to the table or reaching up high to get something from the top shelf and set it on the floor. Give each group a different motion. Each group then must analyze the motion they are given and describe what muscular responses are occurring and in what order as the action is completed. Encourage students to discuss the process of summation including stimuli of the action that would increase frequency of muscle fiber movements as well as cause periods of sustained contractions and muscle tone. Groups could be paired together to collaborate on their action and their answers to the activity.

Differentiated Instruction

This could also be completed in a rotation activity where students move with a small group through stations with different actions completing the same activity above. Each station could have more guidance on the type of motions occurring in muscle to complete the action with an answer key so each group can check their understanding before moving onto the next station.

Additional Discussion Questions

Provide students with myogram printouts and ask them to identify peaks and troughs.

Students should be able to identify the period of contraction and the period of relaxation. A variety of myograms may help the students to differentiate a series of twitches from a summation or tetanic contraction.

Ask students to develop a list of excuses most commonly cited for not exercising and strategies for dealing with these excuses.

Responses should address excuses relating to age, time availability, cost, hopelessness, stress, attitude, etc.

Discuss hypoparathyroidism as it pertains to this chapter objective.

Responses should include a discussion of tetany, a sustained muscular contraction. Low levels of calcium in the blood may result in overstimulation of certain skeletal muscles. Muscles of the hands and feet, as well as the laryngeal muscles, are very susceptible to these spasms.

Discuss the health-related benefits associated with regular aerobic exercise.

Responses should include a discussion of reduction of the risk of cardiovascular disease, help in controlling diabetes, development of stronger bones, promotion of joint stability, reduction in lower back problems, improvement of self-image, etc.



Practice

Practice Questions

1. Define threshold stimulus.

Once threshold is reached, an electrical impulse is generated and the muscle fiber contracts.

2. What is a motor unit?

A motor neuron and the muscle fibers that it controls constitute a motor unit. A whole muscle is composed of many motor units.

3. Distinguish between a twitch and a sustained contraction.

The contractile response of a single muscle fiber to a single impulse is a twitch. A twitch consists of a period of contraction, during which pulling force increase, followed by a period of relaxation, during which the pulling force declines. Summation and recruitment together can produce a sustained contraction. Sustained contractions involve whole muscles and enable us to perform everyday activities.

4. What is recruitment?

An increase in the number of motor units being activated during a contraction is called recruitment. As the intensity of stimulation increases, recruitment of motor units continues until maximal tension is reached.

5. How is muscle tone maintained?

Muscle tone is a response to nervous stimulation that originates repeatedly from the spinal cord and stimulates only a few muscle fibers at a time.

Use the Practices 8.4

Conducting Investigations Allison hypothesizes that the force generated by a muscle is directly related to the number of muscle fibers contracting within the muscle. Research whether or not there is evidence to support Allison's hypothesis.

Answer will vary, accept those that show research

Section 8.5: Smooth Muscle



Classroom Activities

Group Activity: Make a Claim

Recall with students the different characteristics of skeletal muscle as well as reviewing characteristics of smooth muscle. Split the class in half and assign the first half smooth muscle and the other half skeletal muscle. Each side of the class will debate which type of muscle is the most essential. Obviously there is no answer as both are essential to human life. The goal is for students to be able to make a true claim about their muscle type and support it with structural or function details. Each student is to write down two claims about why their assigned muscle type is the most essential. Allow students to debate in a teacher controlled respectful environment. The teacher may choose to set requirements such as each student must contribute by making a comment or defending.

Differentiated Instruction

Instead of the students debating with each other about which muscle type is the most essential, they could work together to create a class presentation comparing the two muscle types. The teacher can collaborate with the lower grade gym classes and allow the students to teach the younger kids about the different movements skeletal muscle helps with smooth muscle as well.

Additional Discussion Questions

Ask students to prepare a brief report that compares the structure and function of multiunit and visceral smooth muscle, including examples of each.

Multiunit smooth muscle exhibits fibers that are well organized. The single fibers contract due to motor nerve impulses or hormonal stimulation. The walls of blood vessels are examples of this phenomenon. Visceral smooth muscles are sheets of spindle-shaped cells composed of a longitudinal outer coat and a circular inner coat. Fibers stimulate each other during rhythmicity. The urinary bladder is an example of visceral smooth muscle.

Peristalsis is the rhythmic contraction of smooth muscle that occurs in certain tubular organs. Discuss examples of reverse peristalsis.

Examples may include the stimulation of the emetic center which induces vomiting, a back flow of urine in the ureters from blockage, or a back flow of blood from an insufficient heart valve

Practice

Practice Questions

1. Describe two major types of smooth muscle.

The two major types of smooth muscle are multiunit and visceral. Multiunit smooth muscle cells are separated, rather than organized into sheets and contracts only in response to stimulation by neurons or certain hormones. Visceral smooth muscle is composed of sheets of spindle-shaped cells in close contact with one another. Visceral smooth muscle is more common than multiunit and displays a pattern of rhythmic contractions.

2. What special characteristics of visceral smooth muscle make peristalsis possible?

Rhythmicity and transmission of impulses from cell to cell are largely responsible for the wavelike motion called peristalsis.

3. How does smooth muscle contraction differ from skeletal muscle contraction?

Two neurotransmitters commonly affect smooth muscle: acetylcholine and norepinephrine. Smooth muscle is slower to contract and to relax than skeletal muscle, and can maintain a forceful contraction longer with a given amount of ATP. Smooth muscle cells can change length without changing tautness, allowing for constant pressure inside organs.

Use the Practice 8.5

Asking Questions Develop a question about why peristalsis is found only in smooth muscle.

Answers will vary. Example: What special characteristics of smooth muscle make peristalsis possible?

Section 8.6: Cardiac Muscle

Learn

Classroom Activities

Writing Connection: Energy Transfer

Pair students in groups and give them the phrase “Cardiac muscle is self-exciting and rhythmic”. Ask students to work together on an explanation of why this statement is correct and use evidence to support their ideas.

Key points to ensure students discuss:

- Intercalated discs
- Actin and myosin
- Size of sarcoplasmic reticulum and transverse tubules

Differentiated Instruction

A more focused task for students would be to just explain the importance of intercalated discs in cardiac muscle. Students could practice explaining this to each other and then to a family member at home. Encourage EL students to practice explaining in their native language as well as English.

Additional Discussion Questions

Ask students to develop a chart that compares various characteristics among skeletal, cardiac, and smooth muscles.

The chart should include information regarding location, appearance, presence or absence of striations, control mechanisms, contraction speed, and functions.

Provide students with a variety of microscope slides of skeletal, cardiac, and smooth muscle. Ask them to draw what they see and to comment on any similarities and differences among the three types.

Responses should include a discussion of striations, nuclear configurations, transverse tubule systems, and intercalated discs.



Practice

Practice Questions

1. How is cardiac muscle similar to smooth muscle?

Cardiac muscle and smooth muscle both have single nuclei in their cells. Cardiac and smooth muscle cells both contract involuntarily. Cardiac and smooth muscle cells contract rhythmically and are both self-exciting.

2. How is cardiac muscle similar to skeletal muscle?

Cardiac and skeletal muscle cells have actin and myosin filaments. Cardiac and skeletal muscles are striated. Cardiac and skeletal muscles have a sarcoplasmic reticulum, many mitochondria, and transverse tubules.

3. What is the function of intercalated discs?

Intercalated discs allow impulses to pass freely so that they travel rapidly from cell to cell, triggering contraction.

4. What characteristic of cardiac muscle contracts the heart as a unit?

Intercalated discs help to join cells and to transmit the force of contraction from cell to cell. Thus, when one portion of the cardiac muscle network is stimulated, the whole structure contracts as a functional unit.

Use the Practice 8.6

Constructing Explanations Using what you have learned about muscle contraction, describe how the structure of cardiac muscle allows it to produce rhythmic, synchronized contractions.

Cardiac muscle releases a greater amount of calcium into the sarcoplasm resulting in a longer twitch. Intercalated discs connect cell to cell and transmit the force on the contraction from one cell to another. Together the slower twitch and the ability to pass the impulse results in the rhythmic contraction of cardiac muscle.

Section 8.7: Skeletal Muscle Actions

Learn

Classroom Activities

Hands-on Activity: Lever Challenge

Pairs students together. Give each pair of students the challenge to create or design a lever that could be used in real-life that simulates the similar functions and motions of the upper limb bending at the elbow and straightening. Each pair of students will design one lever that functions this way. Students will present their designed levers to the class and explain how it functions similar to the elbow.

Differentiated Instruction

Instead of students designing their own lever, the teacher should provide each group of students with a picture of a lever. Some levers may be very similar, and some levers may not be similar to an elbow. Each pair of students should describe how the lever they were assigned is similar and different in terms of structure and function to the movement at the elbow. Remind students to include details on how the muscles affect the movement.

Additional Discussion Questions

Ask students to make a list of 25 muscles and determine by which criteria each muscle derived its name.

Students should categorize the muscles they have chosen by size, location, number of origins, shape, direction of the muscle fibers, action, and origin/insertion points.

Have classmates demonstrate various muscle movements to each other. The classmates should identify the skeletal muscles involved, and determine which muscles are contracting or relaxing during each demonstration.

Demonstrations will vary but should emphasize the concepts of prime movers, antagonists, synergists, and fixators.

Practice

Practice Questions

1. Distinguish between the origin and the insertion of a muscle.

One end of a skeletal muscle usually attaches to a relatively immovable or fixed part on one side of a movable joint, and the other end attaches to a movable part on the other side of that joint, such that the muscle crosses the joint. The less movable end of the muscle is called the origin and the more movable end is its insertion.

2. Define agonist.

An agonist, as it refers to muscles, helps the muscle perform a particular action. For example, for the action of flexion of the elbow, biceps brachii would be the agonist.

3. What is the function of a synergist? An antagonist?

A synergist, as it refers to muscles, is a muscle that contributes to another muscle being able to perform a particular action. For example, pectoralis major and latissimus dorsi are synergistic for medial rotation of the arm. An antagonist, as it refers to muscles, is a muscle

that works against a muscle being able to perform a particular action. For example, triceps brachii is the antagonist for flexion of the elbow, since that muscle works to extend the elbow.

Use the Practice 8.7

Using Models In literature, the protagonist is the main character, and the antagonist is the chief opponent. Use this structure to describe skeletal muscle actions.

Skeletal muscles almost always function in groups. And although skeletal muscles do not have a protagonist, they do have a prime mover or agonist. Working against this action, is the antagonist. Together these muscles create movement.

Section 8.8: Major Skeletal Muscles

Learn

Classroom Activities

EL Strategy: Oral Language Development

Intermediate When discussing the name of skeletal muscles, instruct student partners to make and use flashcards to check each other's pronunciation and understanding. Students should have two copies of figure 8.16 on paper. They can label one and quiz each other with the unlabeled version. Have students repeat each word and point to the visual representation as you review vocabulary.

Visual Literacy: Muscle Scramble

Arrange students in small groups. The teacher should create a printout of the different section of body. Each group is responsible for creating a game to help other students remember the muscles in their assigned region, including the origins, insertions, and actions. Depending on the length of the activity, groups could be given time to bring in materials or create a game virtually. Once all games are complete, rotate groups around the room so they have a chance to play every game and practice with the different muscles in the human body.

Differentiated Instruction

Instead of students designing their own games, the teacher could assign each group a game to create for their muscle type. This would ensure a variety of games to engage students as well as reduce the amount of time required for students to create the game. Pair groups of students together to practice their games and help each other complete them.

Demonstration Activity: Muscle Shirt

For this activity, have students bring in a plain white t-shirt. Provide them with permanent markers to draw the different types of muscles as you talk. You may choose to do this activity by focusing on mainly the different types of skeletal muscles, or you may decide to have the students draw the three different types of muscles – skeletal, smooth, and cardiac, using different colors.

Additional Discussion Questions

Ask students to locate on a wall chart or model as many superficial skeletal muscles of the anterior and posterior aspects as possible. The name, origin, insertion, and major actions should also be noted.

Students should be able to identify and discuss a minimum of 36 skeletal muscles.

Discuss the adverse effects of anabolic steroid use to build muscular strength and endurance.

Responses should include the following possible side effects: increase in aggressive behavior, addiction, psychosis, hair growth, sexual dysfunction, high blood pressure, atherosclerosis, liver damage, cancer, etc.



Practice

Practice Questions

1. What information is imparted in a muscle's name?

The name of a muscle may indicate its size, shape, location, action, number of attachments, or direction of its fibers.

2. Which muscles provide facial expressions? Ability to chew? Head movements?

Facial expressions: epicranius, orbicularis oculi, orbicularis oris, buccinator, zygomaticus, and platysma. Chewing: masseter and temporalis. Head movement: sternocleidomastoid, splenius capitis, semispinalis capitis, and the scalenes.

3. Which muscles move the pectoral girdle? Abdominal wall? Pelvic outlet? The arm, forearm, and hand? The thigh, leg, and foot?

Pectoral girdle: trapezius, rhomboid major, levator scapulae, serratus anterior, and pectoralis minor. Abdominal wall: internal and external obliques, rectus abdominis, and transversus abdominis. Pelvic outlet: levator ani, coccygeus, superficial transversus perinei, bulbospongiosus and ischiocavernosus. Arm: coracobrachialis, pectoralis major, teres major, latissimus dorsi, supraspinatus, deltoid, subscapularis, infraspinatus, and teres minor. Forearm: biceps brachii, brachialis, brachioradialis, triceps brachii, supinator, pronator teres, and pronator quadratus. Hand: flexor carpi radialis, flexor carpi ulnaris, palmaris longus, flexor digitorum profundus, extensor carpi radialis longus, extensor carpi radialis brevis, extensor carpi ulnaris, and extensor digitorum. Thigh: psoas major, iliacus, gluteus maximus, gluteus medius, gluteus minimus, tensor fasciae latae, adductor longus, adductor magnus, and gracilis. Leg: sartorius, biceps femoris, semitendinosus, semimembranosus, rectus femoris, vastus lateralis, vastus medialis, and vastus intermedius. Foot: tibialis anterior, fibularis tertius, extensor digitorum longus, gastrocnemius, soleus, flexor digitorum longus, tibialis posterior, fibularis longus, and fibularis brevis.

Use the Practice 8.8

Using Mathematics The human skeleton has 206 bones, but the muscular system contains more than 600 muscles. Explain the benefit of having more muscles than bones.

Muscles do more than move our bodies, they are responsible for pumping blood and controlling digestion. In addition, muscles provide the tug on the bones to make them move. But because muscles can only pull on bones, and not push on bones, for every movement (or bone) we need at least two muscles.



Assess



Career Corner: Physical Therapy Assistant

Consider This: Of the 3 muscle types, with which type do you think a physical therapy assistant is most concerned?

A physical therapy assistant works primarily with skeletal muscles. Through exercise, cardiac muscle also benefits, and healthy cardiac muscle ensures healthy smooth muscle.



Healthy Lifestyle Choices: Steroids and Athletes - An Unhealthy Combination

1. Explain what happens to the levels of testosterone in a male athlete who abuses steroids and how this explains the signs and symptoms of steroid abuse (hint: think about negative feedback loops).

As mentioned in the excerpt, the levels of testosterone and estrogen are increased in a male who abuses steroids. Since there are increased levels of testosterone in the blood from the steroids, the testicles stop making their own testosterone and shrink. The estrogen levels are increased due to the negative feedback the steroids have on the testicles. The breast tissue is stimulated by the now excess estrogen.

2. Describe how the metabolic capacity of a muscle changes with physical exercise.

With high-intensity exercise, which depends more on glycolysis for ATP, a muscle synthesizes more glycolytic enzymes, and its capacity for glycolysis increases. With aerobic exercise, more capillaries and mitochondria form, and the muscle's capacity for aerobic respiration is greater.



Healthy Lifestyle Choices: Use and Disuse of Skeletal Muscles

1. Describe the difference between slow-twitch and fast-twitch muscle fibers.

Slow twitch fibers are used for endurance activities, like swimming or running. Increasing the use of slow twitch fibers results in greater endurance, but not necessarily their size or strength. Conversely, fast twitch fibers are used in forceful exercise. Increasing fast twitch fibers can increase a muscle's size and contraction strength, but not its endurance.

2. Muscles respond to increased use by hypertrophy, which is the enlargement of the muscle fibers. Can you think of a part of the body where hypertrophy could cause a problem?

Enlargement of cardiac muscle fibers is problematic and great pains are taken to prevent this from occurring. The enlargement of the cardiac muscle, seen in conditions like aortic stenosis, occurs when the left ventricle must pump blood against a narrowed aortic valve. The left ventricle has to increase its pumping force in that situation, and does so by enlargement of the cardiac myocytes. As time goes by, the heart loses its ability to maintain these high pumping pressures and failure ensues.



Genetics Engineering: Inherited Diseases of Muscle

1. Describe how hereditary idiopathic dilated cardiomyopathy disrupts the rhythm of cardiac muscle.

The condition is caused by a mutation in a gene that encodes a form of actin found only in cardiac muscle. The mutation disturbs actin's ability to anchor to the Z lines in heart muscle cells, preventing actin from effectively transmitting the force of contraction.

2. Describe how the protein dystrophin differs in Duchenne and Becker muscular dystrophies, and why this difference results in one type being more severe than the other.

In Duchenne muscular dystrophy (DMD), the protein dystrophin is severely shortened or missing entirely. This produces symptoms that start in childhood. In Becker muscular dystrophy, the correct form of dystrophin is produced but at extremely low levels.



Case Study Connection

page 241: If these facial muscles were all the same size, which would require more caloric energy, smiling or frowning?

Frowning

page 242: Knowing that his muscles are functioning normally, will the child with a myostatin mutation have the same ratio of myosin to actin as his siblings without the mutation?

Yes – he will just have many more muscle cells

page 252: Because he has more muscle mass, will the child with the myostatin mutation need more blood volume and more blood vessels?

More

page 252: This child has significantly more muscle mass than his peers. Last week in his Kindergarten class, the school's heat system broke and the classroom was cold. How do you think this child felt in the cold room compared to his classmates?

Since muscle produces so much body heat, the child with the myostatin mutation should feel warmer

page 254: Muscle atrophy is common in AIDS and other diseases. What might occur in AIDS patients if a myostatin inhibitor (a drug that could stop the action of myostatin) was given?

Accept all answers which show sound reasoning

Chapter Assessment

Chapter Review Questions

Multiple Choice

- Exercise that includes strength training offers all of the following benefits except
 - increases the body's energy efficiency
 - lowers blood pressure
 - decreases the risks of developing arthritis and osteoporosis
 - increases bone density and bone length
- The sheet of dense connective tissue that separates individual muscles and helps hold them in position is called
 - fascicles
 - fascia
 - epimysium
 - endomysium
- The cell membrane of a skeletal muscle fiber is called the
 - sarcolemma
 - sarcoplasm
 - sarcomere
 - sarcoplasmic reticulum

4. All of the following describe the sliding filament model of muscle contraction except
 - a. ATPase catalyzes the breakdown of ATP to ADP and phosphate inside myosin heads.
 - b. Calcium binds to troponin, pulling tropomyosin aside to expose binding sites on actin.
 - c. The length of the thick myosin filaments shortens as thin actin filaments slide past.**
 - d. When ATP binds to myosin, the connection between the two filaments is broken.
5. Which of the following muscle cell components aids in the ability to store the oxygen required for energy muscle cells, which utilize relatively large quantities of energy?
 - a. creatine phosphate
 - b. myoglobin**
 - c. hemoglobin
 - d. lactic acid
6. Continuous, forceful muscular contraction without relaxation is called
 - a. latency.
 - b. summation.
 - c. complete tetany.**
 - d. partial tetany.
7. Fill in the blanks: *Peristalsis* describes the _____ waves of _____ smooth muscular contraction in the walls of certain tubular organs such as the stomach intestines.
 - a. rhythmic; visceral**
 - b. rhythmic; multiunit
 - c. random; visceral
 - d. random; multiunit
8. Which of the following descriptions truly applies to cardiac muscle?
 - a. Cardiac muscle cells contain many nuclei.
 - b. Cardiac muscle cells contract and relax slowly.
 - c. Cardiac muscle cells lack transverse tubules.
 - d. Cardiac muscle cells junction at intercalated discs.**
9. When a person extends their knee to straighten their leg, three muscles work together as prime movers called the rectus femoris, the vastus medialis, and the vastus lateralis (all quadriceps). What is the best term for these three muscles working together in leg extensions?
 - a. agonists
 - b. synergists**
 - c. antagonists
 - d. origins
10. Which muscle functions to compress the cheeks with its origin at the alveolar processes of maxilla and mandible?
 - a. epicranus
 - b. buccinator**
 - c. masseter
 - d. temporalis

Short Answer

1. What are all of the functions of the muscular system?

Muscle provides body movement, heart beats, and digestive tract movement. It also helps with thermoregulation.

2. What is fascia?

A dense connective tissue that separates individual muscles.

3. Describe a myofibril.

A myofibril is a tube of muscle cell. Within a myofibril there are two contractile proteins, actin and myosin.

4. Distinguish between actin and myosin.

Actin is shaped like a long beaded necklace and is surrounded by the regulatory proteins troponin and tropomyosin. Myosin has extensions called heads.

5. Describe the unique structure of a muscle cell.

A muscle cell is a long tube. It is multinucleate for efficient protein synthesis; to sustain the great energy demands it has a high density of mitochondria. It has a unique ER called the sarcoplasmic reticulum that is built to propagate a stimulus rapidly throughout the entire cell.

6. What is a sarcomere?

Sarcomeres are the smallest functional units of contraction that contribute to a muscle generating a force. Actin and myosin are organized in an overlapping fashion for contraction in sarcomere. Sarcomeres separated from each by Z lines.

7. Describe the sliding filament model of muscle contraction.

When a muscle cell is stimulated the myosin heads attach to the actin filaments, pulling them toward the middle, causing a contraction of the sarcomere. This generates a force.

8. What is a motor unit?

A motor unit consists of a motor neuron and all of the muscle cells it stimulates.

9. What is recruitment?

A muscle cell either contracts or it does not. If only a few motor units fire off the force generated is small. If a larger force is needed, more motor units will be recruited to help.

10. What is the neuromuscular junction?

The neuromuscular junction is the place where the motor neuron meets the motor end plate of a muscle cells. Neurotransmitters bind to receptors on the muscle cell here.

11. Distinguish between flexors and extensors.

Flexors are muscles that aid in closing an angle at a joint. Extensors are muscles that aid in opening the angle at a joint.

12. Distinguish between origin and insertion.

The origin is the tendinous attachment to the less movable end of a muscle. It is often attached to a bone that does not move during the action. The insertion is the tendinous attachment to the more movable end of a muscle. It is usually attached to a bone that moves during the action.

13. What is the relationship between agonists, antagonists and synergists?

An agonist is a muscle that brings about a desired action. An antagonist is a muscle that opposed the action. A synergist is a muscle that aids the agonist.

14. Distinguish between smooth muscle and cardiac muscle.

Smooth muscle is under involuntary control for digestion and vasoconstriction. It contracts slowly and is non-striated. Cardiac muscle is under involuntary control and found only in the heart. It is striated and contracts/relaxes like skeletal muscle.

15. What is oxygen debt and fatigue?

Muscle fatigue is not fully understood but contributing to it are, lack of energy and changes in pH.

Critical Thinking and Clinical Applications

1. WRITING ➤ Connection Discuss how connective tissue is part of the muscular system.

Layers of fibrous connective tissue separate an individual skeletal muscle from adjacent muscles and hold it in position. Connective tissue also forms broad fibrous sheets which may attach to bone or to the coverings of adjacent muscles.

2. All muscles contain fast and slow muscle fibers in various ratios. This is controlled mostly genetically. What would be the difference between these ratios in a marathon runner and a sprinter?

In a world class marathon runner you would expect to find muscles that had more than the average amount of slow fibers for endurance. In a sprinter, you would find the opposite, muscles with many fast fibers.

3. The drug neostigmine inhibits the function of acetylcholinesterase. What do you predict will be the effects of this drug?

Acetylcholinesterase degrades acetylcholine after muscle contraction. Therefore, muscle cells would stay in state of contraction longer than usual because of the abundance of acetylcholine.

4. CLINICAL ➤ Connection The poison curare blocks Ach from binding to receptors in the neuromuscular junction. What would be the effects of this? How could this be used in a clinical/medical setting?

Muscles would not be able to contract, thereby causing paralysis. It could be used to treat muscle spasms and maybe for localized temporary paralysis for medical procedures.

5. What steps might be taken to minimize atrophy of the skeletal muscles in patients confined to bed for prolonged times?

Passively moving or electrically stimulating the injured muscle would help prevent muscle atrophy and contractures.

Lab Data Analysis: Mutations in a Giant Gene

Think Critically

1. Based on the chart, describe the various roles of the dystrophin gene and protein.

Clearly, the dystrophin protein is essential in many different intracellular processes. Among them, it is especially active in the contractile function of the heart muscle cell ("Contractile Apparatus"), as well as production of ATP as evidenced by its role in the "Citric Acid Cycle" and "Oxidative Phosphorylation".

2. Which cellular function is most dependent on the dystrophin gene?

Given that the "contractile apparatus" constitutes 31% of all dystrophin activity within the cell (more than any other cellular

function), we can conclude that dystrophin is most vital to helping the heart muscle cell contract.

3. Recall the Genetic Engineering feature "Inherited Diseases of Muscles" (page 219). Describe how the role of dystrophin in muscle cells explains some of the symptoms observed in muscular dystrophy.

Many of the symptoms in muscular dystrophy relate to muscle weakness and degeneration. Dystrophin holds skeletal muscle cells together and also relates to their ability to contract. Without dystrophin, muscle fibers cannot contract normally, leading to weakness and eventual degeneration.