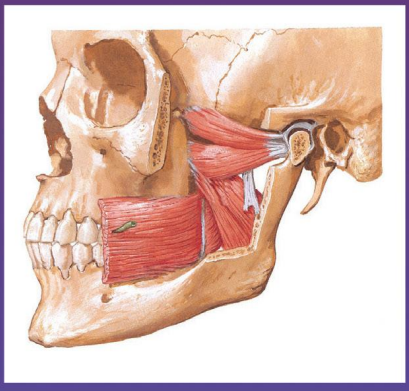
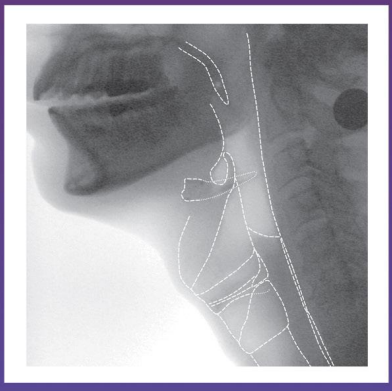
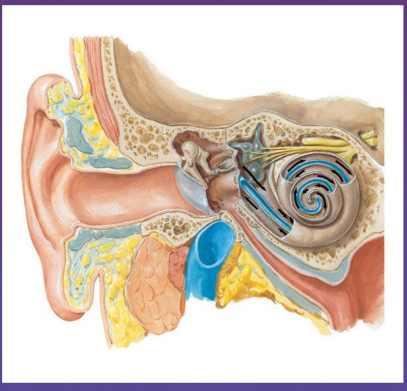
F. Netter M.D.

DAVID H. McFARLAND

NETTER'S ATLAS of ANATOMY for SPEECH, SWALLOWING, and HEARING







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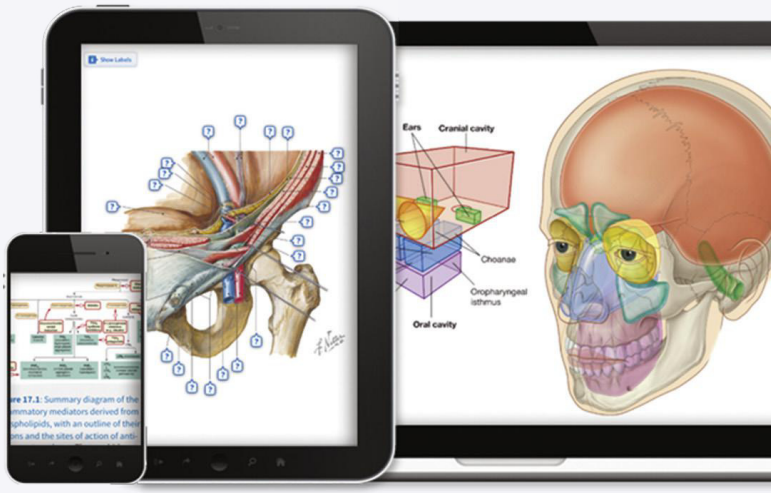

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NETTER'S ATLAS of ANATOMY for SPEECH, SWALLOWING, and HEARING

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NETTER'S ATLAS of ANATOMY for SPEECH, SWALLOWING, and HEARING

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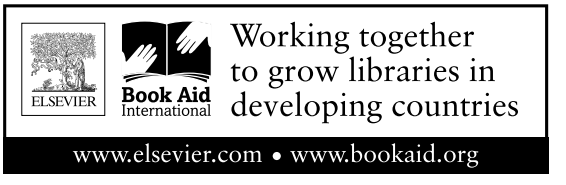

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PREFACE

Speech, swallowing, hearing, and balance are human behaviors that are vital to everyday life. Diagnosing and treating their disordered function requires a thorough understanding of the many body systems involved.

The purpose of this atlas is to provide readers with a comprehensive reference for the essential aspects of speech, swallowing, hearing, and vestibular anatomy. Key physiological and nervous system processes, which cannot be dissociated from anatomy, have also been summarized to deliver a more complete picture of these functions. This fourth edition was an opportunity to greatly expand content and create and include five more key anatomical illustrations.

AUDIENCE

This atlas is for anyone interested in the body systems involved in speech, swallowing, hearing, and balance, either for understanding normal processes or as a basis for clinical practice. It is specifically tailored for instructors and students in both undergraduate and graduate programs, in addition for researchers and clinicians in the fields of speech-language pathology, audiology, and related medical disciplines. My sincere ambition for this book is that it will serve as a useful learning tool for students and be a faithful reference for practitioners and researchers. I also hope that it will become a functional guide for clinicians who work with disorders of speech, swallowing, and hearing and used to educate patients suffering from these problems. Perhaps one day it may even become a platform for shared communication among the diverse professionals encountering the challenges of these complex disorders.

CONCEPT AND IMPORTANCE TO THE PROFESSION

The inaugural edition of this atlas was the first time that the medical illustrations of Frank Netter had been gathered into a volume dedicated to speech, swallowing, and hearing. These seminal illustrations were chosen in part because they are used extensively in other disciplines and thereby represent a common base of study and clinical reference for students, instructors, and professionals in these fields. The images also have garnered the favor of scholars and clinicians because they provide just the right level of detail and clearly convey the relationship among key anatomical structures. We have been fortunate in this fourth edition to be able to supplement and update some of the Netter illustrations and to create new images highlighting key aspects of structure and function.

ORGANIZATION

For the physiological component of the book, I adopted a targeted approach to provide essential information that is useful and appropriate for clinical practice. Clear parallels are made between the structure being referenced on the left page and the accompanying illustration on the right. Each section concludes with summary tables featuring key muscles or cranial nerves. Core physiological concepts were reviewed and greatly expanded upon in this fourth edition.

Ease of use was one of my main organizational objectives. Because education is one of the primary purposes of this work, the content reflects the way the anatomy and physiology of speech and swallowing are traditionally taught. It begins with a basic introduction to anatomy and moves on to a more detailed discussion of the three key systems involved in speech, voice, and swallowing—the respiratory, laryngeal-phonatory, and oropharyngeal-articulatory systems. It concludes by covering fundamental hearing, vestibular, and neurological systems.

DISTINCTIVE FEATURES

- *Full-Color Presentation:* This is the first and only atlas of anatomy specific to speech, swallowing, and hearing to include full-color Netter images, providing maximum detail and accuracy for students and clinicians.
- *Stellar Art Program:* The remarkable, time-honored, and detailed images of renowned illustrator Dr. Frank Netter take center stage in this atlas. Dr. Netter's artwork has been used for years to teach leading health care professionals and researchers. Images are presented from various orientations and levels of detail to ensure that readers gain the foundation they need to work with patients who have disorders of speech, swallowing, and hearing.
- *Atlas Format:* Information on targeted anatomical and related physiological mechanisms is found on the left page, with a corresponding image detailing the related anatomy on the right page. This "read-it, see-it" approach appeals to a wide variety of learning styles and makes it ideal for clinical reference.
- *Instruction-Based Organization:* The organization of the sections follows a logical order that is consistent with the way this content is taught in educational programs—an overview of anatomy followed by successive sections detailing the anatomy and related physiology of the respiratory, laryngeal-phonatory, oropharyngeal-articulatory, auditory and vestibulatory, and nervous systems—making it an ideal complement to any related courses.
- *Appropriate Depth of Coverage:* The text—often presented in a bulleted-list style for easy reference and comprehension—presents readers with the essential, need-to-know information relevant to speech, swallowing, and hearing and vestibular mechanisms. This unique and targeted approach provides just the right level of depth and detail to give the artwork proper context.
- *Summary Muscular Tables:* The chapters on the respiratory, laryngeal-phonatory, and oropharyngeal-articulatory systems conclude with tables detailing the relevant musculature of that body system, which include the origin, insertion, innervation, and action of each. The chapter on the nervous system concludes with a table detailing the cranial nerves most significant for speech, mastication/swallowing, and hearing/balance. These tables present vital information in a quick, easy, and consistent format ideal for study or quick reference.

ANCILLARIES

A companion Evolve website (http://evolve.elsevier.com/McFarland/Netter) has been developed to accompany this book with tools to enhance teaching for instructors and learning for students.

INSTRUCTOR RESOURCES

- *Test Bank:* Approximately 275 objective-style questions—multiple-choice, true/false, fill-in-the-blank, and matching—with accompanying rationales for correct answers and page-number or page-range references for remediation.

STUDENT RESOURCES

- *Self-Test Questions:* Approximately 150 objective-style questions—multiple-choice, true/false, fill-in-the-blank, and matching—are available for examination preparation and accompanied by instant feedback and remediation assistance.
- *Labeling Exercises:* Many of the book's illustrations have been turned into interactive exercises as a practice tool to help students master the relevant anatomy.

David H. McFarland

ACKNOWLEDGEMENTS

They say a picture is worth a thousand words. I decided to add words anyway to these classic anatomical images after my students told me that a tool like this would be invaluable to them in their training as speech-language pathologists.

It is hard to imagine that what started out as a simple teaching tool would now be a book in its fourth edition with versions in French, Spanish, Portuguese, Greek, and Chinese. This has been a remarkable journey and one that would not have been possible without the motivation of students past and present and of exceptional colleagues who have reviewed key sections of the book for accuracy, completeness, and clinical relevance.

This fourth edition includes additional key information on the auditory system, most notably the anatomy of the vestibular system. The oropharyngeal-articulatory system has been revised and expanded, and an overview of the procedures that make it possible to visualize vocal tract structures has been added. The chapter on the nervous system was increased to provide important additional details on motor pathways, spinal nerves, cerebral circulation, and the cortical innervation of cranial and spinal nerves. Five key medical illustrations were added, one illustrating the anatomy of the vestibular system; one to illustrate the sensory innervation of the larynx, pharynx, and the oral and nasal cavities; one to show the extensive anatomical overlap of the physiological systems involved in speech and swallowing; and one to illustrate the zone of apposition between the diaphragm and rib cage. A final addition is a static radiographic image of the head and neck to orient readers to those anatomical structures typically visualized in videofluoroscopic examinations of swallowing.

In addition to all of the persons who have contributed to past editions, I would like to thank Kate Davidson, Dr. Bonnie Martin-Harris, Dr. William Pearson, and Daniel Piché for the assistance in the creation of the illustration of the static radiographic image of the head and neck.

A very special thank you to Simone Poulin and Annie Joëlle Fortin for the invaluable support they gave to ensure that this fourth edition was of the highest quality.

Finally, I would like to thank my colleagues at Elsevier, as well as the students, clinicians, and faculty around the world who use this reference book for educational purposes or to support their clinical work with people with speech, voice, language, and swallowing disorders. I am very grateful for the trust you place in my book. It is an honor to guide you through the wonderful world of clinical speech-language pathology anatomy and physiology.

TABLE OF CONTENTS

INTRODUCTION

Speech differs from many other skilled human movements in that the goal is not to move the body or interact with an object, but to communicate. It has been estimated that we may produce up to 15 speech sounds per second, which may require the activity of approximately 100 muscles distributed across the different physiological systems involved in speech production, including the respiratory, laryngeal, and oral-articulatory systems. The use of these different systems makes speech production one of the most complex of all human skilled movements. The underlying neural control processes are similarly complex and involve several hierarchically organized cortical and subcortical structures interacting with sensory feedback from peripheral speech structures. As illustrated in Figure 1 [p. 2], swallowing uses many, if not all, of the same anatomical structures (and neural control processes) that are involved in speech production, but for different purposes. For example, the vocal folds, crucial for sound production for speech, are key elements in protecting the airway during swallowing. The oral articulators that shape the sound produced by the vibrating folds are used in the preparation and transportation of foods and liquids for swallowing. The pharynx, part of the vocal tract, moves the swallowed bolus toward the esophagus and stomach. Given this high degree of anatomical overlap, it is not surprising that disease or damage affecting speech may also affect swallowing.

The goal of this book is to summarize our current understanding of the anatomical basis of normal speech, voice, and swallowing function and to provide a platform for the diagnosis and treatment of disorders of these vital behaviors. This is combined with an introduction to hearing and vestibular functional anatomy. Physiology is briefly summarized because structure and function are intimately related and are only artificially separated in this book to simplify learning.

This book is organized around the pioneering medical illustrations of Frank M. Netter. Anatomical descriptions are presented with specific reference to these classic illustrations, and the relevant structures are highlighted. Understanding anatomy requires a visual representation of structure from various orientations, and Netter's figures provide this thorough perspective. Summary tables of muscle origin, insertion, innervation, and function are provided throughout. Figures from other talented illustrators have been added throughout the different editions of this book to highlight key structure and function. In this edition, we have added our original figures to orient the learner to understanding the anatomical structures observable in a videofluoroscopic assessment of swallowing.

We begin with an overview of anatomical classification systems, a summary of anatomical nomenclature, a list of the terms used to describe direction and movement, and a description of the different types of anatomical tissues. We continue with descriptions of the respiratory, laryngeal, and oropharyngeal structures and end with hearing anatomy and key neurological systems involved in the control and coordination of speech and swallowing movements.

The study of anatomy is one of the oldest medical sciences, and its origins can be traced back to at least the early Greeks. You are embarking on this grand and noble tradition in the study of human anatomical principles.

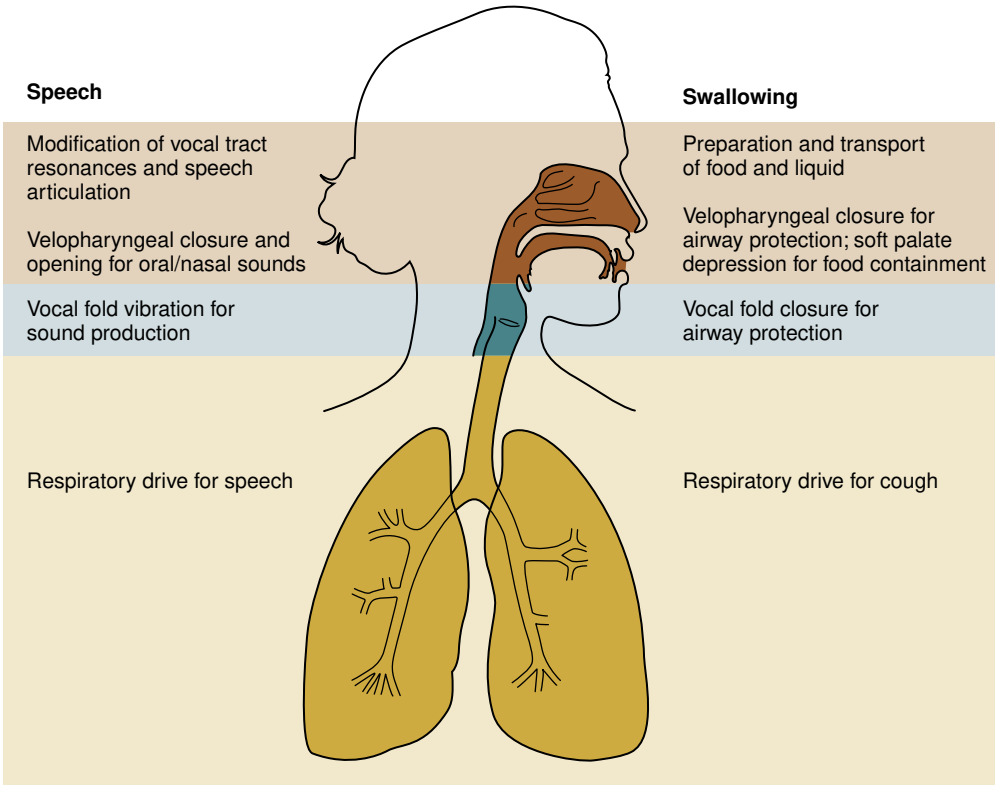


Figure 1 Shared anatomical structures involved in speech and swallowing.

ANATOMY

There are many ways of classifying and consequently studying anatomy. Some of these are described in the next sections. This book uses many of these methods to cover the following aspects of anatomy in relation to speech, swallowing, and hearing:

- The normal structure of organs and systems
- The topographical or anatomical relationships between structures
- The function of anatomical structures
- The development of anatomical structures and systems
- The neurological aspects of a structure's normal function
- Certain clinical aspects of disordered function

Systemic Anatomy

Systemic anatomy classifies the body by biological systems and subsystems. The major systems include the integumentary system, the skeletal system, the muscular system, the articular system, the nervous system, the circulatory system, the respiratory system, the digestive system, the urinary system, the reproductive system, and the endocrine system.

Regional Anatomy

Regional anatomy emphasizes the different regions or divisions of the body and the relationship between the anatomical structures of those divisions. The typical regions are as follows:

- Head and neck
- Back
- Thorax
- Abdomen
- Pelvis and perineum
- Upper limb
- Lower limb

Developmental Anatomy

Developmental anatomy concerns the prenatal and postnatal development of anatomical structures.

Functional Anatomy

Functional anatomy classifies the relationship between a structure and its function, combining anatomy and physiology.

Clinical Anatomy

Clinical anatomy emphasizes the relationship between anatomy and medical or other clinical practice.

NOMENCLATURE

Before beginning to discuss the human body, it is important to know the terms most frequently used by anatomists to describe a structure and its location. These terms greatly facilitate the understanding and study of anatomy.

Anatomical Position (Figure 2)

All structures are described in relationship to a standard position, which is called the *anatomical position.* In *humans,* the anatomical position is standing, facing the observer, arms along the body, palms turned forward, legs together or slightly separated, and feet straight ahead.

Because most nonhuman animals are on all fours, their anatomical position and terms of direction are different from those of humans. This should be kept in mind when comparing nonhuman with human anatomy.

PLANES AND SECTIONS

Anatomical planes divide the body into different sections and are used to describe structures and anatomical movements. To visualize these different planes, we will ask you to imagine a sheet of paper that "cuts" the body into different sections. Following is a description of the three main anatomical reference planes (see Figure 2).

Sagittal

The sagittal plane is a longitudinal plane that is parallel to the sagittal suture of the skull. To visualize this plane, imagine the sheet of paper aligned vertically between your eyes. All sagittal planes are parallel to this sheet. The *median* or *midsagittal* plane is the sagittal plane that divides the body into two equal left and right halves. All other sagittal planes or sections are termed *parasagittal,* or just *sagittal.*

Frontal or Coronal

The frontal, or coronal, plane is a longitudinal plane that crosses the sagittal plane at a right angle. To visualize this plane, imagine holding the sheet of paper directly in front of you and parallel to the coronal or frontal suture of the cranium. All frontal planes will be parallel to this sheet. Coronal planes divide the body front to back (anteriorly to posteriorly). The terms *midfrontal* or *midcoronal* are sometimes used to designate the plane that divides the body into equal anterior and posterior halves.

Transverse or Horizontal

The transverse, or horizontal, plane divides the body or structure into superior/inferior portions. To visualize this plane, imagine the sheet of paper placed horizontally in front of your face that divides your head into upper and lower halves. All transverse planes are parallel to this sheet. The term *midtransverse* is used to designate the plane dividing the body into two equal superior and inferior halves.

NOTE: An oblique plane is oriented obliquely between one of the planes described here.

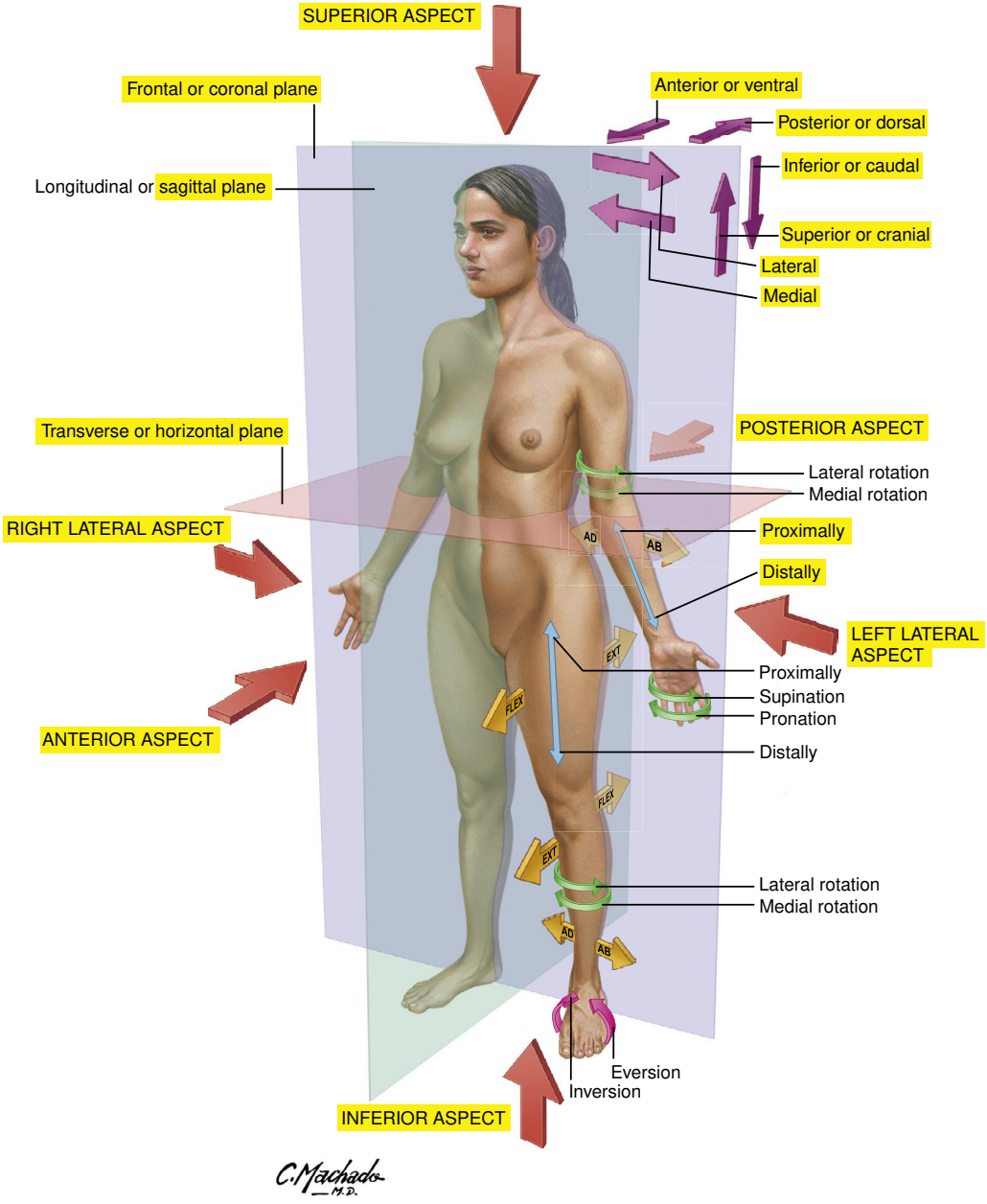


Figure 2 Anatomical position, terms of relationships, and body planes.

NOTE: Labels of certain figures are highlighted in yellow to emphasize the related elements in the corresponding text.

ANATOMICAL TERMS

Directional terms are used to locate anatomical structures and to explain the spatial relationship between structures relative to the anatomical position. They are presented in contrasting pairs (see Figure 2 [p. 5] – refer to the purple and blue arrows).

Superior and Inferior

- Superior (rostral, cranial) is toward the upper portion or located above a structure of the body.
- Inferior (caudal) is toward the lower portion or below a structure of the body.

Anterior and Posterior

- Anterior (ventral) is toward the front or in front of a structure of the body.
- Posterior (dorsal) is toward the back or behind a structure of the body.

Medial, Lateral, and Median

- Medial is toward the midline, or central axis, of the body.
- Lateral is away from the central axis, or midline, of the body.
- Median is on the central sagittal plane.

Proximal and Distal

- Proximal is toward the origin of a structure of the body.
- Distal is away from the origin of a structure of the body. Proximal and distal are often used to describe the limbs.

External, Internal, and Intermediate

- External (superficial) is toward the surface of a structure of the body.
- Internal (deep) is away from the surface of a structure of the body.
- Intermediate (middle) is between internal and external.

These terms are often used to describe anatomical relationships between structures, such as one structure being deep to or superficial to another.

Parietal and Visceral (see Figure 6 [p. 11])

- Parietal is the outer layer or covering of a body cavity.
- Visceral is the inner layer of a cavity wrapped around body organs.

Prone and Supine

- Prone is the anatomical position of the body with the face and ventral surface of the body facing down.
- Supine is the anatomical position of the body with the face and ventral surface of the body facing up.

Ipsilateral, Contralateral, and Bilateral

- Ipsilateral refers to the same side of the body.
- Contralateral refers to the opposite side of the body.
- Bilateral refers to both sides of the body.

Note that the terms ipsilateral, contralateral, and bilateral are commonly used in reference to the innervation of a structure. Innervation is the supply or distribution of motor and/or sensory nerves to or from an organ, muscle, or gland.

VIEWS, ASPECTS, AND SURFACES

Anatomy requires the visualization of structures from different perspectives. The terms *view, aspect,* and *surface* are used to describe these orientations. A view describes how we are oriented to observe the body or a structure (see Figure 2 [p. 5] – refer to the red arrows):

- A superior view is when the observer is positioned above a structure, whereas an inferior view is when the observer is positioned below a structure (see Figure 3 [p. 8]).
- An anterior view is when the observer is positioned in the front of a structure, whereas a posterior view is when the observer is positioned behind a structure (see Figures 4 [p. 9] and 6 [p. 11]).
- A lateral view is when the observer is positioned farther from the median plane of the body (see "Sagittal," p. 4), whereas a medial view is when the observer is positioned directly on the median plane (see Figures 4 [p. 9] and 5 [p. 10]).

Surface refers to the outside/uppermost layers of an anatomical structure (e.g., see the anterior surface of the lungs in Figure 6 [p. 11]). Aspect refers to that part of an anatomical structure viewed from a particular direction (see the lateral aspect of the skull in a lateral view, as shown in Figure 5 [p. 10]).

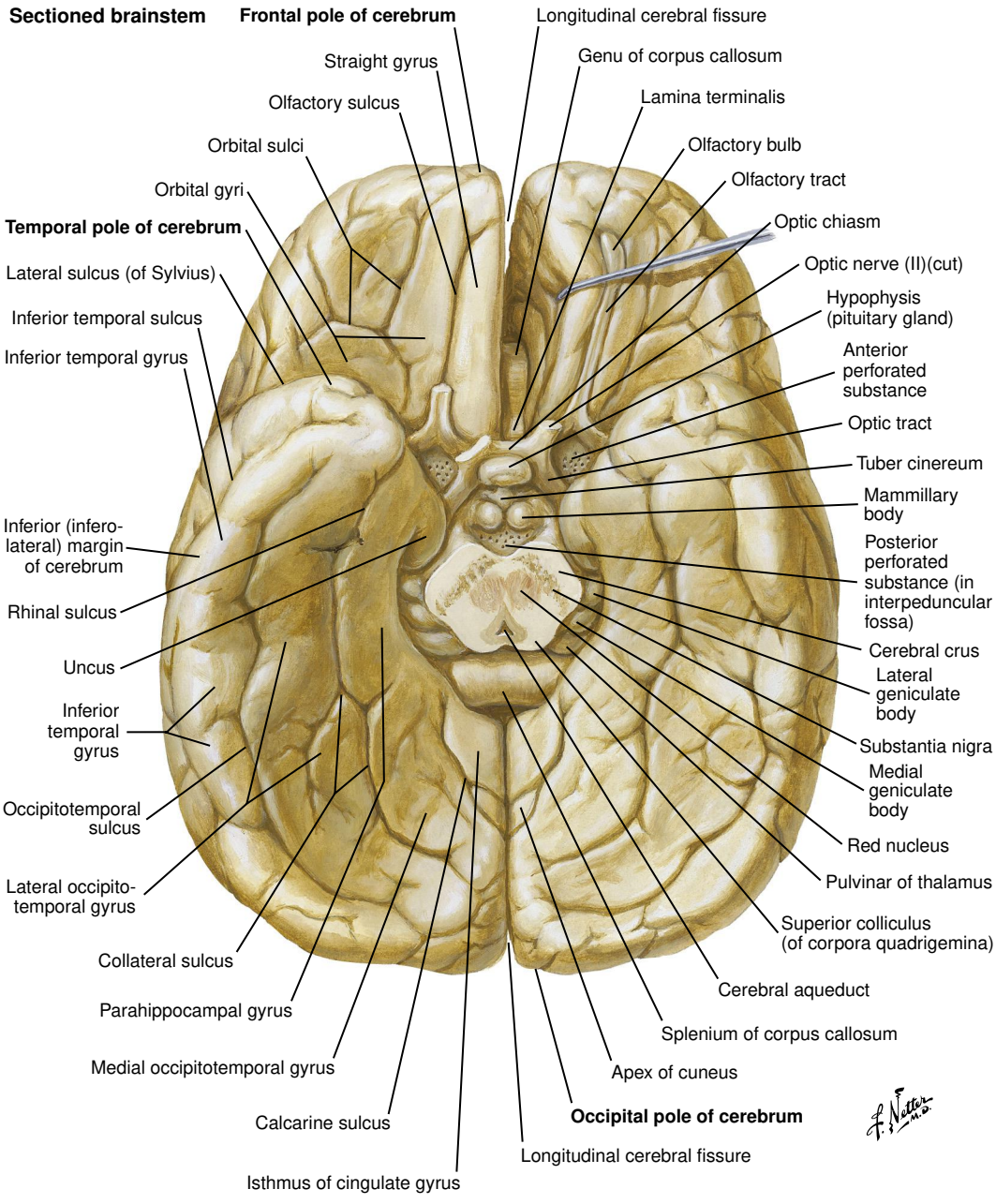


Figure 3 Inferior view of the cerebrum.

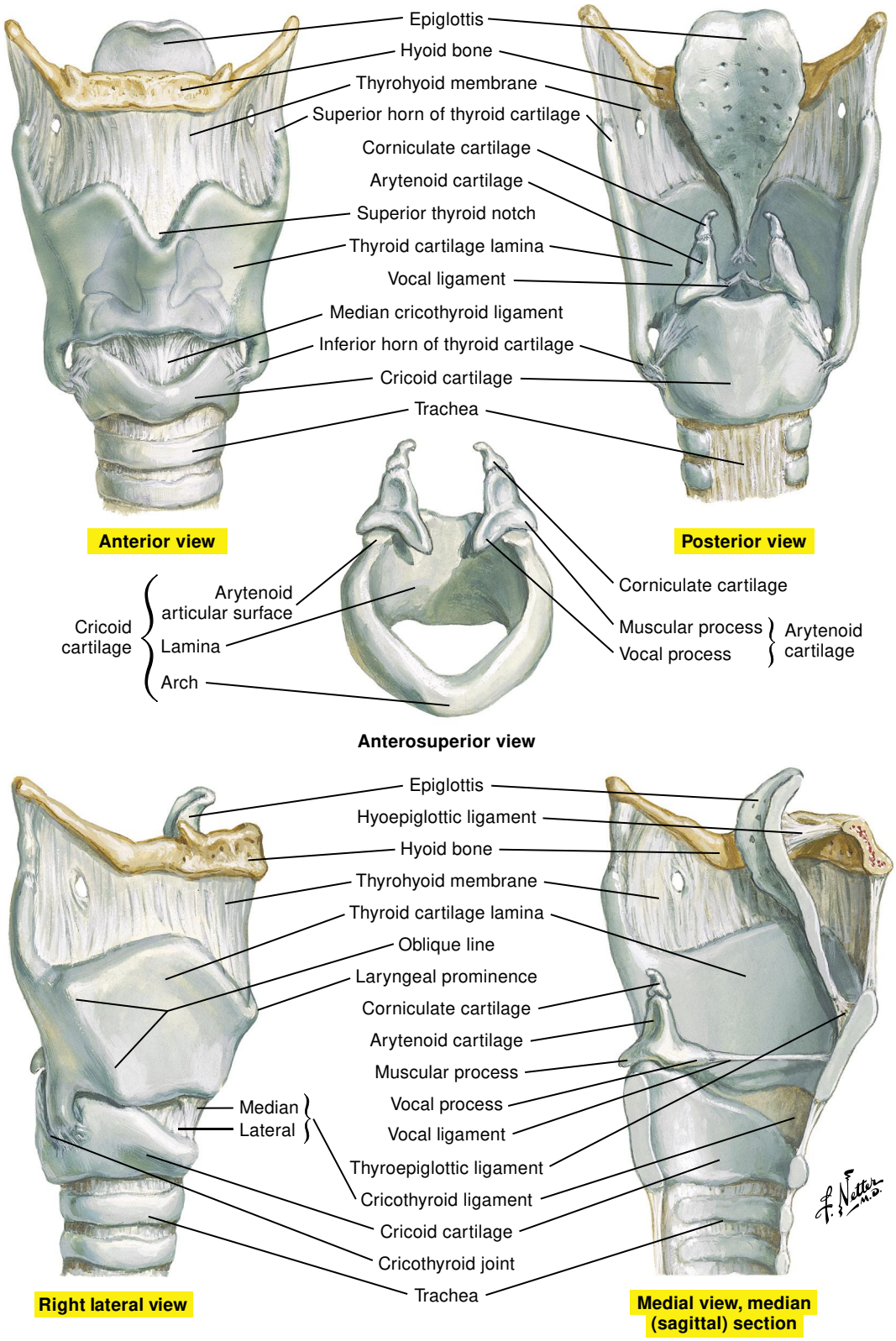
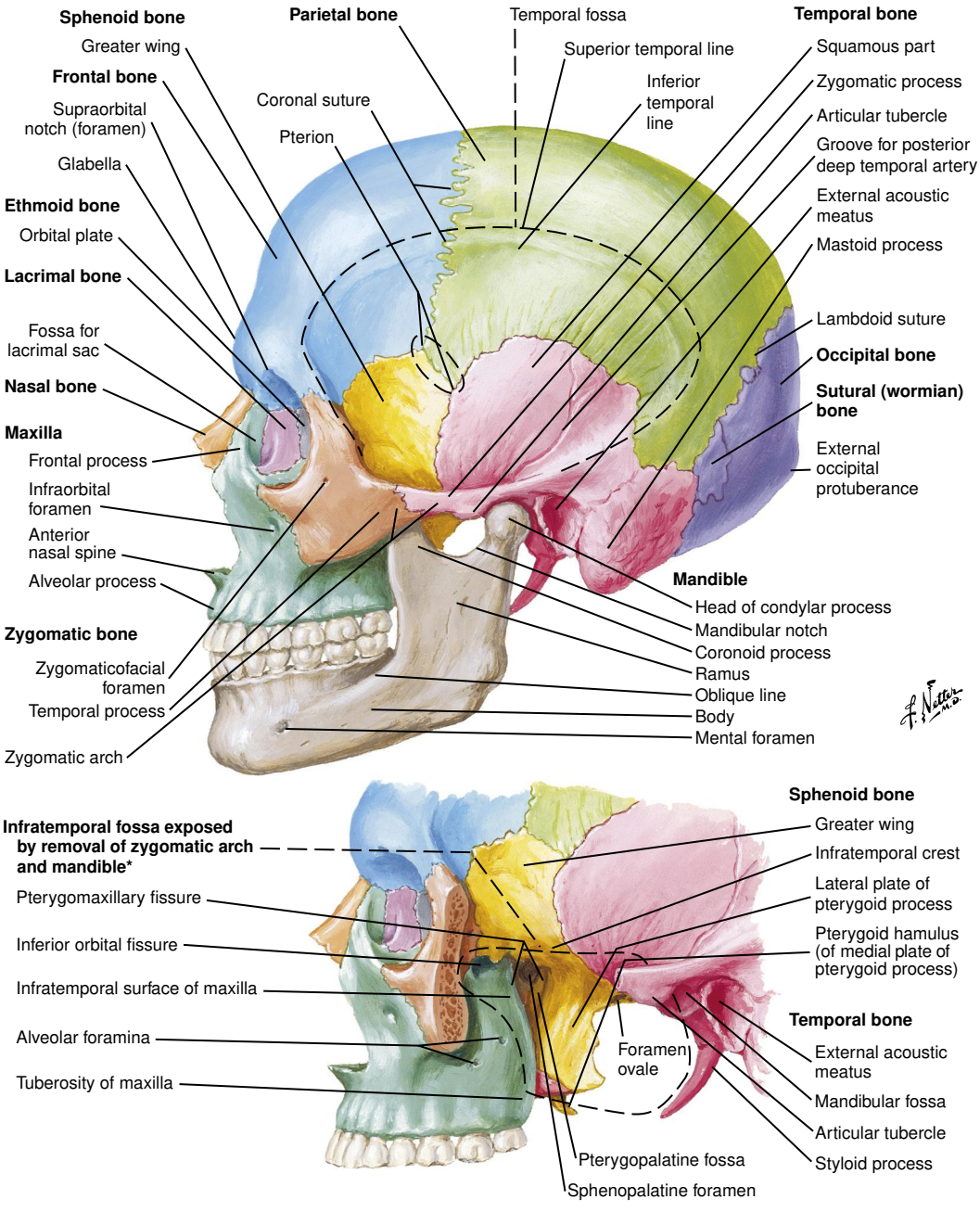


Figure 4 Anterior, posterior, lateral, and medial views of the cartilages of the larynx.



*Superficially, mastoid process forms posterior boundary.

Figure 5 Lateral view of the skull.

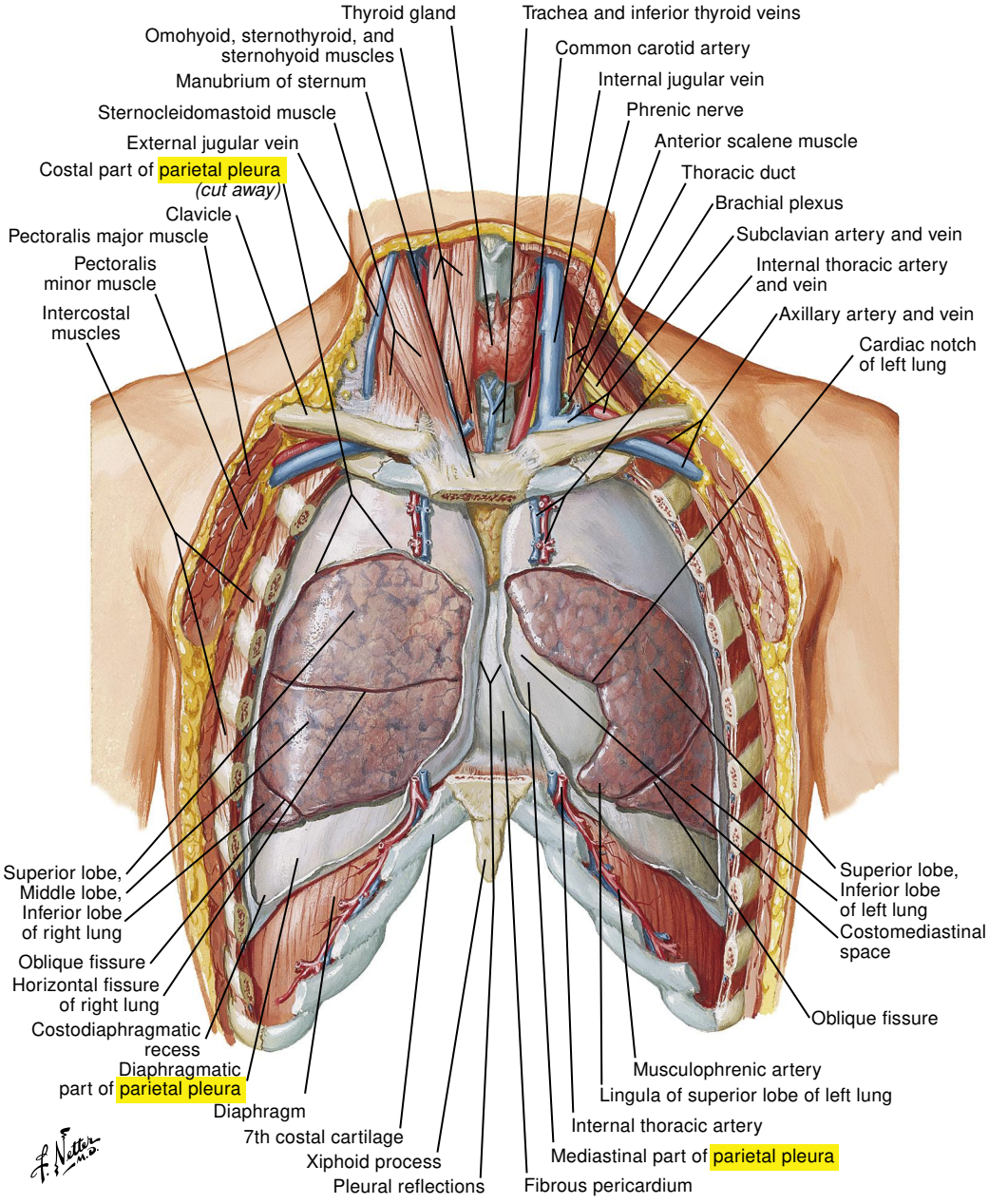


Figure 6 Anterior view of the lungs in situ. Note the parietal pleura.

ANATOMICAL MOVEMENT

As with terms of direction, anatomical movements are usually described in contrasting pairs. Each pair is detailed in the following sections (see Figure 2 [p. 5]).

Flexion and Extension

- Flexion is the movement around a joint that brings two adjacent bones or body segments closer together, reducing the angle of articulation.
- Extension is the movement around a joint that brings two adjacent bones or body segments farther apart, increasing the angle of articulation.

Abduction and Adduction

- Abduction is the movement of a structure away from the midline.
- Adduction is the movement of a structure toward the midline.

Elevation and Depression

- Elevation is the upward movement of a structure.
- Depression is the downward movement of a structure.

Protrusion and Retrusion

- Protrusion (protraction) is the forward movement of a structure.
- Retrusion (retraction) is the backward movement of a structure.

Supination and Pronation

Supination and pronation refer to rotational movements of certain structures such as the arm and hand:

- Supination refers to the rotation of the arm and hand so that the palm is facing anteriorly (with arm straight) or upward (with arm bent).
- Pronation refers to the rotation of the arm and hand so that the palm is facing posteriorly (with arm straight) or downward (with arm bent).

VOCABULARY SPECIFIC TO ANATOMY

Many structures are named according to either their anatomical location on the body (e.g., external intercostal muscles, supraglottic, and so on) or their function (e.g., levator scapulae muscle, depressor anguli oris muscle, and so on). In addition to their anatomical name, other structures have names originating from mythology (e.g., Achilles tendon) or from the first person who associated the structure with a disease or a malformation or the first person who described the structure (e.g., circle of Willis).

Names of muscles and ligaments may also correspond to their points of attachment, as follows:

- Origin corresponds to the point of attachment of a muscle that remains relatively fixed during muscular contraction.
- Insertion corresponds to the more mobile point of attachment.

In general, the origin is named first and the insertion second. Sometimes, origin and insertion can be interchanged (insertion first and origin second) if both are considered of equal mobility. Muscle names may also provide information about the form of the muscle, such as the number of bellies or portions of the muscle (e.g., *di*gastric, or two bellies), its overall shape or location (e.g., *external* intercostals), or its action (e.g., *tensor* veli palatini).

PRIMARY TISSUES

Tissues are groups of cells with similar structure that perform a common function. The four primary tissue groups are as follows:

1. Epithelial
2. Connective
3. Muscular
4. Nervous

Epithelial Tissue (Epithelium, Epithelia)

Epithelia cover surfaces of the body and the body cavities of different systems (respiratory, digestive, cardiac, and vascular systems). This group of tissue performs the following functions:

- Protection
- Absorption and filtration
- Excretion and secretion
- Sensation

Connective Tissue

Connective tissue is a key component (with muscles and the skeleton) of the musculoskeletal system. It is widespread in the human body, and its principal functions are as follows:

- Fixation and support
- Protection
- Energy reserve
- Transportation of fluids and other substances

Connective tissue can be solid, liquid, or gelatinous and can be classified in several different ways. Connective tissues are generally divided into two main categories: (1) connective tissues proper and (2) specialized connective tissues.

Connective Tissues Proper

This type of connective tissue includes different subcategories depending on the type, amount and arrangement of the cells, fibers, and extracellular matrix that compose them. The following classification is presented, but there are several other ways to group the different subcategories. It should also be noted that types of tissue are more of a continuum than discrete entities.

Loose

- **Areolar** connective tissue is a supple and gelatinous tissue formed of collagen and elastin fibers that surrounds and forms a cushion for organs and other body structures.
- **Adipose** connective tissue is composed of adipose cells and stores fat, protects and supports certain organs, and acts as an insulator.
- **Reticular** connective tissue is similar to areolar tissue and is composed only of reticular fibers. It forms the stroma, which has a supporting function in lymphoid and hematopoietic organs (e.g., lymph nodes and bone marrow).

Dense

- **Dense regular** connective tissue is composed primarily of collagen fibers and some elastic fibers that follow a parallel orientation. It interconnects and supports body structures. Collagen fibers are quite stiff relative to elastic fibers and take longer to recover from deformation (like stretch). Tendons, ligaments, fascia, and aponeuroses are composed of dense regular connective tissue.
- **Dense irregular** connective tissue is principally composed of collagen fibers with no specific orientation and few elastic fibers. Its function is to reinforce and protect. Dense irregular connective tissue is found in the deep fascia of the body, the joint capsules, and the dermis (skin).
- **Elastic** connective tissue has a high concentration of elastic fibers (elastin and others), which confer flexibility and resistance. Such tissues are found in the bronchial tree and larynx, including the vocal ligament of the vocal folds.

Specialized Connective Tissues

The following types of connective tissue are categorized separately, as their structure and function are highly specialized.

Cartilage

- **Hyaline** cartilage is the most common cartilage. It contains collagen fibers and provides strength and flexibility. Some examples are costal, nasal, tracheal, and most laryngeal cartilages.
- **Elastic** cartilage is similar to hyaline cartilage but contains more elastic fibers and is thus more flexible. Some examples are the external ear, pharyngotympanic tube, epiglottis, and cuneiform and corniculate cartilages.
- **Fibrocartilage** is composed of dense collagen fibers and provides strength and shock absorption. Examples are the intervertebral discs and pubic symphysis.

More detail is provided on the following types of connective tissues that appear frequently in the atlas:

- **Membranes** are layers of epithelial and/or connective tissue that cover and protect body cavities and other surfaces. There are four types of membranes: mucous, serous, synovial, and cutaneous.
- **Tendons** are strong bands of dense regular connective tissue that connect skeletal muscle to bone. Tendons are flexible but resist extension (stretch). They are supplied with important sensory nerve endings: the Golgi tendon organs.
- **Aponeuroses** are broad tendinous-like sheets that cover muscle or are the points of origin or insertion of skeletal muscle.
- **Ligaments** are strong bands of dense regular connective tissue that connect bone to bone, cartilage to cartilage, and cartilage to bone. Ligaments are slightly elastic ("stretchy") and lengthen under tension.
- **Fascia** is connective tissue that covers and groups anatomical structures (muscles and organs) and also serves as a point of attachment of some muscles.

Osseous Tissue

Osseous tissue is hard and rigid tissue that is composed of collagen fibers and minerals. Bones produce red and white blood cells, store minerals, support the body, protect vital organs, and provide skeletal support for movement. They also serve a sound transmission role in bone-conducted hearing.

Blood

Although a fluid, blood is classified as a specialized connective tissue. It is composed of red blood cells, white blood cells, and platelets suspended in plasma. It transports respiratory gases, nutrients, and other substances crucial for normal body functions.

Muscular Tissue

- **Skeletal** muscles are composed of striated muscle fibers and are involved in the production of movements.
- **Cardiac** muscles are composed of striated cells and have involuntary control of the heart.
- **Smooth** muscles are composed of nonstriated cells and are involved in the involuntary control of body organs.

Nervous Tissue

The nervous system is composed of the following types of nervous tissue:

- Neurons are specialized cells that conduct nerve impulses.
- Glial cells are nonconducting cells that support, insulate, and protect neurons.

TERMS RELATIVE TO BONES

Terms relative to bones are classified into the following categories:

1. Depressions
2. Elevations

Depressions

- A fissure is a cleft.
- A foramen is a natural opening (Figures 7 and 8 [p. 18]).
- A fossa is a depression (see Figure 8 [p. 18]).
- A groove is a furrow (see Figure 8 [p. 18]).
- A meatus is a passageway (see Figures 8 [p. 18] and 9 [p. 19]).
- A sinus is a cavity (see Figure 9 [p. 19]).

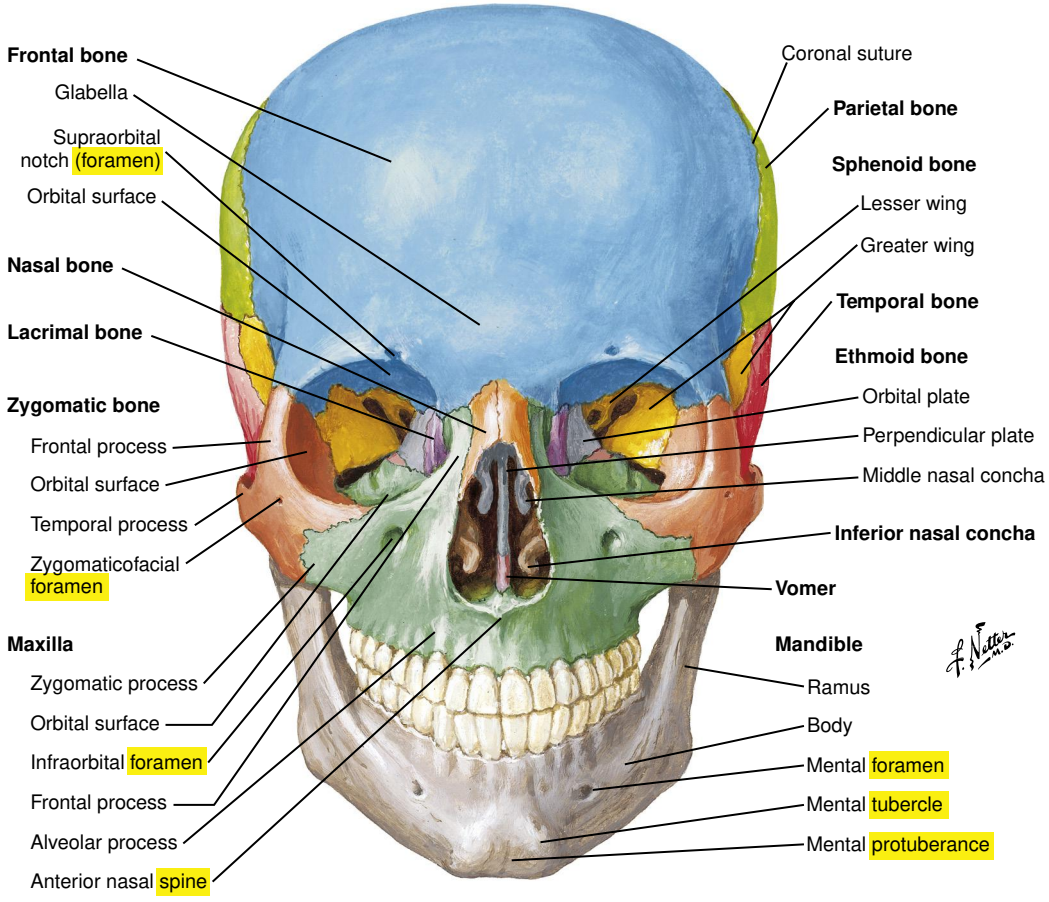


Figure 7 Anterior view of the skull, showing examples of the foramen, tubercle, spine, and protuberance.

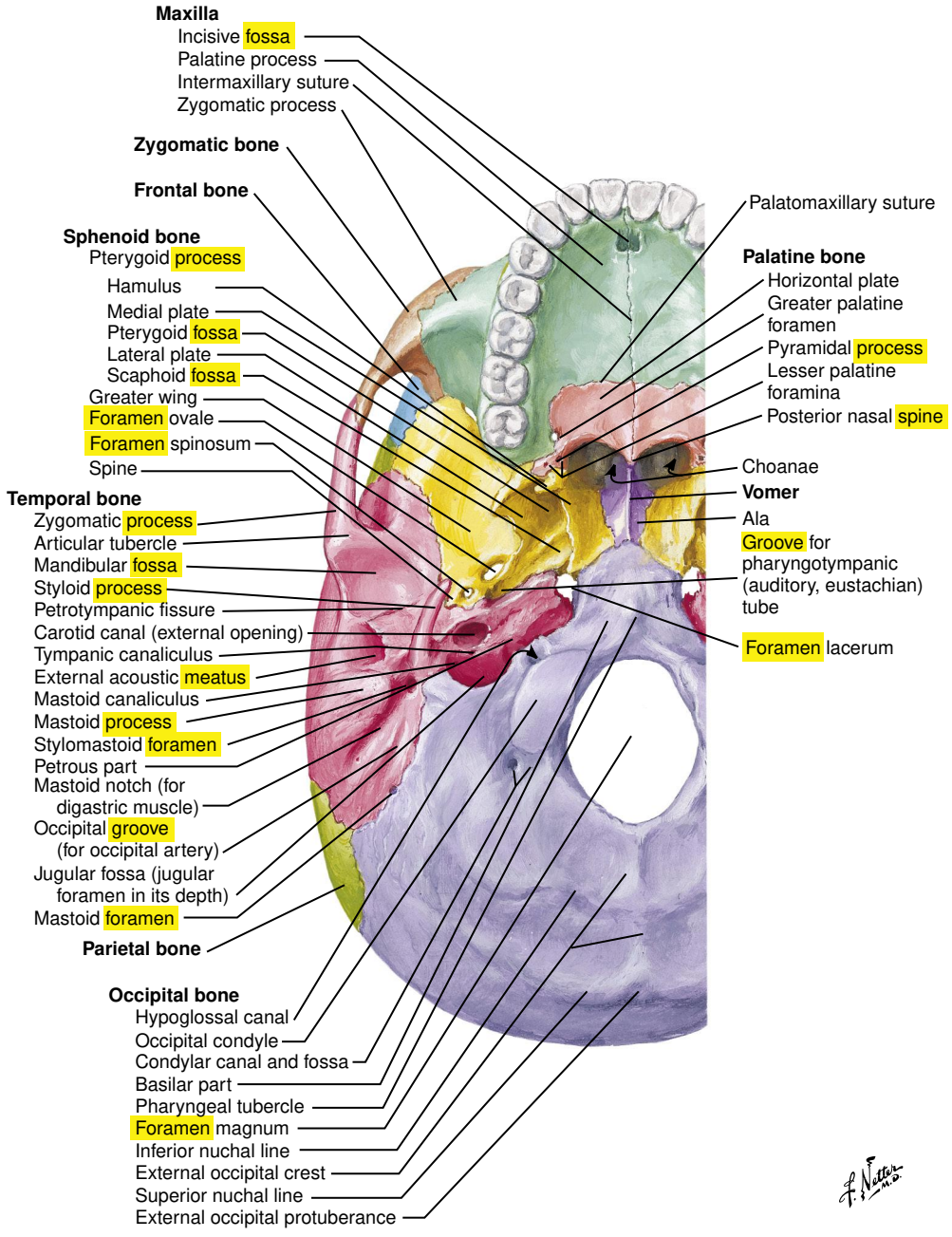


Figure 8 Inferior view of the cranial base. Note the fossa, foramen, meatus, groove, spine, tubercule, and process.

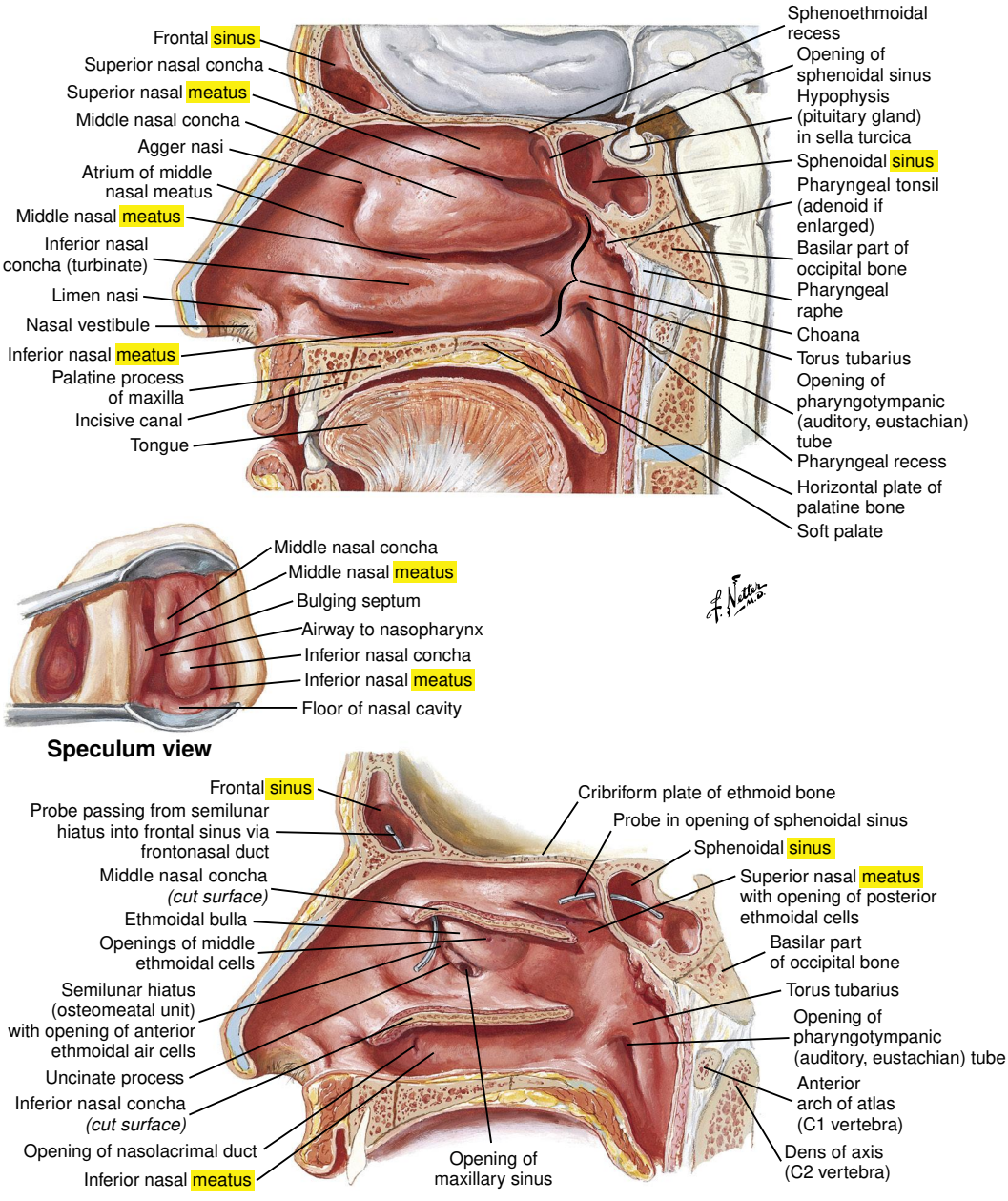


Figure 9 Lateral wall of the nasal cavity showing examples of a sinus and meatus.

Elevations

- A condyle is a rounded point of articulation (Figure 10).
- A crest is a ridge (Figure 10).
- A head is an enlargement of the extremity of a bone (Figure 10).
- A process is a prominence or extension (see Figure 8 [p. 18]).
- A protuberance is a projection beyond the surface.
- A spine is a spike-shaped projection.
- A tubercle is a small, rounded protuberance (Figure 10; see also Figure 7 [p. 17]).
- A tuberosity is a larger, rounded protuberance (Figure 10).

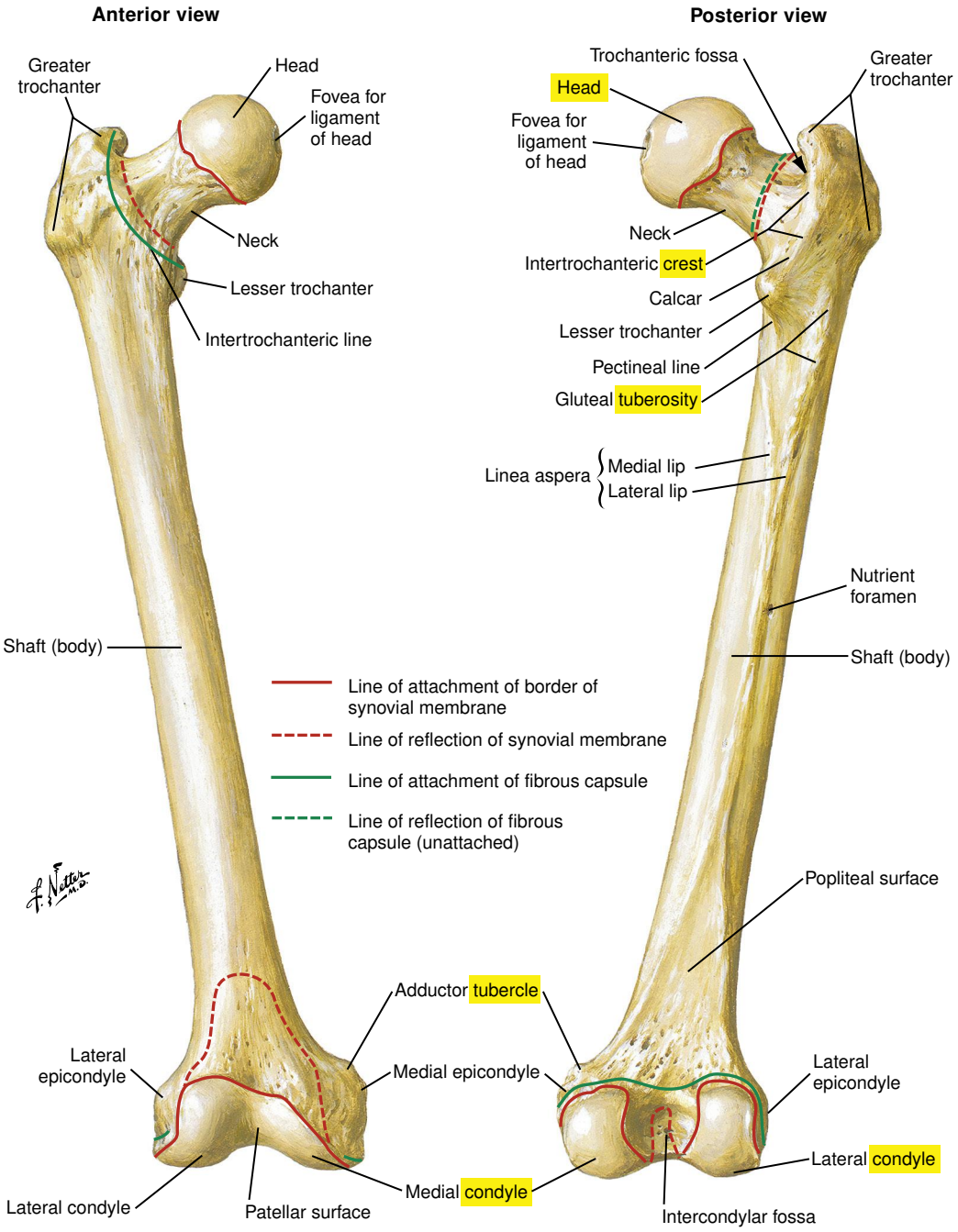


Figure 10 Anterior and posterior views of the femur. Note the condyle, crest, head, tubercle, and tuberosity.

RESPIRATORY SYSTEM

1

OVERVIEW

The respiratory system is vital for the elimination of carbon dioxide and the absorption of oxygen. Superimposed on this primary biological function is the use of the respiratory system for speech production. The respiratory system is the source of energy for vocal fold vibration and consonant production by the oral articulators. Breathing and swallowing must be well coordinated to protect the airways, and the respiratory system is also involved in airway-protective functions, such as cough.

For speech production, the pressure beneath the closed vocal folds (subglottal pressure) must be maintained within a relatively narrow range. The maintenance of a relatively constant subglottal pressure requires a complex interaction between the forces generated by the passive mechanical properties of the lungs and thorax and those generated by active muscular contraction. Even though subglottal pressure is maintained relatively constant for vocal fold vibration, it is possible to modulate this pressure up or down for changes in loudness (intensity).

Speech is produced within a relatively small range of vital capacity. During speech, inspirations usually terminate at lung volumes slightly higher than those associated with quiet breathing, and they are rapid to avoid interruptions to the flow of speech. Expirations are prolonged compared with those during quiet breathing, and because we speak during the expiratory phase, their duration, and whether they go to lung volumes below the resting expiratory level (lung volume at the end of expiration during quiet breathing), is influenced by communication demands.

Swallowing requires precise coordination with respiratory processes to ensure adequate airway protection during the passage of food and fluids, including saliva. The airways need to be protected during swallowing because the food or liquid bolus and air share a common passageway. Effective coordination helps prevent aspirations that occur when a portion of food, liquid, or saliva enters the lower respiratory tract. Airway-protective mechanisms during swallowing include vocal fold closure, anterior-superior displacement of the larynx, velopharyngeal closure, and respiratory inhibition. Swallowing typically begins in the mid to late expiratory phase of quiet breathing. This coordination is optimal for swallowing efficiency and airway protection. Cough, which is important for airway protection, involves high expiratory forces and sufficient air flow to clear the airways.

The respiratory system is the topic of Part 1, beginning with a brief overview of the skeletal support for respiration and then addressing the lungs and associated respiratory structures. Finally, respiratory muscles and their functions are reviewed.

SKELETAL SUPPORT FOR RESPIRATION

Skeletal support for respiration is composed of the following elements (see Figures 1.3 [p. 31] and 1.4 [p. 33]):

- Posteriorly by the vertebral column
- Anteriorly by the sternum and cartilages
- Laterally by the ribs
- Superiorly by the scapular girdle
- Inferiorly by the pelvic girdle

Vertebral Column (Figure 1.1)

The vertebral column contains 32 to 33 vertebrae that are numbered superiorly to inferiorly in 5 regions, as follows:

- 7 cervical vertebrae
- 12 thoracic vertebrae (that articulate with 12 ribs)
- 5 lumbar vertebrae
- 5 sacral vertebrae
- 3 to 4 coccygeal vertebrae

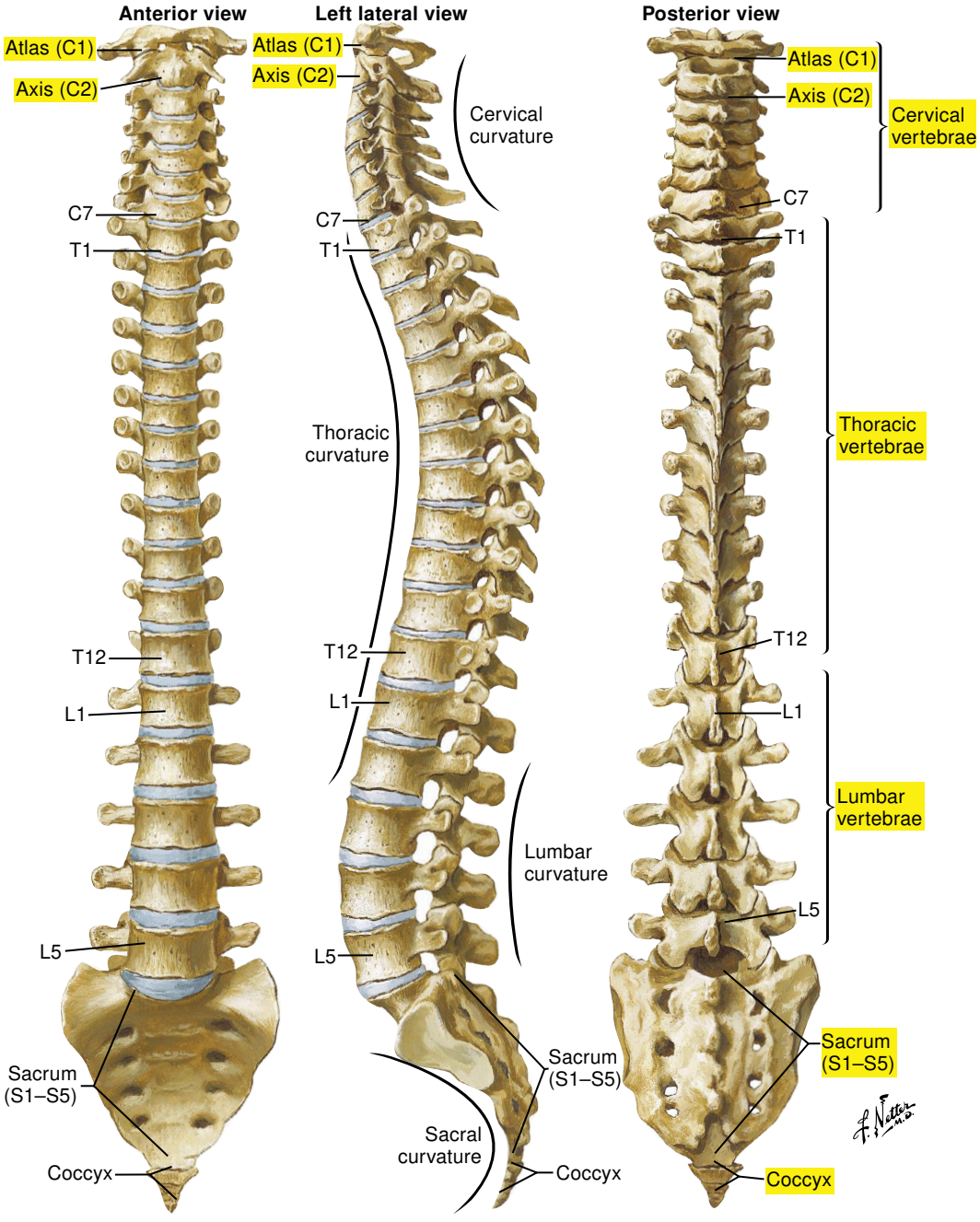


Figure 1.1. The vertebral column.

Note: Labels of certain figures are highlighted in yellow to emphasize the related elements in the corresponding text.

A *typical thoracic* vertebra contains the following elements (Figure 1.2):

- A vertebral body with two superior and two inferior costal facets that articulate with the head of the ribs above and below each vertebra (to *articulate* means to "come closer and form a junction").
- A vertebral foramen (canal for the spinal cord).
- Two superior and two inferior articular processes and facets where adjacent vertebrae articulate.
- Two transverse processes projecting laterally with transverse costal facets at their extremities, which articulate with the tubercle of the ribs. Transverse processes of thoracic vertebrae are points of attachment of several deep back muscles and ligaments.
- A spinous process projecting posteriorly and slightly downwards that provides a point attachment of deep and superficial muscles and ligaments of the back.

Refer to Figure 1.1 (p. 27) to see the following:

- Note the change in the form of the vertebrae. Inferior vertebrae are more massive to support more weight.
- The vertebral column contains four curves (cervical, thoracic, lumbar, and sacral). These curves give a double S shape to the vertebral column and increase its strength and flexibility to support body weight and movement.
- Two cervical vertebrae have anatomical and functional characteristics that are different from the other vertebrae. The first cervical vertebra (C1), or atlas (after Greek mythology), has no body or spinous process, supports the head, and allows for head rotation and other movements. The second cervical vertebra (C2), or axis, has an odontoid (meaning toothlike) process that serves as a pivot point for head rotation.
- The seventh cervical vertebra (C7) has a long spinous process that is often easy to locate and palpate on the skin's surface.
- Sacral vertebrae are normally fused in the adult. They reinforce and stabilize the pelvis and form the sacrum.
- Coccygeal vertebrae are also fused and form a small triangular bone, the coccyx.
- Intervertebral discs of fibrocartilage lie between adjacent vertebrae, except for between the atlas and axis and between adjacent sacral and coccygeal vertebrae (which are fused). There is a large intervertebral disc between the last lumbar (L5) and first sacral (S1) vertebrae (the lumbosacral joint) and a small, atypical disc between the last sacral (S5) and first coccygeal (Co1) vertebrae (the sacrococcygeal joint). Discs provide for movement and shock absorption.

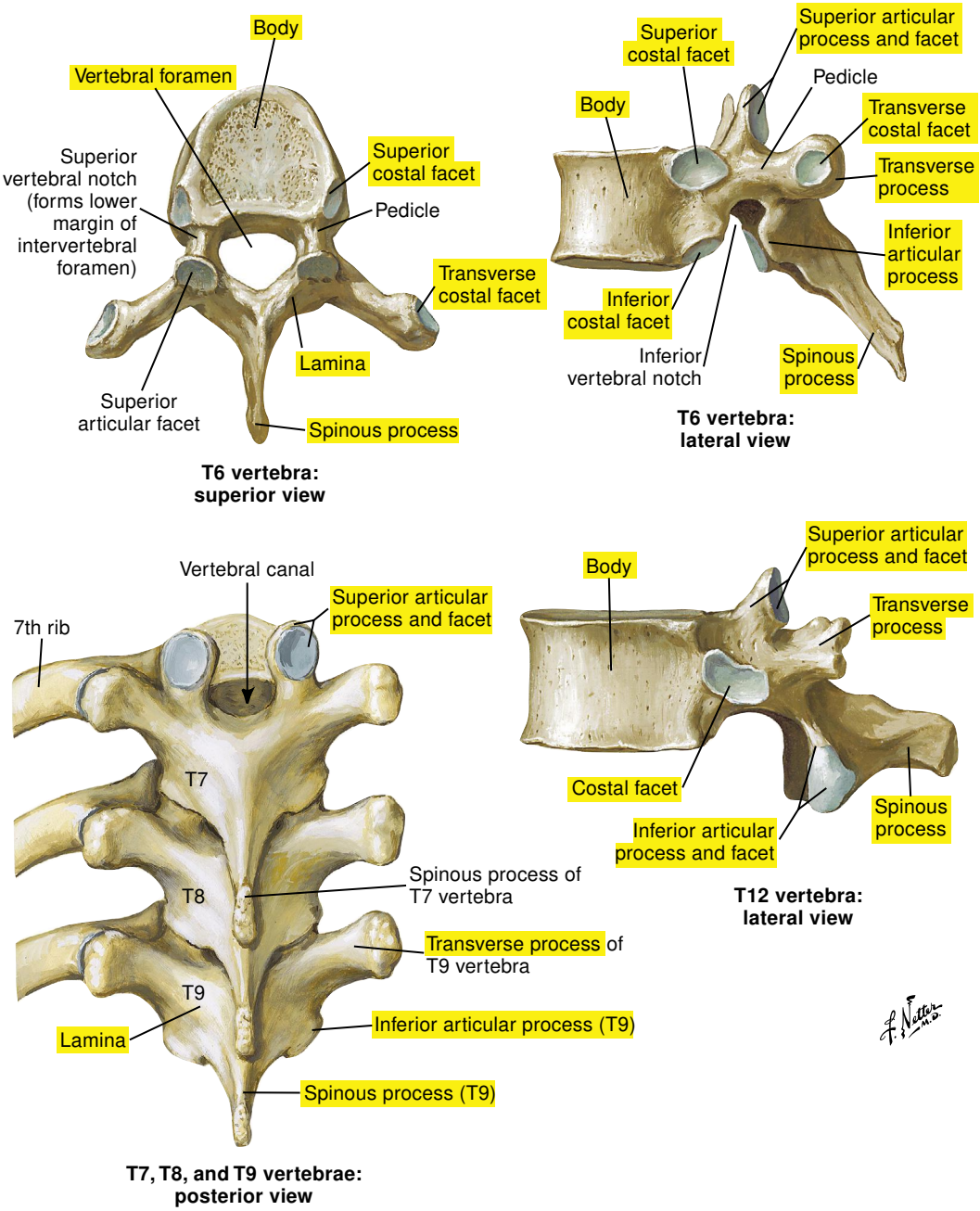


Figure 1.2. The thoracic vertebrae.

Rib Cage (Ribs, Cartilages, Sternum) (Figure 1.3)

The human body contains the following 12 pairs of ribs:

- Ribs 1 through 7 are "true" ribs (or vertebrosternal ribs) and connect directly to the sternum via costal cartilages (for mobility).
- Ribs 8, 9, and 10 are "false" ribs and connect to the sternum via a common cartilage that joins the seventh costal cartilage.
- Ribs 11 and 12 are "floating" ribs; their anterior extremity is free (not connected to the sternum).

The posterior extremity of each rib is connected to the vertebral column. The sternum is connected to the ribs and clavicles and is composed of the following three parts:

1. The manubrium
2. The body or corpus
3. The xiphoid process

The articulation of the manubrium with the corpus forms the sternal angle, or angle of Louis, and marks the approximate location of the second costal cartilages and the level of tracheal bifurcation.

Pectoral, Scapular, or Shoulder Girdle (Figure 1.3)

- The pectoral, scapular, or shoulder girdle is formed anteriorly by the clavicle (long thin bone) and posteriorly by the scapula (triangular flat bone).
- The clavicle allows for the projection of the scapula away from the thoracic cage.
- The humerus is attached to the glenoid cavity of the scapula.
- The pectoral girdle is the point of attachment for many accessory muscles of respiration such as the pectoralis major and sternocleidomastoid muscles. Fixation or stabilization of the pectoral girdle is needed for forced inspiration and expiration, as well as for heavy lifting and other strenuous activities.

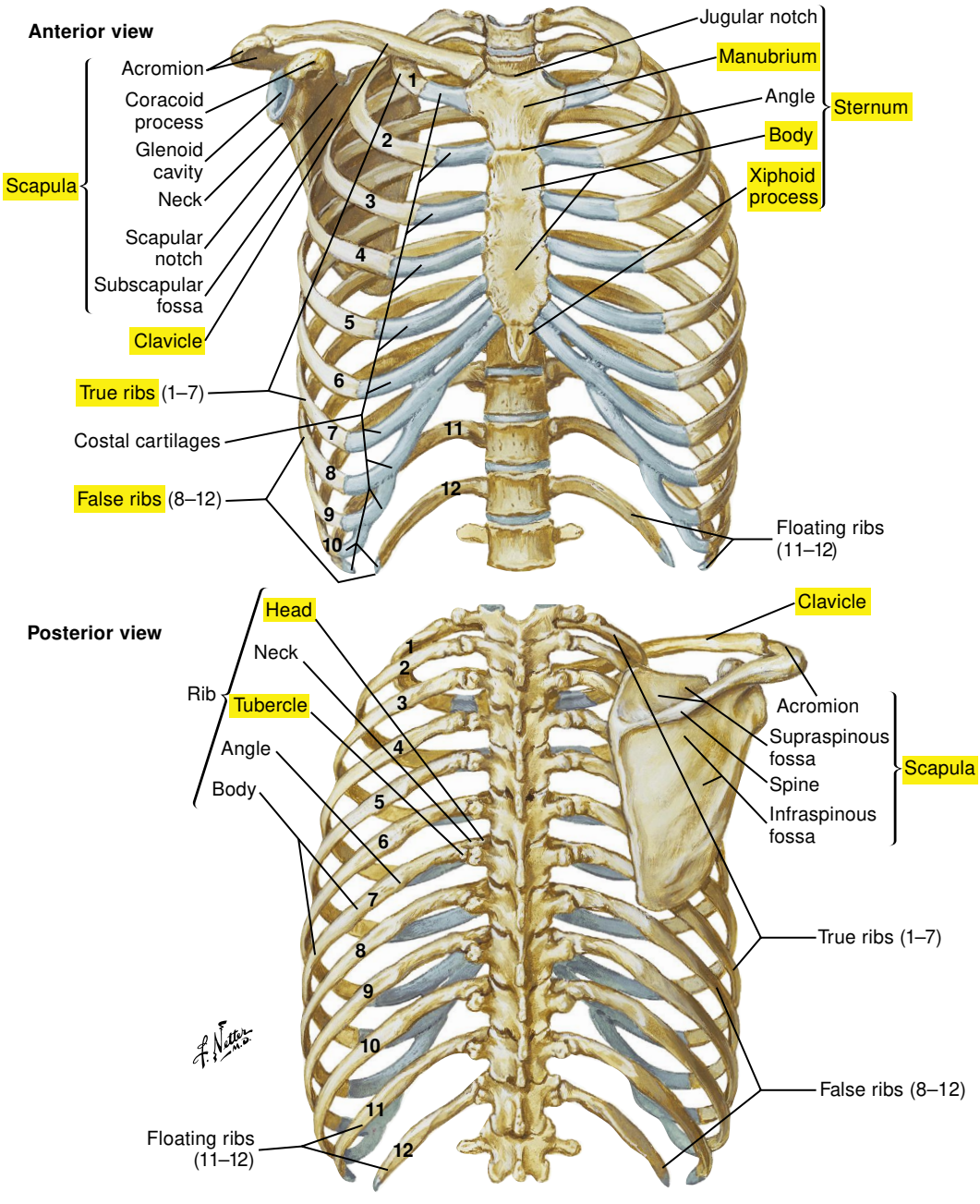


Figure 1.3. The bony framework of the thorax.

Pelvic Girdle or Bony Pelvis (Figure 1.4)

The pelvic girdle is formed by the following:

- A pair of symmetrical coxal, or hip, bones that are joined together anteriorly at the pubic symphysis and posteriorly by the sacrum. Each hip bone is composed of three distinct bones that fuse during development. The following individual structures retain their names despite the fact that they are fused and no suture lines may be visible:
  - Ilium
  - Ischium
  - Pubis
- The sacrum is attached to the ilium at the sacroiliac joint, an extremely strong and stable joint that supports the weight of the upper body.
- The coccyx is the final segment of the vertebral column and is often referred to as the "tailbone."

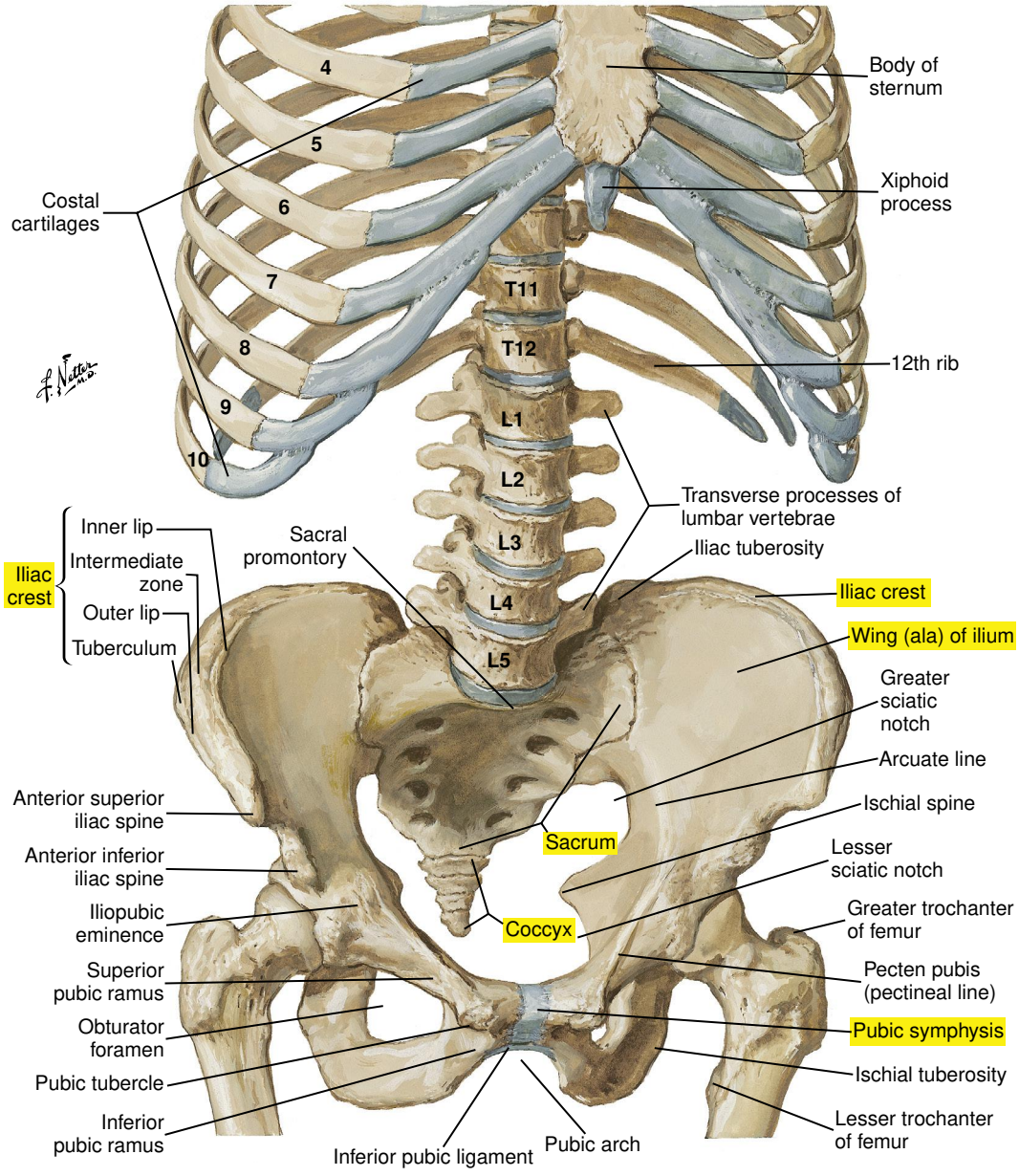


Figure 1.4. The bony framework of the abdomen.

RESPIRATORY TRACT

Air circulates in the following respiratory areas:
- Nasal cavity
- Oral cavity
- Pharynx
- Larynx
- Trachea
- Bronchi
- Lungs

Nasal Cavity (Figure 1.5)

The nasal cavity is the first segment of the upper respiratory tract and participates in olfaction (see Part 3: Oropharyngeal-Articulatory System, pp. 107–171).

Oral Cavity

The oral cavity is delimited anteriorly and laterally by the teeth, posteriorly by the palatoglossal arch (anterior faucial pillar), superiorly by the hard palate and soft palate, and inferiorly by the tongue. It is located posteriorly and medially to the oral vestibule (the space between the lips or the cheeks and the gums and teeth), and anteriorly to the pharynx (see Part 3: Oropharyngeal-Articulatory System, pp. 107–171).

Pharynx (Figure 1.6 [p. 36])

The pharynx is a vertically oriented, muscular passageway that provides communication between the buccal/oral cavity and the esophagus and between the nasal cavity and the larynx (see Part 3: Oropharyngeal-Articulatory System, pp. 107–171).

The pharynx is composed of the following:
- Nasopharynx (portion located behind the nasal cavity)
- Oropharynx (portion located behind the oral cavity)
- Laryngopharynx or hypopharynx (portion located behind the larynx)

Larynx (Figure 1.7 [p. 37])

The larynx is located directly above the trachea and in front of the pharynx. The principal biological function of the larynx is to protect the lower respiratory tract (see Part 2: Laryngeal-Phonatory System, pp. 77–106).

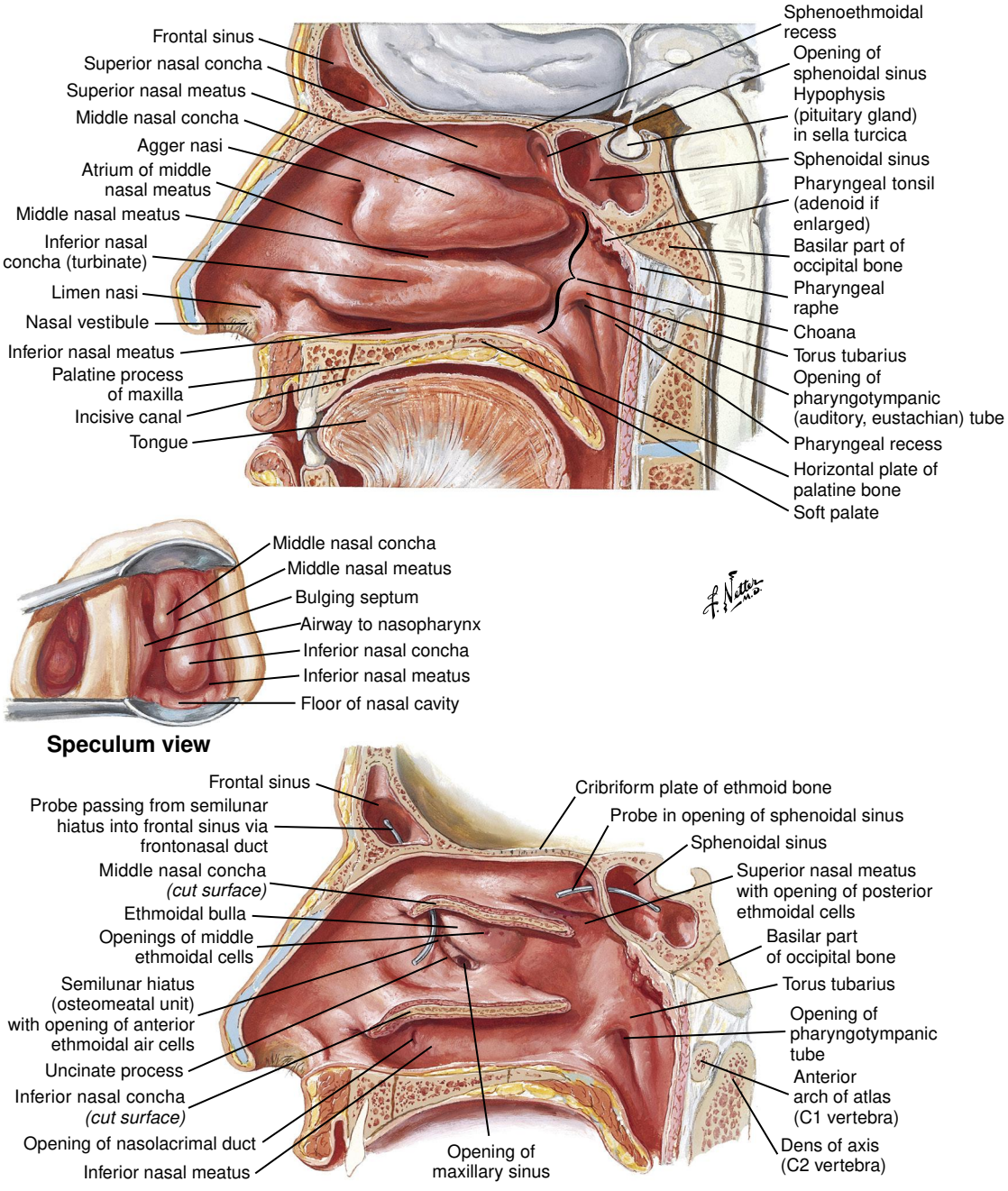


Figure 1.5. The lateral wall of the nasal cavity.

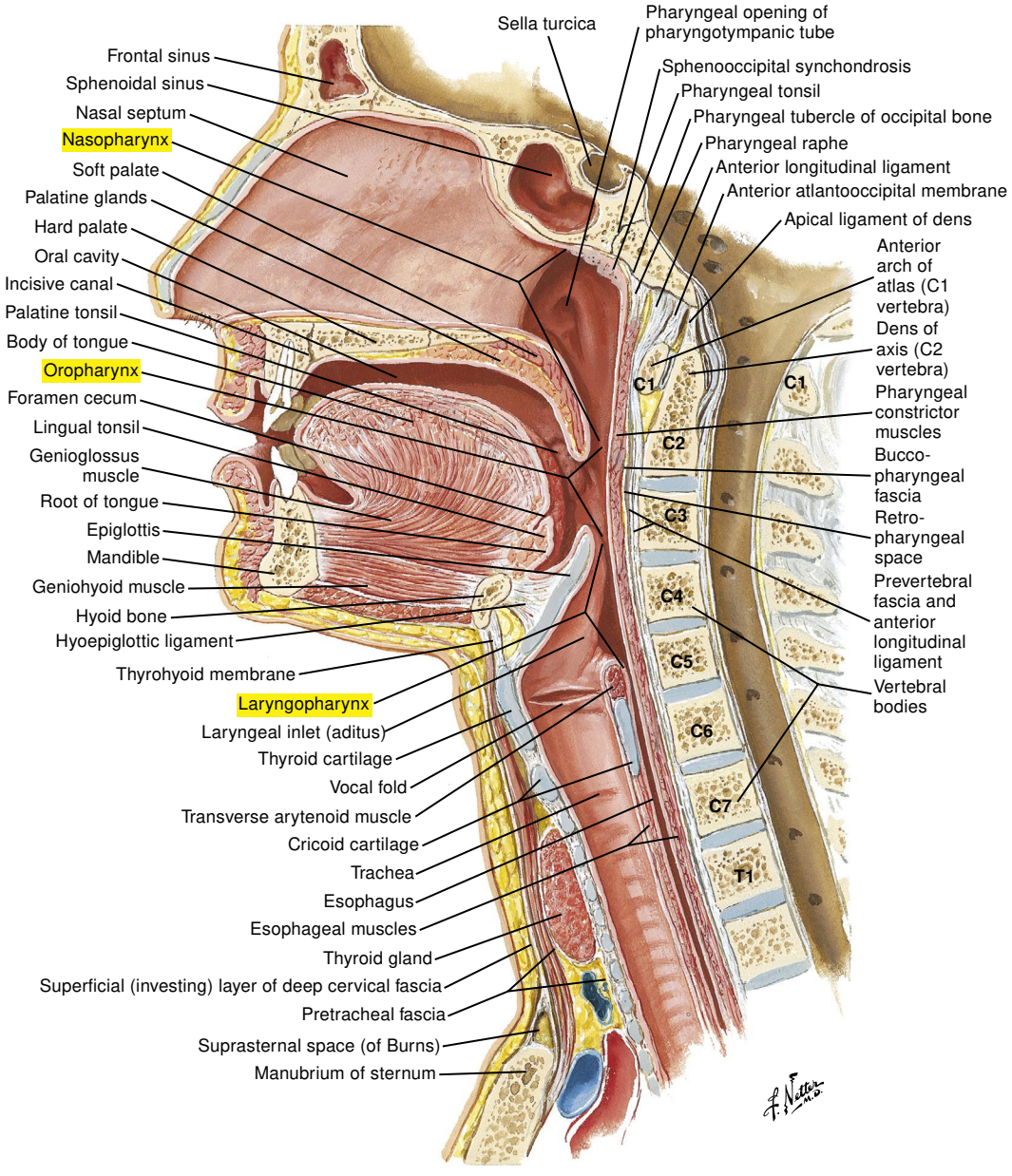


Figure 1.6. A median section of the pharynx.

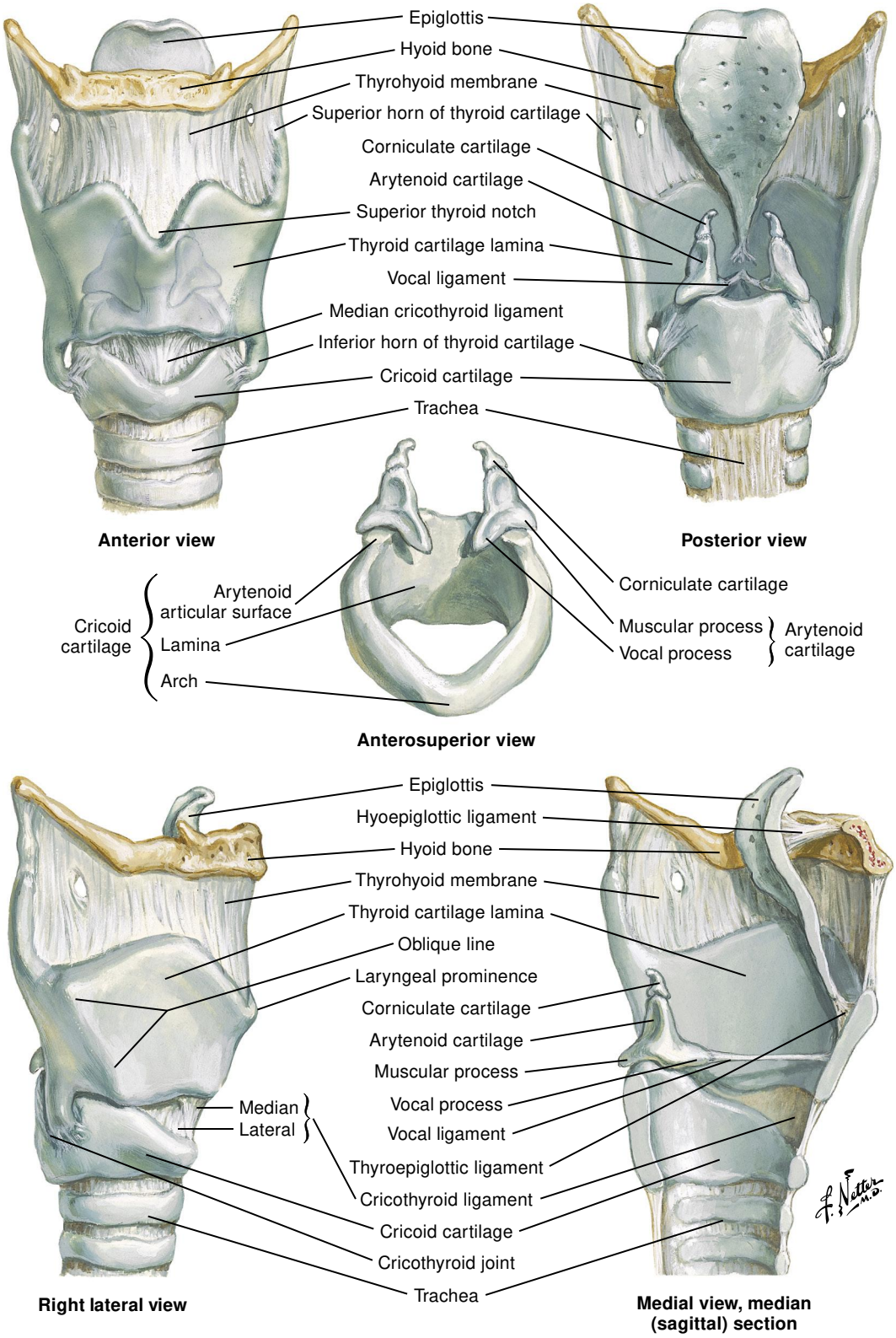


Figure 1.7. The cartilages of the larynx.

Trachea (Figure 1.8)

The trachea extends from the larynx to the bronchi. It contains 16 to 20 incomplete cartilaginous, horseshoe-shaped rings connected by ligaments. The rings are deficient posteriorly to accommodate the attachment to the esophagus. The trachea has two portions: (1) cervical and (2) thoracic.

Bronchi (Figures 1.8 and 1.9 [p. 40])

The trachea divides, or bifurcates, at the level of the sternal angle (T4 to T5) to form the main, or primary, bronchi (right and left), as follows:

- The main bronchi divide into lobar or secondary bronchi, one for each lung lobe: three for the right lung (superior, middle, and inferior) and two for the left lung (superior and inferior).
- The lobar bronchi further divide to form segmental or tertiary bronchi (third-order bronchi), each supplying a specific bronchopulmonary segment: 10 for the right and 8 to 10 for the left (depending on whether certain bronchopulmonary segments share the same segmental bronchus).
- The segmental bronchi continue to divide many times (20 to 25 generations) to eventually become terminal bronchioles ("little tubes") with diameters of less than 0.5 mm. The terminal bronchioles are the end of the conducting respiratory passageways.

The respiratory portion of the pathway in which gas exchange occurs begins with the respiratory bronchioles, then the alveolar ducts, the alveolar sacs, and the alveoli, in which the main part of pulmonary gas exchange occurs (Figure 1.10 [p. 41]).

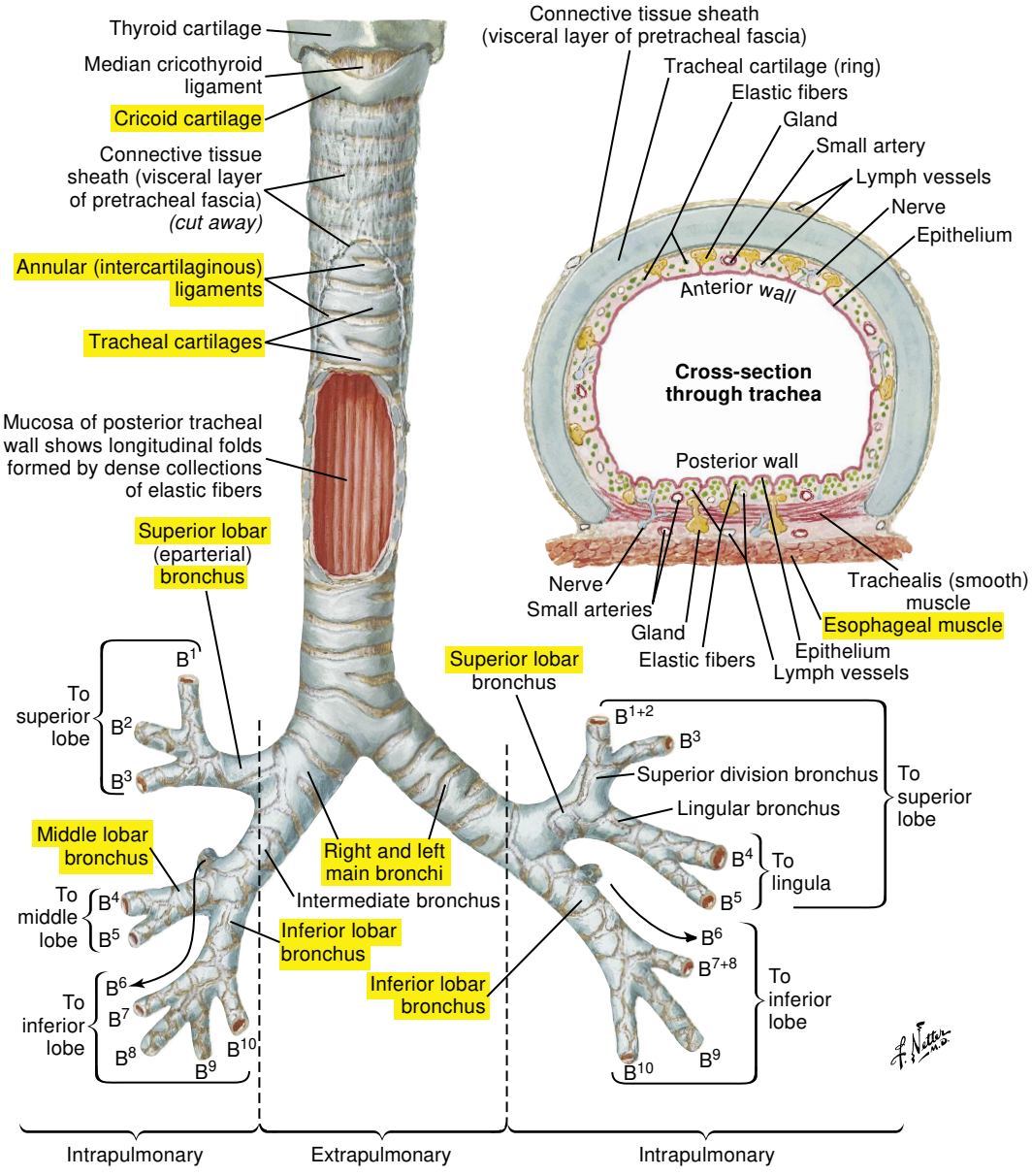


Figure 1.8. The trachea and major bronchi.