

FOUNDATIONS OF SPEECH AND HEARING

Anatomy and Physiology

SECOND EDITION

**Jeannette D. Hoit
Gary Weismer
Brad Story**





5521 Ruffin Road
San Diego, CA 92123

e-mail: information@pluralpublishing.com
Website: <https://www.pluralpublishing.com>

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Preface

The second edition of *Foundations of Speech and Hearing: Anatomy and Physiology* was written for students who are being introduced to the discipline of speech and hearing sciences. This edition includes some reorganization of material, line-by-line revisions of text, and conceptual additions and reductions from the first edition, all done in the service of greater clarity. Many new and revised figures have been included, most created by master illustrator Maury Aaseng. An important addition to this second edition of *Foundations* is a set of highly instructive videos that complement concepts presented in the text and bring these concepts to life. As in the first edition of *Foundations*, only those topics that are ultimately important to understanding, evaluating, and managing clients with speech, hearing, and swallowing disorders are included in this book. In short, it has been written with clinical endpoints and future speech-language pathologists and audiologists in mind.

Although the current text lists three authors, a significant portion of the material was originally conceptualized and written by Tom Hixon (1940–2009) in the writing of our original edition of *Preclinical Speech Science*. Tom's extraordinary vision and effort over a decade ago created the foundation upon which *Foundations* is built.

Sidetracks

Throughout the book you'll find a series of sidetracks. These are short asides that relate to topics being discussed in the main text. Many of the sidetracks in the book are a bit less formal and a bit more lighthearted than the main text they complement. This is intended to enhance your reading enjoyment and to put some fun in your study of the material. We hope you enjoy reading these sidetracks as much as we enjoyed writing them.

Acknowledgments

Many of the people we acknowledge for contributions to this text are the same people we thanked for the first three editions of *Preclinical Speech Science*. Even if their efforts are historical, their influence is reflected in the current textbook. Special thanks to Tim McCulloch and Michelle Ciucci for providing our readers with videos on swallowing, Robin Samlan for laryngeal images, and Adam Baker and Shrikanth Narayanan for magnetic resonance images.

About the Illustrator

Maury Aaseng began illustrating as a freelancer for young-adult nonfiction publications in San Diego, California. While there, his work expanded into the realm of medical and anatomical art. He collaborated with authors and experts to create digitally rendered illustrations for publications that illuminate concepts in the health sciences, the body, and nature. Beyond medical illustration, his range includes cartooning, watercolor, logos, line art, ink, and digital art. Clients include various publishing companies, podcasts, botanical gardens, lawyers, public works utilities, an opera company, and a creative studio in Melbourne, Australia.

His work first won recognition in the juried exhibition Upstream People Gallery in 2008. In 2016, a collection of his watercolor work was displayed at the Great Lakes Aquarium gallery. He has taught classes covering scientific illustration and nature-inspired watercolor and recently has “drawn on” his experience to create books that demonstrate techniques to other budding artists.

Maury resides with his wife, Charlene, a graphic designer, and their two children in Duluth, Minnesota, near the shores of Lake Superior. They enjoy spending time outdoors as much as possible in the surrounding woods and lakes.



Introduction to Basic Concepts

INTRODUCTION

This book is about the *anatomy* (the study of the structure of organisms and the relations of their parts) and *physiology* (the study of functions of living organisms or their parts) of the speech and hearing mechanisms. In this first chapter, we provide an overview of certain overarching and basic concepts that will make the reading of later chapters much easier. It begins with a general anatomical description of the speech and hearing *subsystems*, anatomic *directions and planes*, and *tissue types*. The next section focuses on *movements and forces*, phenomena that are critical to understanding speech production and certain aspects of hearing. The chapter concludes with a simple description of the *stages of spoken communication*, a general framework meant to guide the reader through the material in the remaining chapters.

SUBSYSTEMS

The human body operates as an elegant, integrated system. Although it cannot actually be divided into parts without sacrificing its functional integrity, it is convenient to discuss separate parts of the system as

a way to make the information easier to understand and remember. In this book, we divide the material into *speech* and *hearing* mechanisms, and each of these can be divided into *subsystems*.

Speech Subsystems

Most textbooks divide the speech mechanism into three or four subsystems. The first two, respiratory and laryngeal, are also used in this book. Where this book diverges from the others is in the treatment of the region above the larynx. Some textbooks present this region as a single subdivision of the speech mechanism, often called the *articulatory subsystem* and encompassing the pharyngeal, oral, and nasal cavities and associated structures. Other textbooks present this region as two subdivisions, using terms such as *articulatory* (in this context meaning the oral region) and *resonatory* (usually meaning the velopharyngeal region and sometimes including the nasal region). The term *articulatory* is problematic when used in this context because it is not the only speech subsystem that contains an articulator (defined as a movable structure that contributes to the production of speech sounds); the larynx also acts as an articulator (see Chapters 3

and 5), as does the velopharynx (see Chapter 4). Similarly, the term *resonatory* is problematic because the resonators (defined as parts of an acoustic system that emphasize certain sound frequencies and reject others) are not found exclusively in the velopharyngeal and nasal regions; the lower pharynx and the oral cavities also serve as acoustic resonators. Also, it is important to acknowledge that these anatomical regions are not used exclusively for articulating or resonating but also serve other functions, such as swallowing. For all these reasons, we have adopted an anatomical approach to naming the speech subsystems.

In this book, we divide the speech system into four subsystems, as depicted in Figure 1-1: *respiratory*, *laryngeal*, *velopharyngeal-nasal*, and *pharyngeal-oral*.

The respiratory subsystem consists of the pulmonary apparatus (lungs and lower airways) and the chest wall that surrounds it (rib cage, diaphragm, abdomen and its contents). The laryngeal subsystem includes a set of structures that are located at the exit of the respiratory subsystem. The *velopharyngeal-nasal* subsystem includes both the velopharynx and the nasal airways and associated structures. The nasal portion is included because it is critical to understanding the aeromechanic and acoustic functions of this part of the speech system. The *pharyngeal-oral* subsystem includes the middle and lower pharynx and the oral cavity and associated structures. Inclusion of the pharyngeal part of the apparatus reflects the fact that during speech production, this part of the pharynx acts as an articulator and resonator

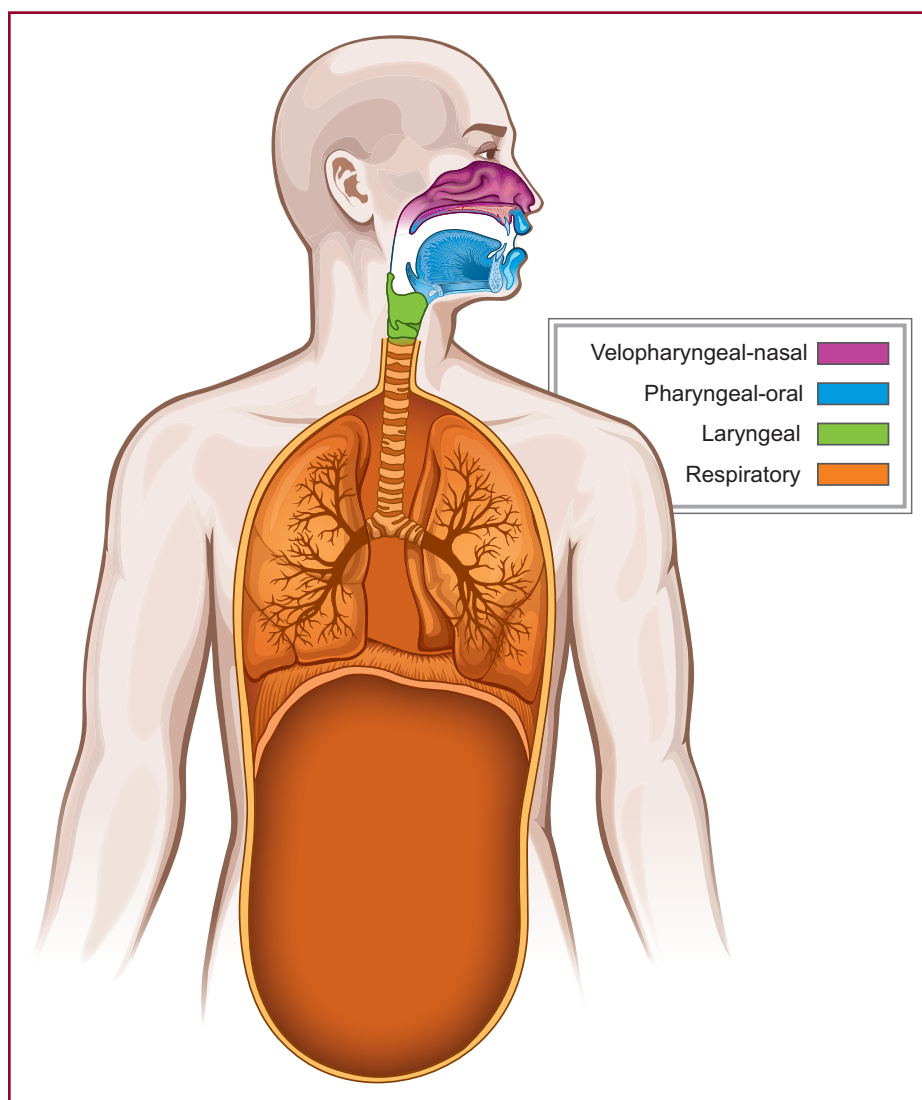


FIGURE 1-1. The speech subsystems. Four subsystems are shown: respiratory (orange), laryngeal (green), velopharyngeal-nasal (purple), and pharyngeal-oral (blue).

along with its oral counterparts. It is also critical for swallowing.

The pharyngeal-oral and velopharyngeal-nasal subsystems form what is called the upper airway. In this book, the term *upper airway* is used in the context of the anatomy and physiology of this region to be consistent with terms such as *lower airways*, *laryngeal airway*, *velopharyngeal-nasal airway*, and *oral airway*. The term *vocal tract* also refers to the pharyngeal-oral regions but is used primarily when referring to their acoustic (sound) properties. Similarly, the term *nasal tract* is often used when discussing the acoustic properties of the nasal air spaces.

Hearing Subsystems

The hearing mechanism, like the speech mechanism, acts as an integrated system but is often divided into parts. The most conventional way to divide the hearing system, and the one that is adopted in this book, is into regions simply called the *outer ear*, *middle ear*, and *inner ear*, shown in Figure 1–2 with color-coding. It is

important to recognize that the inner ear contains both auditory (hearing) structures and vestibular (balance) structures. The major hearing structure of the inner ear is the part that looks like a snail's shell (called the cochlea), and the vestibular portion looks like a trio of loops (called semicircular canals). Figure 1–2 should give the reader an appreciation of the location of the auditory-vestibular system within the head, as well as how small it is relative to most of the other structures discussed in this book. More details are provided in Chapter 6.

DIRECTIONS AND PLANES

A special vocabulary is used when describing locations and orientations of anatomical structures. This vocabulary pertains to *directions* and *planes* and is generally discussed in the context of what is called the *anatomical position* of the body. This position is described as the body standing erect with the arms at the sides and the palms facing forward, as shown in Figure 1–3.

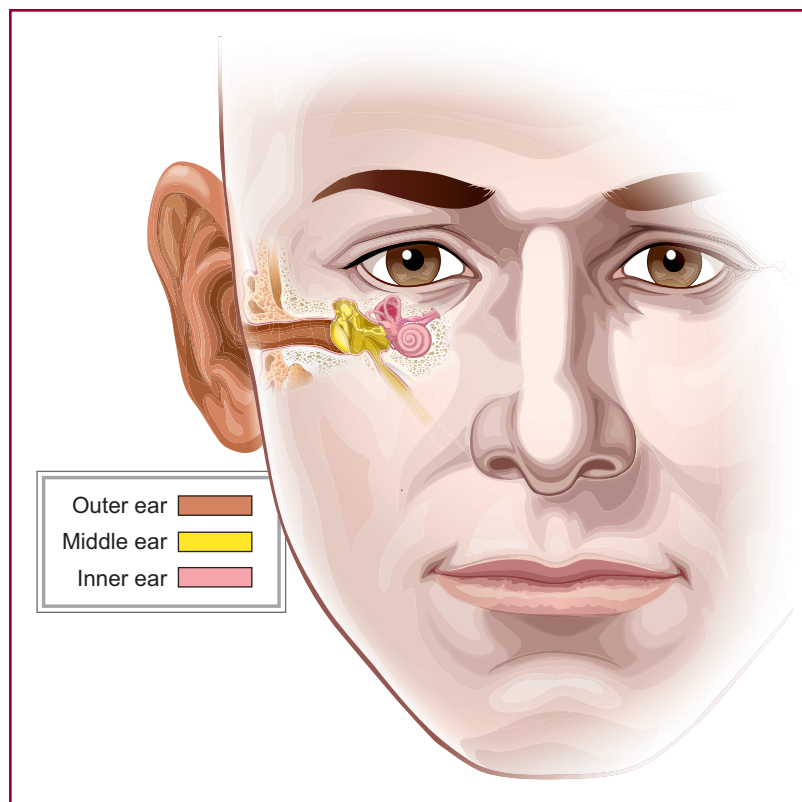


FIGURE 1-2. The hearing subsystems. Three subsystems are shown: outer ear (*brown*), middle ear (*yellow*), and inner ear (*pink*). Note that the inner ear also contains vestibular (balance) structures.

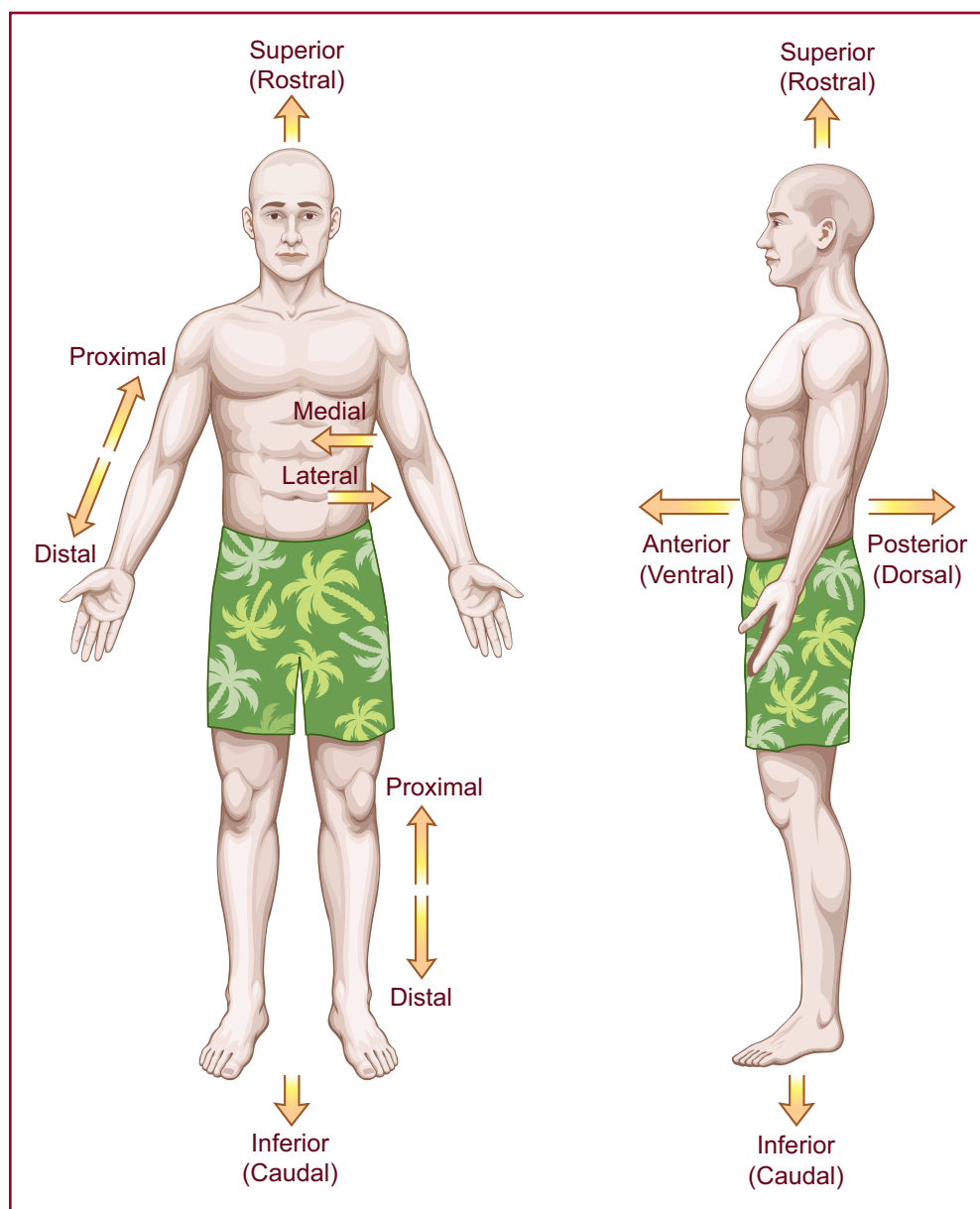


FIGURE 1-3. Anatomical directions. Four sets of anatomical directions are shown: anterior (ventral) and posterior (dorsal), superior (rostral) and inferior (caudal), medial and lateral, and proximal and distal. Note that the definitions of ventral and dorsal differ when applied to the upper part of the brain (see associated text and Chapter 8).

Directions

Several directional terms are used in this book to describe anatomical locations and orientations within the speech and hearing mechanisms. These terms are *anterior/posterior (ventral/dorsal)*, *superior/inferior (rostral/caudal)*, *medial/lateral*, *proximal/distal*, *external/internal (superficial/deep)*, and *ipsilateral/contralateral*. The first three sets of terms are depicted in Figure 1-3.

Anterior/Posterior (Ventral/Dorsal)

Anterior means toward the front of the body and *posterior* means toward the back of the body. Similarly, *ventral* means toward the front of the body (literally, toward the belly), and *dorsal* means toward the back of the body. Thus, in many contexts, *anterior* and *ventral* can be used interchangeably, as can *posterior* and *dorsal*. Nevertheless, it is best to use them in their des-

ignated pairs (e.g., *anterior* and *posterior*) rather than mix them (e.g., *anterior* and *dorsal*). An example of how these terms are used is: The umbilicus (belly button) is *anterior* (ventral) to the spine and the spine is *posterior* (dorsal) to the umbilicus.

There is an important exception to how the terms *ventral* and *dorsal* are used. When applied to the upper region of the brain comprising the cerebral hemispheres, *ventral* means toward the bottom and *dorsal* means toward the top of the cerebral hemispheres. This is explained and illustrated more fully in Chapter 8.

Which Way Is Up?

Anatomy is hard enough to learn without having to learn that certain terms means different things in different contexts. It's just not fair. Why doesn't *ventral* just mean "toward the front" and *dorsal* just mean "toward the back"? Period. Why assign these terms different meanings when talking about the lower part of the brain versus the higher part? Believe it or not, it's simpler than you think. What may seem arbitrary at first glance is actually completely logical. Try this exercise: Ask your cat or dog or other four-legged pet to stand quietly while you view it from the side. Now ask yourself these questions: "Which direction is ventral? Which direction is dorsal?" It should be immediately apparent that ventral is toward the lower part of the brain (cerebral hemispheres) and dorsal the opposite. Clear as a bell. The confusion comes when the animal stands on its two back legs. If we humans had only stayed on all fours, learning the anatomical directions would have been so much easier!

Superior/Inferior (Rostral/Caudal)

Superior and *rostral* mean toward the head. Sometimes the term *cranial* is also used to mean toward the head. The terms *inferior* and *caudal* mean toward the tail or, in the case of the human, away from the head. For example, the brain is *superior* (rostral) to the spinal cord and the spinal cord is *inferior* (caudal) to the brain.

Medial/Lateral

Medial means toward the midline. *Lateral* means away from the midline or toward the side. For example, the nose is *medial* to the ear and the ear is *lateral* to the nose.

Proximal/Distal

Proximal means toward the body and *distal* means away from the body. These terms are usually applied to the limbs (arms and legs). For example, the fingers are *distal* to the wrist and the wrist is *proximal* to the fingers.

External/Internal (Superficial/Deep)

When something is closer to the outer surface of the body than something else, it is said to be *external* (or *superficial*) to it. Conversely, when something is farther away from the outer surface of the body than something else, it is said to be *internal* (or *deep*) to it. These terms are often used interchangeably. An example of their usage is: The skin is *external* (or *superficial*) to the muscle and the muscle is *internal* (or *deep*) to the skin.

Ipsilateral/Contralateral

Ipsilateral means the same side of the body. *Contralateral* means the opposite side of the body. For example, the right ear is *ipsilateral* to the right arm and *contralateral* to the left arm.

Planes

Many structures of the speech and hearing mechanisms (and all structures of the nervous system) are inside the body and can only be viewed when exposed by slicing open the body. An example of this is Figure 1-1, which depicts the cranial portion of the speech mechanism (velopharyngeal-nasal and pharyngeal-oral subsystems) as viewed with that part of the body sliced in half. These slices are called planes of reference, and three are commonly used in anatomy: sagittal, coronal (frontal), and horizontal (transverse or axial). These three planes are illustrated in the upper part of Figure 1-4.

Sagittal Plane

A *sagittal* plane divides the body into right and left parts. When the plane divides the body into halves (equal parts), it is called the *midsagittal* plane. Sagittal cuts away from the midline are called *parasagittal* planes. The lower left image in Figure 1-4 shows a magnetic resonance (MR) image of the head and neck of a young man in the midsagittal plane.

Coronal Plane

A *coronal* plane (also called a *frontal* plane) divides the front and back parts of the body. The *midcoronal* plane

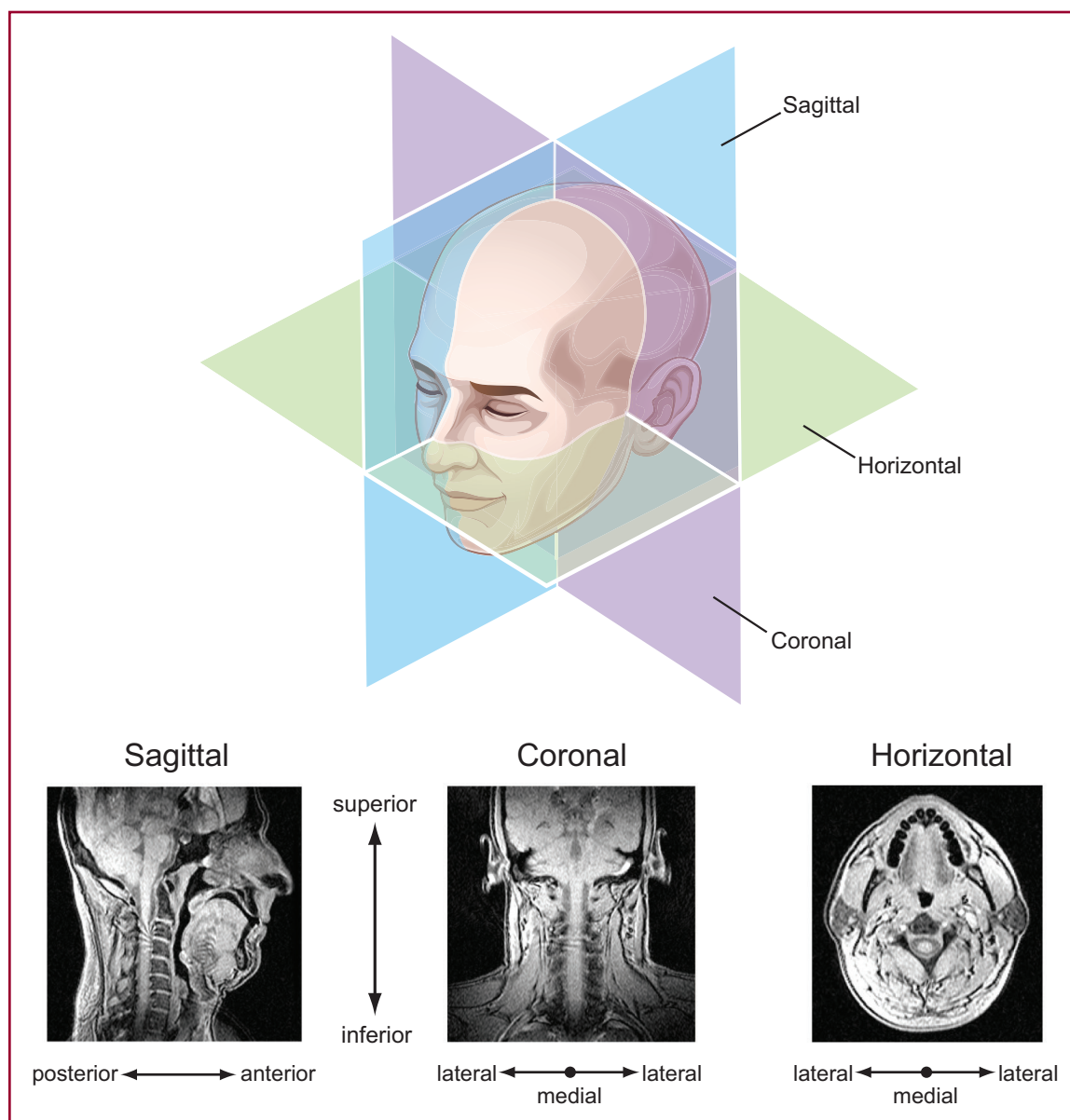


FIGURE 1-4. Anatomical planes. Three anatomical planes are illustrated in the upper panel: sagittal, coronal (also called frontal), and horizontal (also called transverse or axial). The lower panel contains magnetic resonance (MR) images of the head of a young man in the same three planes.

divides the front and back (anterior and posterior) parts of the body equally. The lower middle image in Figure 4-1 is a coronal MR image of the head and neck at the approximate location as the ears as viewed from the back (in a posterior-to-anterior direction).

Horizontal Plane

The *horizontal* plane is also called a *transverse* plane or *axial* plane. This plane divides the upper (superior or cranial) part of the body from the lower (inferior or

caudal) part of the body. Figure 1-4 shows an example of a horizontal MR image of the head located just below the ears.

TISSUE TYPES

The speech and hearing mechanisms are made up of cells. Cells, the basic living constituent of the human body, comprise a nucleus and the material that surrounds the nucleus, called the cytoplasm. The number

of cells in the human body continues to be debated, but it is undoubtedly on the order of the tens of trillions. Cells come in many forms and are made up of a multitude of components.

Groups of similar cells that work together to perform a particular function are called *tissues*. There are four types of tissues: *epithelial tissue*, *connective tissue*, *muscle tissue*, and *nerve tissue*. The first three of these are discussed below; nerve tissue is discussed in Chapter 8.

Epithelial Tissue

Epithelial tissue consists of layers of cells that cover external and internal surfaces of the body. For example, epithelial tissue makes up the superficial layer of the skin (external) on the face and lines the inside of the oral cavity (internal). Epithelial tissue serves to protect deeper layers of tissue and perform other functions depending on the specific type of epithelial tissue. There are many types of epithelial tissue; only two types will be described and illustrated here.

One type of epithelial tissue is called stratified squamous epithelium, an example of which is shown in Figure 1–5 (left side). This is the type of epithelium that covers the anterior part of the vocal folds (further discussed in Chapter 3). Another type is pseudostratified columnar epithelium, which consists of a single layer of cells, although it can appear as if there are multiple layers (thus, the reason for the prefix *pseudo* before stratified). The example shown in Figure 1–5 (right side) also contains hair-like projections called cilia. This is the type of epithelium that covers the upper respiratory airways; the cilia move mucous away from the respiratory airways toward the pharynx.

Connective Tissue

As with epithelial tissue, there are many types of connective tissue. They can be divided into two general categories: connective tissue proper and supportive connective tissue. Included under connective tissue proper are tendons, aponeuroses, and ligaments; included under supportive connective tissue are cartilage and bone. All of these are shown in Figure 1–6. Note that this figure does not depict an actual anatomical system but rather presents a generic set of structures that are typical of each of these types of connective tissue.

Those tissues that belong in the connective tissue proper category are made up of collagen fibers (tissue fibers that are not stretchable). These fibers are arranged in patterns that make them resistant to traction (pulling) forces. Tendons are dense bundles of fibers that attach muscles to bones. Aponeuroses (singular is aponeurosis) are like tendons, except that they are broad and flat. Ligaments, like tendons, comprise bundles of fibers, the difference being that they attach bones to cartilages and bones to bones.

Muscle Tissue

Muscle tissue is made up of long, thin cells. There are three types of muscle tissue: *smooth*, *cardiac*, and *skeletal*. Smooth muscle is found in blood vessels, the gastrointestinal (digestive) tract, the urinary bladder, and other body organs, and cardiac muscle is found only in the heart. Both smooth and cardiac muscle are considered to be under involuntary (unconscious) control. In contrast, skeletal muscle is under voluntary (conscious) control. Skeletal muscles are found throughout the

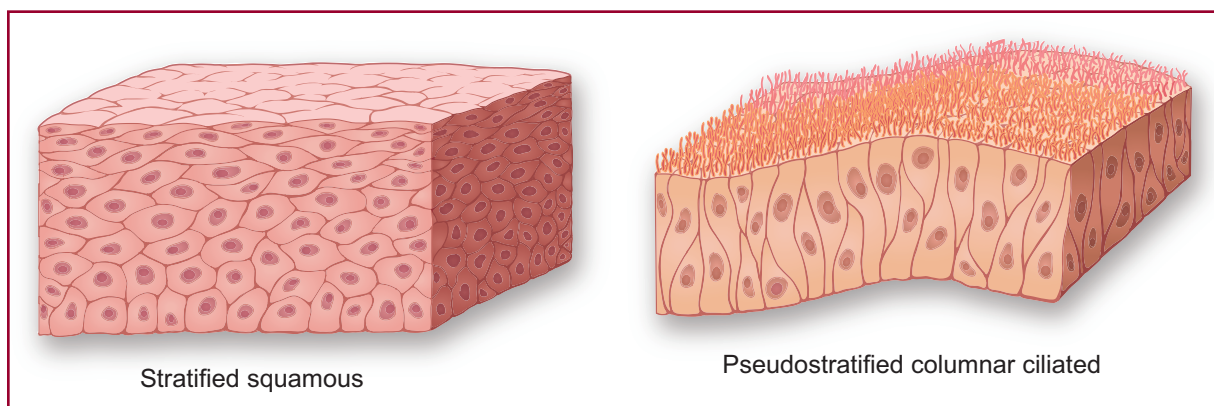


FIGURE 1-5. Example of stratified squamous epithelium (*left*) and pseudostratified columnar epithelium (*right*).