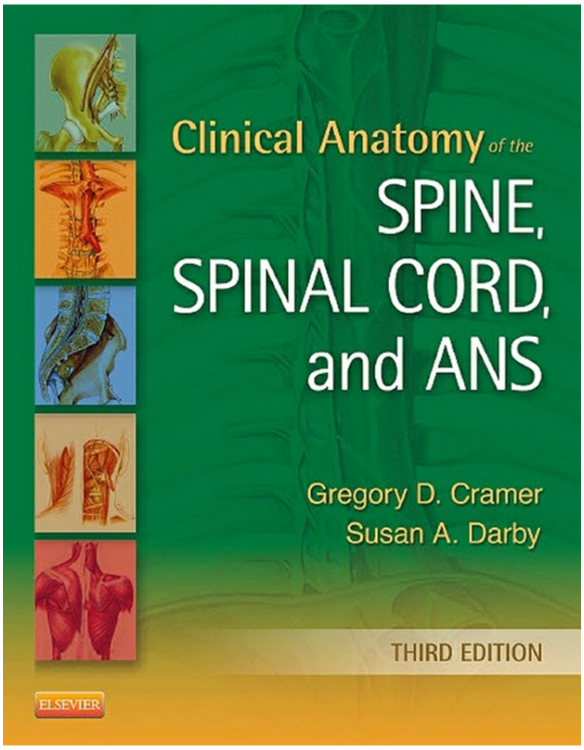

Clinical Anatomy of the SPINE, SPINAL CORD, and ANS

Gregory D. Cramer
Susan A. Darby

THIRD EDITION

ELSEVIER

Clinical Anatomy of the Spine, Spinal Cord, and ANS

THIRD EDITION

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Dedication

To

Chris and David

Dave, Katherine, and Jason

Thank you for your invaluable support, patience, and encouragement throughout the writing of the first and subsequent editions of this text.

Forewords

It seems as though it has only been a short period of time since publication of the second edition of ***Basic and Clinical Anatomy of the Spine, Spinal Cord, and ANS.*** The first two editions of this ambitious work have been an important reference for me. I have been most appreciative of the clarity of expression and the illustrations, making this a primary resource for the student of spinal anatomy. I have never hesitated to recommend readings to learners at many levels, all of whom have appreciated the ease of understanding of text and figures, while not sacrificing the academic rigor that one would expect from authors who have spent their lives researching and teaching about the spine. I highly recommend this work to any health professional engaged in treating patients with spinal disorders and particularly to those who might be struggling to stay abreast with current concepts.

As remarkable as it seems, and as fresh and relevant as the information contained within the second edition continues to be, it has been 8 years since publication of that edition. Over this period of time there have been advances in imaging, clinical biomechanics, physiology, and pathophysiology that necessitate revisiting some of the concepts presented in the book. I am impressed with the way in which volumes of recent literature have been distilled to a level that is both understandable and useful to students and practitioners alike. As an educator, I am particularly looking forward to the improvements and additions to the already excellent figures and illustrations since I use them liberally in my teaching. I am very certain that you will find the third edition to be a great contribution to your library whether you are a beginning learner, an advanced practitioner, or an educator looking to stay current with today's advancements.

Rand S. Swenson, DC, MD, PhD, Professor of Anatomy and Neurology, Chair, Department of Anatomy, Geisel School of Medicine at Dartmouth, Hanover, New Hampshire

Drs. Cramer and Darby, with the able assistance of colleagues in the Departments of Anatomy and Physiology at National University of Health Sciences, have again updated and improved a remarkable resource for both clinicians and students.

This new edition of *Clinical Anatomy of the Spine, Spinal Cord, and ANS* is designed to facilitate a learner's understanding of important anatomic concepts and their relationship to clinical practice. The most important aspects of this book include comprehensive coverage of spinal anatomy and related neuroanatomy, with clear explanations of structural relationships, the extensive use of illustrations and photographs to enhance anatomic detail, and numerous well-referenced clinical pearls that relate anatomy to clinical care.

Every chapter has been updated with new illustrations and images. Several chapters have undergone major revisions and expansions. The authors have embarked upon an evidence-based approach by supporting the book's content with new research reports and reviews.

Anatomy faculty and students will find that this book goes beyond a mere description of the structures of the spine and nervous system. It strives to explain how a structure develops, to uncover patterns of distribution, and to foster an appreciation of the morphologic basis of variation. Anatomic facts are presented within the context of their mutual relationships and clinical relevance. This inevitably leads to comprehension of the underlying principles involved and facilitates anatomic reasoning and easier acquisition of additional morphologic facts and concepts.

For the clinician, this book provides essential background knowledge for the safe and appropriate care of patients with neuromusculoskeletal disorders of the spine. Special emphasis is placed on structures that may be affected by manual spinal techniques.

I highly recommend this invaluable resource to all students and practitioners who regularly care for patients with spinal disorders.

Alan H. Adams, MS, DC, Vice-President of Academic Affairs and Program Development, Texas Chiropractic College, Pasadena, Texas

At our institution the text *Clinical Anatomy of the Spine, Spinal Cord, and ANS* has been required for many years in the anatomy courses that cover various aspects of spinal anatomy and neuroanatomy. We teach anatomy at a high level of detail and this textbook helps us to accomplish the appreciation of anatomy of the spine and related neuroanatomy in the depth and breadth we feel are important.

The text completely reflects what we want to present and teach in our courses. The content is academically sound, detailed, and remarkably well organized. The writing is clear and easy to understand. The material is current (including use of the most recent morphologic terminology), clinically applicable, well illustrated, and fully referenced.

The broad range of topics is covered in depth. Clinical applications are included throughout every aspect of the book, and the text has excellent bridges between morphology and clinical diagnosis. For example, Chapter 11, Pain of Spinal Origin, is presented as a case study and would be very appropriate for use in gross and/or neuroanatomy courses of programs that deal with the treatment of disorders of the spine. The chapter focuses on the mechanisms of back pain, which is the primary symptom that confronts clinicians when diagnosing and treating spinal disorders.

The content is essential for students and clinicians who plan to diagnose, treat, or prevent disorders of the spine. Having a single text devoted to all aspects of spinal anatomy (from embryology and pediatrics to the pathoanatomy of spinal degeneration) and related neuroanatomy allows students and practicing clinicians to concentrate on the anatomic relationships of the spine, related neuroanatomy, and clinical applications of the anatomy, without having to access separate texts of embryology, histology, neuroanatomy, and gross anatomy.

I recommend this book as a required text for all anatomy courses that teach in-depth content related to the gross and microscopic anatomy of the spine, neuroanatomy of the spinal cord and related tracts, and neuroanatomy of the autonomic nervous system. I also strongly recommend the text to all clinicians who treat disorders of the spine.

Myroslava Kumka, MD, PhD, Chair, Department of Anatomy, Canadian Memorial Chiropractic College, Toronto, Ontario, Canada

Preface

This text was originally written to fill a need for a cohesive, well-illustrated text covering spinal anatomy, including the neuroanatomy of the spinal cord and the autonomic nervous system. We are grateful for the enthusiastic support of the book from a wide range of practicing health care providers, anatomists, and students since the publication of the first edition in 1995. We also appreciate the suggestions received from individuals of these same groups. Many of the additions and changes made to this (third) edition are in response to suggestions received since the publication of the second.

In addition to revisions of every chapter in the text, this edition also contains 46 new illustrations, x-rays, and MRI scans. In preparation for the revisions, more than 50 broad-based literature searches were performed on topics related to the text. In addition, hand searches of five anatomy and spine journals from 2004 to 2012 were completed. From the thousands of papers identified from these searches, approximately 800 were selected for closer scrutiny. Of these, the results of approximately 350 new research papers and reviews were included in this edition of the book. In response to the suggestions of second edition readers, figures exhibiting normal radiographic anatomy (x-ray) and normal magnetic resonance imaging anatomy of each spinal region have been included. Additional vertebral artery angiograms have also been included. Illustrations clarifying difficult to understand gross and neuroanatomic concepts or the results of new research have also been added throughout the text.

Significant additions were made to several chapters and sections of chapters. The chapter on the cervical region (Chapter 5) has undergone substantial revision with many new figures added. A more complete description of the neurophysiology of movement and the interneuronal circuitry involved in movement has been added to Chapter 9. In Chapter 10, the sections on the enteric nervous system and the connection of the ANS to the immune system were expanded. In addition, a large section on the relationship between inflammation and the ANS was added to Chapter 10. Finally, a large, illustrated section that includes recently developed knowledge from the emerging field of fascia research has been added to Chapter 14.

In sum, the threefold objective we planned to accomplish for the first two editions remains our conviction for the third:

- **To provide an accurate and complete text for students studying the spine, spinal cord, and autonomic nervous system.** To our knowledge, this text maintains its unique position as the most comprehensive exploration of these three specific areas and their related functions.
- **To serve as a reliable reference for spinal anatomy and related neuroanatomy for clinicians and researchers.** Even though the science of anatomy is very old, studies related to spinal anatomy continue to appear in the scientific literature. So as aforementioned, we have thoroughly reviewed contemporary findings and have been decisive in our selection of included material. In keeping with the previous editions, clinically applicable material remains highlighted, allowing doctors of chiropractic, medical professionals (e.g., orthopedic surgeons, neurologists, radiologists, neurosurgeons, head and neck surgeons, physiatrists, general practitioners treating back pain), physical therapists, and other health practitioners quick access to detailed summaries on topics of particular clinical relevance.
- **To help bridge the gap between the basic science of anatomy and the applied anatomy of clinical practice.** Our broad review of the recent literature and updating of the illustrations and text not only provides the most current and evidence-based material, but also relates this material to clinical practice in order to extend the knowledge base of a widening audience of users and to acknowledge the importance of their connections.

Once again, we greatly appreciate the support of those who have found this book to be a useful initial and reference text for anatomy of the spine, spinal cord, and ANS and believe the third edition will provide an even greater service to students and clinicians alike.

Gregory D. Cramer

Susan A. Darby

Introduction

This book has been organized with two groups of readers in mind: those studying the spine for the first time and those clinicians and researchers who have previously studied the spine in detail. Therefore we have accepted the daunting task of designing a book to act as a source of reference and as a book that is “readable.” To this end an outline has been included at the beginning of each chapter. This format should help the reader organize his or her thoughts before beginning the chapter and also provide a quick reference to the material of interest. A complete subject index is also included at the end of the text for rapid referencing. In addition, items of particular clinical relevance and the results of clinically relevant research appear with a red bracket beside the material throughout the book. This highlighting procedure is meant to aid students and clinicians alike focus on areas that are thought to be of particular current importance in the detection of pathologic conditions or in the treatment of disorders of the spine, spinal cord, and autonomic nervous system. Discussions of the clinical relevance of anatomic structures are included to relate anatomy to clinical practice as efficiently as possible.

Chapter 1 discusses surface anatomy. It contains information useful not only to the student who has yet to palpate his or her first patient, but also to the clinician who examines patients on a daily basis. Chapters 2 and 3 relate the general characteristics of the spine and spinal cord, using a basic approach. These chapters are directed primarily to the novice student. A quick review of these chapters, with attention focused on the sections highlighted by red brackets, should also be of benefit to the more advanced student. Chapter 2 includes a section on advanced diagnostic imaging. This section is provided for the individual who does not routinely view advanced imaging. A brief description of the strengths and weaknesses of computed tomography and magnetic resonance imaging and a concise overview of other less frequently used advanced imaging procedures are included. Chapters 3 and 4 relate soft tissues to the “bones” by describing the spinal cord and its meningeal coverings, and the muscles that surround and influence the spine. This material is followed by a detailed study of the regional anatomy of the spine in Chapters 5 through 8. These chapters also include information concerning the ligamentous tissues of the spine. A more thorough presentation of the anatomy of the spinal cord and autonomic nervous system is found in Chapters 9 and 10, and the development (from inception to adulthood) and histologic composition of the spine and spinal cord are found in Chapters 12 through 14. It should be noted that the first four chapters provide the groundwork for later chapters that are more detailed and contain additional information with specific clinical relevance. Therefore certain material is occasionally discussed more than once. For example, Chapters 2 and 3 are concerned with general characteristics of the spine and spinal cord, with a discussion of the various components of a typical vertebra, the vertebral canal, and the spinal cord within the canal. These structures are discussed again regionally (Chapters 5 through 8) to a much greater depth to explore their relative importance and clinical significance in each region of the spine and to appreciate the neuroanatomic connections within the spinal cord (Chapter 9).

Chapter 11 is devoted to pain producers (those structures that receive nociceptive innervation), the mechanisms and neuroanatomic pathways of nociception from spinal structures, and the peripheral, spinal, and supraspinal modulation of these impulses. This chapter is designed for readers who have already completed study in spinal anatomy and neuroanatomy. Chapter 12 discusses the development of the spine and is designed for use by students studying spinal anatomy and for clinicians who wish to refresh their knowledge of the development of the spine and spinal cord. Chapter 13 covers the pediatric spine and should be useful to all readers. Chapter 14 describes the microscopic anatomy of the zygapophysial joints, intervertebral discs, and all other spine-related tissues. Because much of the current research on the spine is focused at the tissue, cellular, and subcellular levels, both students and clinicians should find this chapter useful at some point in their careers. Because of the rather specialized nature of the last four topics, they have been positioned at the end of the book.

Clarification of Abbreviations and Terms

Vertebral levels are frequently abbreviated throughout this text. The initials C, T, and L are used to abbreviate cervical, thoracic, and lumbar, respectively. Vertebral levels can then be easily identified by placing the appropriate number after the abbreviated region. For example, “T7” is frequently used rather than “the seventh thoracic vertebra.”

In addition, some potentially confusing terminology should be clarified. Throughout this text the term kyphosis is used when referring to a spinal curve that is concave anteriorly, and the term lordosis is used for a curve that is concave posteriorly. The term hyperlordosis refers to an accentuation of a lordosis beyond what is usually accepted as normal, and the term hyperkyphosis is used for an accentuation of a kyphosis beyond the range of normal. This is in contrast to the terminology of some texts that refer to normal spinal curves as being “concave anteriorly” or “concave posteriorly” and reserve the terms “kyphosis” and “lordosis” for curves that are deeper than normal. Although both sets of terminology are correct, the prior one was chosen for this text because we felt that this terminology would lend the most clarity to subsequent discussions.

The spellings “zygapophyseal” and “zygapophysial” are both considered correct. The terms are most often used when referring to the most appropriate name of the spinal “facet joints,” that is, the “zygapophysial joints.” We have chosen “zygapophysial” because most researchers in the field use this spelling.

Finally, we hope that you, the reader, believe as we do that the long-standing interest of clinicians in the anatomic sciences is not an accident. Greater awareness of structure leads to a keener perception of function, and an increased understanding of pathologic conditions is the natural consequence. This results in a better comprehension of current therapeutic approaches and the development of new treatment procedures based upon a scientific foundation. Therefore astute clinicians are vigilant for developments in the structural sciences, being aware that their concepts of human mechanisms may be influenced by new discoveries in these disciplines. Whenever new information about the causes underlying dysfunction is available, new therapeutic approaches are sure to follow, and clinicians who have kept abreast of these recent discoveries will find themselves leaders in their field.

Acknowledgments

This project would not have been possible without the support of the members of the administration, faculty, students, and staff of the National University of Health Sciences, who allowed us the time and facilities necessary to review the literature, write several drafts of text, and work on the development of supporting figures. We greatly appreciate their support of, and in some instances commitment to, this work.

In addition, many people have helped with the production of this book. We would like to take this opportunity to thank those who helped with proofreading portions of various drafts of the first through third editions of this work and whose suggestions were extremely helpful in the development of the final manuscripts. These people include Robert Appleyard, PhD; Joe Cantu, DC; Jim Christiansen, PhD; John DeMatte, DC; Richard Dorsett, DC; Rebecca Furlano, DC; Kris Gongaware, DC; Michael Kiely, PhD; Joshua K. Mack; Allan Mathieu, DC; James McKay, DC; Nathan Miller, DC; Carol Muehleman, PhD; Ken Nolson, DC; Joseph Papuga, DC; Nyarai S. Paweni; and Nancy Steinke, MS. A special thanks to Lynn Zoufal, MBA, who spent countless hours keying in editorial changes to the second edition manuscripts.

We would also like to thank Patrick W. Frank, DC, for his beautiful dissections of the muscles of the back, which appear in Chapter 4. The work of Victoria Hyzny, DC, and Terese Black, DC, ND, in the dissections that appear in Chapters 3, 5, 9, and 10 is greatly appreciated. The inexhaustible support of Joshua W. Little, DC, PhD, who performed countless literature searches and monitored the files for the literature for the second edition, was extremely valuable. Rebecca Furlano, DC, and Jennifer Dexheimer, BS, MT, assumed these important roles for the third edition. Christopher Allin, DC; Kim Anderson, DC; Terese Black, DC, ND; Jordan Bray; Matt Imber, DC; Anna M. Rodecki, DC; Gina Sirchio, DC; Michelle Steinys, DC; and Matt White, DC, also assisted with searching the literature and compiling the reference lists, and we thank them. We thank Judy Pocius, MS; Sheila Meadows, DC; and Terese Black, DC, ND, for organizational help with photographs and illustrations for the first and second editions. We are also grateful for the graphic support of Robert Hansen, BFA, and the computer graphics added by Dino Juarez, MA, to several of the magnetic resonance imaging scans found in Chapters 11 and 13. We are also grateful for the continuous support (from the first edition to the present) of the faculty and staff of the NUHS Learning Resource Center, especially Peggy Carey, BS, LTA, and Russ Iwami, MALS, for filling countless requests for difficult to find papers, many interlibrary loan requests, and innumerable additional requests for help.

The magnetic resonance imaging scans, computed tomograms, and x-ray films were graciously provided and labeled by William Bogar, DC, DACBR, of the National University of Health Sciences and Dennis Skogsbergh, DC, DABCO, DACBR. Many of the x-rays of spinal pathology and congenital anomalies were provided by Jeffery A. Rich, DC, DACBR. We would like to thank them for their contributions to this text. Where possible, diagnostic images are presented in a larger format than in the first edition (thank you for the suggestion, Dr. Barber).

We thank Michael L. Kiely, PhD, for his review of the entire manuscript for the first edition. We also appreciate the work and patience of the publishing staff at Elsevier Inc., particularly that of the executive editors: James Shanahan and Martha Sasser for the first edition; Christie Hart and Kellie White for the second edition; and Kellie White and Joe Gramlich for the third edition, and our project manager, Jeanne Genz. And, thanks to Thomas Grieve, DC, MPH for his help in proofreading the pages.

We would also like to gratefully acknowledge our parents, Dr. and Mrs. David Cramer (David deceased, March 2012, and Louise deceased, August 2012) and Mr. and Mrs. George Anderson (George deceased, May 2006, and Helen deceased, April 2011), whose encouragement and early instruction gave us a strong desire to learn more and to help others.

The outstanding teaching and mentoring of Mr. Curtis Dee Cooley and Drs. Joseph Janse, Delmas Allen, Liberato DiDio, William Potvin, Frank Saul, Dennis Morse, Richard Yeasting, Richard Lane, and Robert Crissman will never be forgotten. Their example provided much of the motivation for beginning, and completing, this endeavor. Thank you all very much.

Gregory D. Cramer

Susan A. Darby

PART 1

Characteristics of the Spine and Spinal Cord

CHAPTER 1

Surface Anatomy of the Back and Vertebral Levels of Clinically Important Structures

Barclay W. Bakkum

Surface anatomy is defined as the configuration of the surface of the body, especially in relation to deeper parts. A thorough knowledge of surface anatomy is necessary for the proper performance of a physical examination. Information gathered by the eyes (inspection) and fingers (palpation) is often critical in the assessment of a patient. An understanding of the topography of the human body also allows the health care provider to locate the position of deep structures that may need further evaluation.

The locations of structures in reference to the surface of the body are always approximations, although it has been shown that reliability of locating spinal structures by palpation can be enhanced by training and experience (Byfield et al., 1992; Downey et al., 1999; Phillips et al., 2009). Individual variations are common and are influenced by such factors as age, sex, posture, weight, and body type. Respiratory movements also can have marked effects on the locations of structures, especially those of the thorax. Determining the position of the contents of the abdomen can be particularly challenging, and the precise location of abdominal viscera can be established only by verification with appropriate diagnostic imaging procedures.

In keeping with the scope of this text, the surface anatomy included in this chapter is limited to the back. Spinous processes and posterior bony landmarks are used as points of reference in the first part of the chapter. One reason for the use of these as landmarks is to help clinicians with examination and treatment of the back and spine when the patient is in the prone position. In addition, the vertebral levels of structures of the anterior neck and trunk, which are either visible by means of advanced imaging procedures (magnetic resonance imaging [MRI] or computed tomography [CT]) or palpable during physical examination, are included. Knowledge of the normal relationships between the viscera and the spine is becoming increasingly important in clinical practice, since clinicians are asked with greater frequency to interpret or review studies employing these advanced imaging procedures. On a more practical level, knowledge of these relationships helps the clinician quickly become oriented with the vertebral level of diagnostic images taken in the horizontal plane.

Because other texts discuss the location of organs with regard to abdominal regions or quadrants, that method of locating organs is not covered here.

The Back

The back, or dorsum, is the posterior part of the trunk and includes skin, muscles, the vertebral column, spinal cord, and various nerves and blood vessels (Gardner, Gray, & O'Rahilly, 1975). The 24 movable vertebrae consist of, from superior to inferior, 7 cervical (C), 12 thoracic (or dorsal) (T), and 5 lumbar (L). Inferior to the lumbar vertebrae, five sacral vertebrae (S) fuse in the adult to form the sacrum. The lowermost three to five vertebrae fuse late in adult life to form the coccyx (Co).

Intervertebral discs are located between the anterior portions of the movable vertebrae and between L5 and the sacrum. There is no disc located between the occiput and C1 (atlas), or between C1 and C2 (axis). The discs are named for the vertebra found immediately above the disc; that is, the T6 disc is located between the T6 and T7 vertebrae.

Seven processes arise from the posterior portion of the typical vertebra. Several atypical vertebrae have variations in their anatomy and are discussed in Chapters 5, 6, and 7. The spinous process is a midline structure that is directed posteriorly and to a variable degree inferiorly. The transverse processes are a pair of lateral projections. The other four processes are articular, and each vertebra has a superior pair and an inferior pair. These processes are discussed in greater detail in Chapter 2.

The remainder of this chapter discusses visual landmarks of the back, palpatory landmarks of the back, spinal cord levels versus vertebral levels, and vertebral levels of structures in the anterior neck and trunk. This information enables the clinician to gain a thorough understanding of surface anatomy and serves as a reference for future patient assessment, both in the physical examination and through diagnostic imaging procedures, including plain film x-ray examination, CT, and MRI.

Visual Landmarks Of The Back

In the midline of the back is a longitudinal groove known as the median furrow (or sulcus) (Fig. 1-1). Superiorly it begins at the external occipital protuberance (EOP) (see the following discussion) and continues inferiorly as the gluteal (anal, natal, or cluneal) cleft (or crena ani) to the level of the S3 spinous tubercle, the remnants of the spinous process of S3. It is shallow in the lower cervical region and deepest in the lumbar region. The median furrow widens inferiorly to form an isosceles triangle with a line connecting the posterior superior iliac spines (PSISs) forming the base above, and the gluteal cleft forming the apex of the triangle below. The PSISs are often visible as a pair of dimples located 3 to 4 cm lateral to the midline at the level of the S2 spinous tubercle. These indentations are known as the lateral lumbar fossae or dimples of Venus. The gluteal fold (or sulcus) is a horizontal skin fold extending laterally from the midline and roughly corresponds with the inferior border of the gluteus maximus muscle. This fold marks the lower extent of the buttocks.

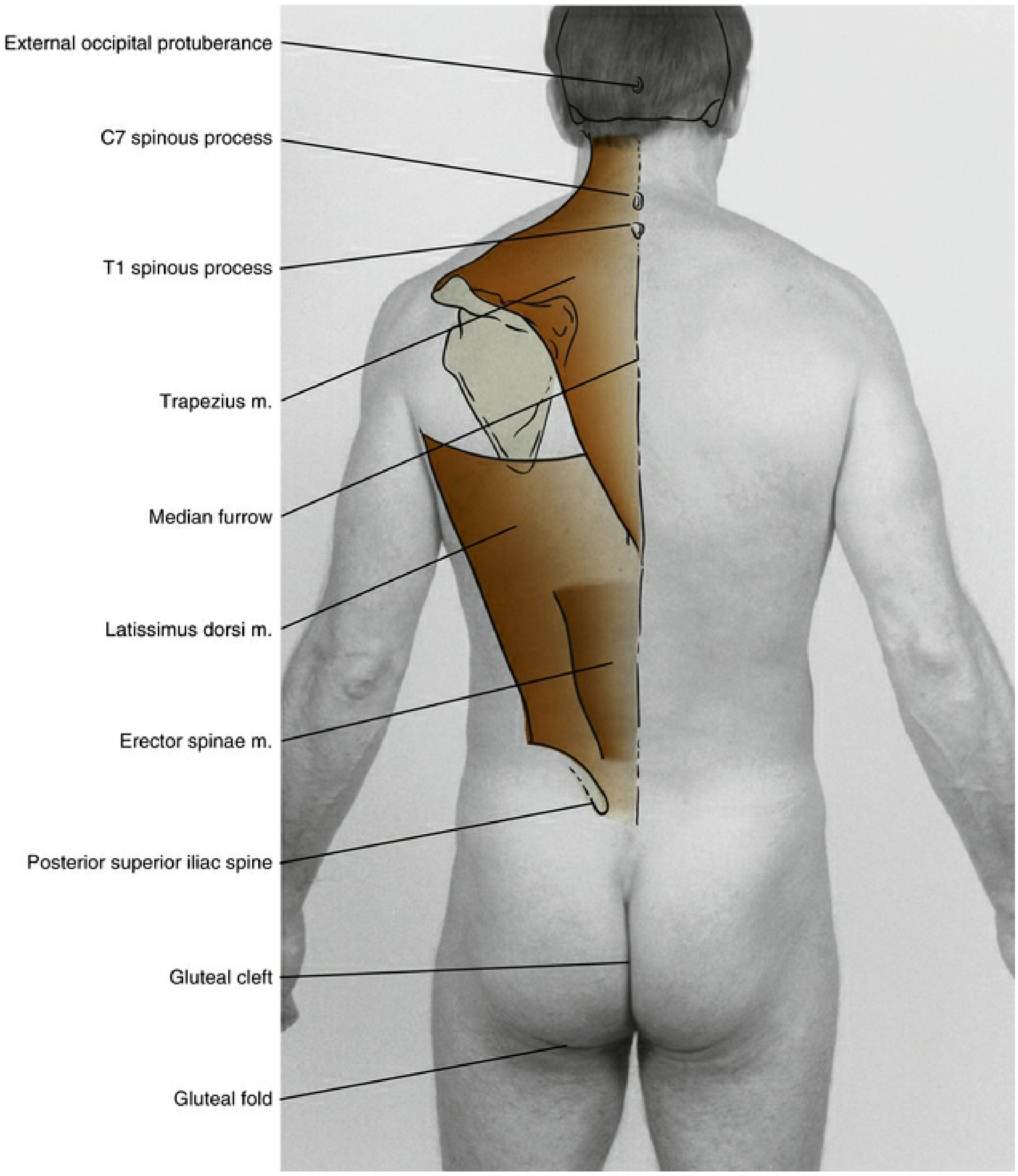


FIG. 1-1 Landmarks of the back.

Several muscles are commonly visible in the back region. The trapezius is a large, flat, triangular muscle that originates in the midline from the EOP to the spinous process of T12 and inserts laterally onto the spine of the scapula. Its upper fibers form the "top of the shoulder," where the neck laterally blends into the thorax. The latissimus dorsi, extending from the region of the iliac crest to the posterior border of the axilla, forms the lateral border of the lower thoracic portion of the back. This muscle is especially noticeable when the upper extremity is adducted against resistance. Between the trapezius medially and the latissimus dorsi laterally, the inferior angle of the scapula may be seen at approximately the level of the T8 spinous process. The erector spinae muscles form two large longitudinal masses in the lumbar region that extend approximately a hand breadth (10 cm) laterally from the midline. These muscle masses are responsible for the deepening of the median furrow in this region.

Besides these muscles, several bony landmarks usually are visible in the region of the back. The spinous process of C7 (the vertebra prominens) usually is visible in the lower cervical region. Often, the spinous processes of C6 and/or T1 also are visible, especially when the patient's head is flexed. Approximately 75% of the time, the C7 spinous process is the most prominent of these structures (Stonelake, Burwell, & Webb, 1988). In about 10% and 15% of the population, the C6 and T1 spinous processes, respectively, are actually the most prominent spinous processes in the region.

In the adult the vertebral column has several visible normal curves. In the cervical and lumbar regions the spine is anteriorly convex (lordotic), and in the thoracic and sacral areas it is posteriorly convex (kyphotic). Normally there is no lateral deviation of the spinal column, but such curvature is known as scoliosis when present. These curves are covered in more detail in Chapter 2.

Palpatory Landmarks Of The Back

The following structures usually are not visible but can be located on palpation. Some of the structures in this discussion of palpable landmarks cannot normally be felt, but their relation to landmarks that can be localized is given.

Cervical Region

The EOP (inion) is in the center of the occipital squama (Fig. 1-2). The superior nuchal line extends laterally from the EOP. The transverse process of the atlas may be found directly below and slightly anterior to the mastoid process of the temporal bone. Care must be taken when palpating this structure because of the relatively fragile styloid process of the temporal bone that lies a few millimeters anterior to the C1 transverse process and the great auricular nerve that ascends in the fascia superficial to the C1 transverse process.

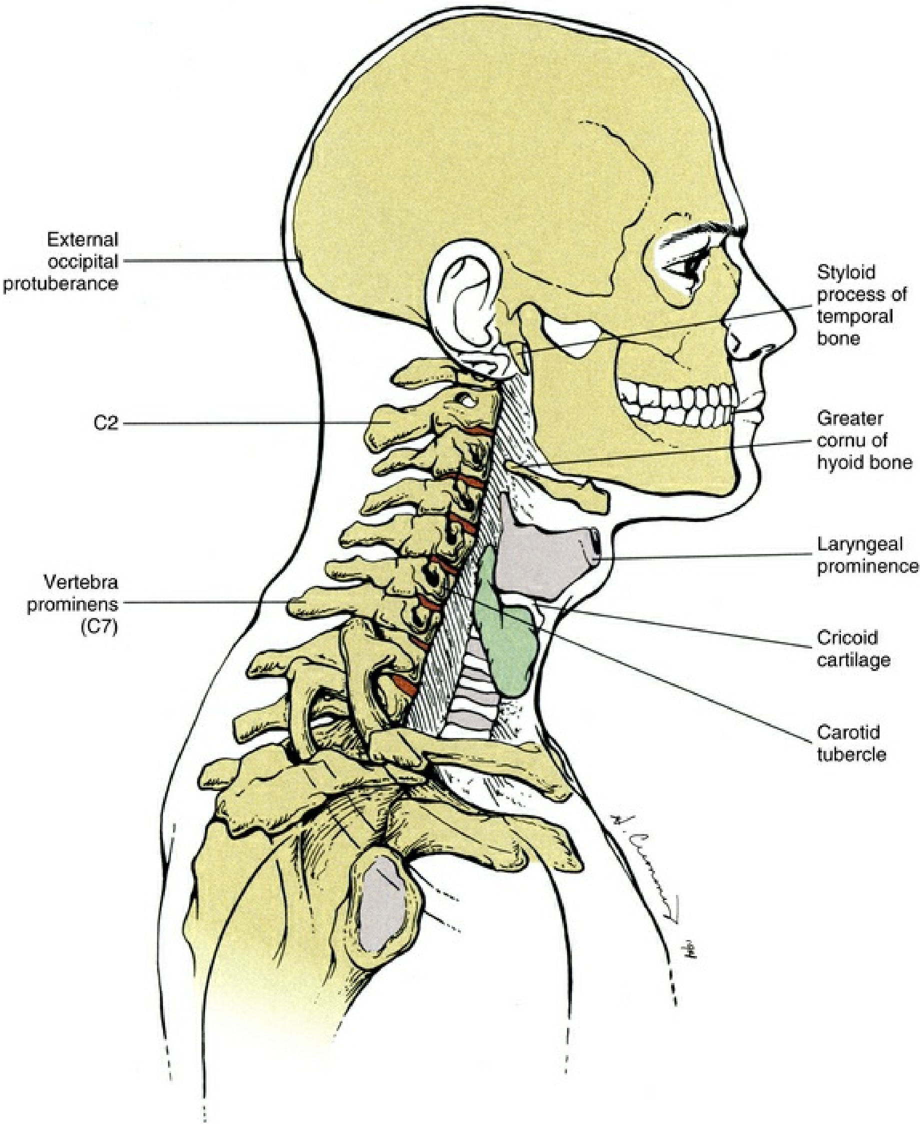


FIG. 1-2 Palpable landmarks of the lateral neck.

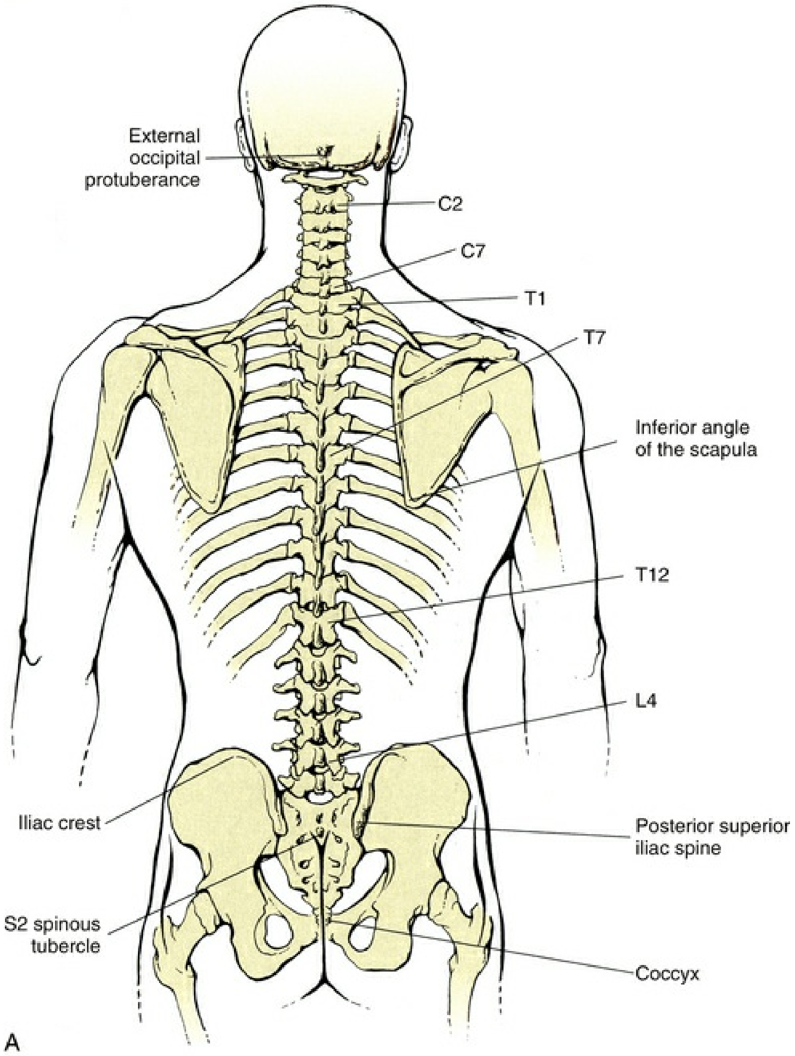
The spinous process of the axis is the first readily palpable bony structure in the posterior midline below the EOP (see Fig. 1-2), although according to Oliver and Middleditch (1991) the posterior tubercle of C1 may be palpable in some people between the EOP and the spinous process of C2. In the midline below the spinous process of the axis, the second prominent palpable structure is usually the spinous process of C7 or the vertebra prominens. In about 75% of the population the vertebra prominens is the most prominent spinous process, whereas the spinous process of C6 or T1 is more evident in the other 10% and 15% of the population, respectively (Stonelake, Burwell, & Webb, 1988). The other cervical spinous processes are variably more difficult to palpate. The spinous process of C3 is the smallest and can be found at the same horizontal plane as the greater cornua of the hyoid bone. The spinous process of C6 is the last freely movable spinous process with flexion and extension of the neck.

The zygapophysial joints between the articular processes of the cervical vertebrae (collectively known as the left and right articular pillars) can be found 1.5 cm lateral of the midline in the posterior neck. With the exception of C1, the tips of the transverse processes of the cervical vertebrae are not individually palpable, but the posterior tubercles of these processes form a bony resistance that may be palpated along a line from the tip of the mastoid process to the root of the neck, approximately a thumb breadth (2.5 cm) lateral of the midline. The anterior aspects of the transverse processes of the cervical vertebrae may be found in the groove between the larynx and sternocleidomastoid muscle (SCM). It may be necessary to slightly retract the SCM laterally to palpate these structures. The anterior tubercles of the transverse processes of C6 are especially large and are known as the carotid tubercles (see Fig. 1-2). These may be palpated at the level of the cricoid cartilage. Care must be taken when locating the carotid tubercles (and the other cervical transverse processes), because they are in the proximity of the common carotid arteries, and they always should be palpated unilaterally.

Anteriorly, the superior border of the thyroid cartilage, forming the laryngeal prominence (Adam's apple) in the midline, may be used to find the horizontal plane of the C4 disc. The body of C6 is located at the same horizontal level as the cricoid cartilage and the first tracheal ring.

Thoracic Region

The spinous process of T1 is usually the third prominent bony structure in the midline below the EOP; the spinous processes of C2 and C7 are the first and second, respectively (Fig. 1-3). Note that in about 10% of the population, the C6 spinous process is also very prominent. The spinous process of T3 is located at the same horizontal plane as the root of the spine of the scapula. The spinous process of T4 is located at the extreme of the convexity of the thoracic kyphosis; therefore it is usually the most prominent spinous process below the root of the neck.


External occipital protuberance
C2
C7
T1
T7
Inferior angle of the scapula
T12
L4
Iliac crest
Posterior superior iliac spine
S2 spinous tubercle
Coccyx
A

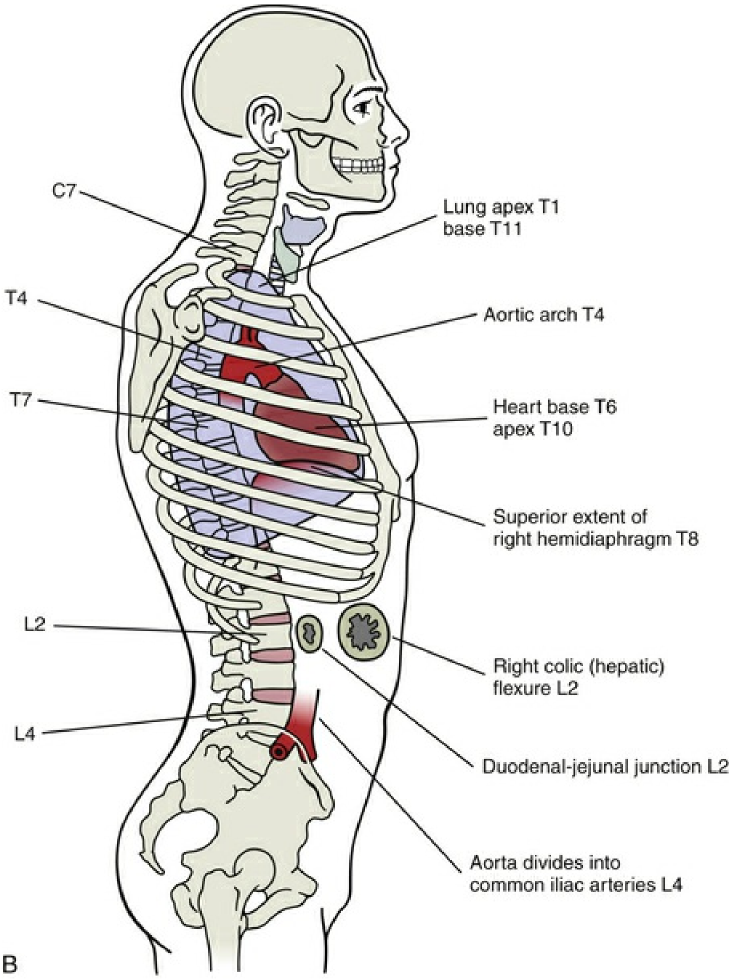


FIG. 1-3 **A,** Palpable landmarks of the back from a posterior view. **B,** Anatomic relationships from a lateral view.

When patients are standing or sitting with their upper extremities resting along the sides of their trunk, the inferior scapular angle usually is at the horizontal level of the spinous process of T8 (Cooperstein & Haneline, 2007; Haneline et al., 2008). This changes when the patient is lying prone with his or her upper extremities resting toward the floor in a flexed position (the most common posture of the patient when this region of the back is palpated). In this position the scapulae are rotated so that the T9 spinous process is more commonly found at the level of the inferior scapular angle (Cooperstein et al., 2009).

The spinous processes of T9 and T10 often are palpably closer together than other thoracic spinous processes, but this is not a consistent finding. Located approximately halfway between the level of the inferior angle of the scapula and the superior margin of the iliac crests is the spinous process of T12.

Because the spinous processes of the thoracic vertebrae project in an inferior direction to different degrees, the remainder of the vertebrae are located variably superior to the tip of the spinous process of the same vertebral segment (Keogh & Ebbs, 1984). The tips of the transverse processes of T1-4 and T10-12 are located one spinous interspace superior to the tip of the spinous process of the same segment. The tips of the transverse processes of T5-9 are located two spinous interspaces superior to the tips of their respective spinous processes because these spinous processes project inferiorly to a greater degree. For example, the tips of the transverse processes of T3 are located in the same horizontal plane as the inferior tip of the spinous process of T2, whereas the tips of the transverse processes of T8 are at the same horizontal plane as the inferior tip of the spinous process of T6. The transverse processes of the thoracic vertebrae progressively shorten from superior to inferior, so that the tips of the transverse processes of T1 are located 3 cm lateral to the midline, although those of T12 are 2 cm. Sometimes the transverse processes of T12 are small and not readily palpable. The angles of the ribs may be palpated 4 cm lateral to the midline at the horizontal levels of their respective transverse processes.

Lumbosacral Region

The posterior aspects of the spinous processes of the lumbar vertebrae differ from those of the thoracic vertebrae in that they present more of a flat surface. The spinous processes of L4 and L5 are shorter than the other lumbar spinous processes and are difficult to palpate, especially the L5 spinous process. The spinous process of L4 is the most inferior spinous process that has palpable movement with flexion and extension of the trunk. In the past the L4 spinous process was considered to be in a horizontal plane with the superior margin of the iliac crests (the supracristal plane), although in approximately 20% of the population the tops of the iliac crests were thought to be aligned with the spinous process of L5 (Oliver & Middleditch, 1991). However, more recent evidence, using ultrasound to localize intervertebral levels, shows the supracristal plane to be at the level of L3-4 in nearly 75% of normal volunteers. In the remainder of the healthy population, this plane is fairly evenly found at either L2-3 or L4-5 (Pysyk et al., 2010).

The tips of the transverse processes of the lumbar vertebrae are located approximately 5 cm lateral to the midline and usually are not palpable. The mamillary processes are small tubercles on the posterosuperior aspect of the superior articular processes of the lumbar vertebrae. They are located approximately a finger breadth (2 cm) lateral to the midline at the level of the spinous process of the vertebra above and are not readily palpable.

The second spinous tubercle, the remnants of the spinous process of S2, is located at the extreme of the convexity of the sacral kyphosis and is the most prominent spinous tubercle on the sacrum. It is also on the same horizontal plane as the posterior superior iliac spines, which are readily palpable 3 to 4 cm lateral to the midline. The third spinous tubercle is located at the upper end of the gluteal cleft. The lowest palpable depression in the midline of the posterior aspect of the sacrum is the sacral hiatus. There are four pairs of posterior sacral foramina located 2.5 cm lateral to the midline and 2.5 cm apart, but usually these are not palpable. The tip of the coccyx is the last palpable bony structure of the spine and can be found in the gluteal cleft approximately 1 cm posterior to the anus.

Spinal Cord Levels versus Vertebral Levels

The spinal cord is the extension of the central nervous system outside the cranium (Fig. 1-4). It is encased by the vertebral column and begins, on a gross anatomic level, at the foramen magnum, located halfway between the inion and the spinous process of C2. In the third fetal month the spinal cord, which is developing from the neural tube, extends the entire length of the embryo, and the spinal nerves exit the intervertebral foramina (IVFs) at their level of origin (Sadler, 2010). However, with increasing development the vertebral column and the dura mater lengthen more rapidly than does the neural tube, and the terminal end of the spinal cord gradually assumes a relatively higher level. At the time of birth the tip of the spinal cord, or conus medullaris, lies at the level of the L3 vertebral body. In the adult the conus medullaris usually is found at the L1-2 level (L1 body, 26%; L1 disc, 36%; L2 body, 20%), but may be found as high as the T12 disc (12%) or as low as the L2 disc (6%) (Fitzgerald, 1985). Chapters 3 and 13 and Table 3-1 provide further details on the inferior extent of the conus medullaris.

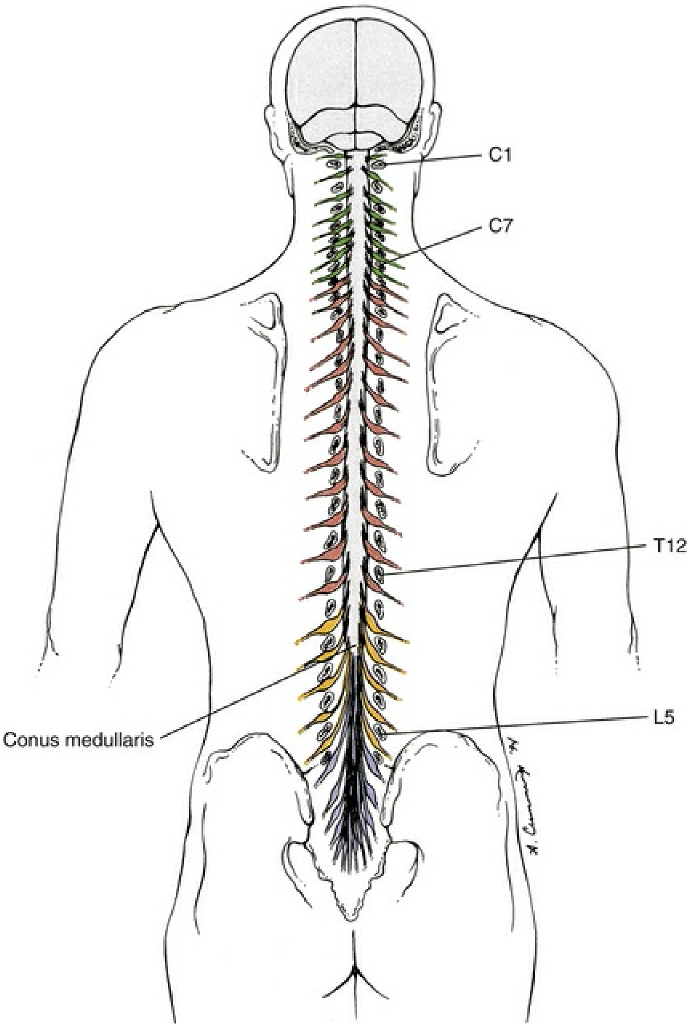


FIG. 1-4 Relationship between vertebral levels and spinal cord levels.

As a result of this unequal growth, the portion of the spinal cord from which the respective pairs of spinal nerve roots begin, known as the spinal cord level, is more superior than the level of the IVF from which the corresponding spinal nerve exits. Therefore the spinal nerve roots run obliquely inferior inside the vertebral (spinal) canal from their spinal cord level to their corresponding IVF. This obliquity is not equal throughout the length of the vertebral column. At the most superior levels of the vertebral column the spinal nerve roots are nearly horizontal, and at more inferior levels they are progressively more oblique. In the lumbosacral region of the vertebral canal, the spinal nerve roots are nearly vertical and form a bundle known as the cauda equina.

A convenient method of locating various structures of the neck and trunk is to relate them to the vertebra, or portion of a vertebra, that lies at the same horizontal level as that structure. This plane is known as the vertebral level of a structure. Unless otherwise noted, the vertebral body serves as the source of reference for the vertebral level. Table 1-1 lists the vertebral levels of many of the clinically important visceral structures in the anterior neck and trunk. When locating structures within the vertebral canal, spinal cord levels must be distinguished from vertebral levels. The cervical spinal cord levels lie at even intervals between the foramen magnum and the spinous process of C6 (Keogh & Ebbs, 1984). The upper six thoracic spinal cord levels are between the spinous processes of C6 and T4, and the lower six thoracic spinal cord levels are between the spinous processes of T4 and T9. The lumbar, sacral, and coccygeal spinal cord levels are located between the spinous processes of T10 and L1, where the spinal cord ends as the conus medullaris.

Table 1-1

Vertebral Levels of Clinically Important Structures

Vertebral Level	Structure
C1	Transition of medulla oblongata into spinal cord Hard palate Anterior portion of soft palate
C2	Inferior border of free edge of soft palate Nasopharynx and oropharynx join
C2 disc	Superior cervical ganglion
C3	Epiglottis Oropharynx becomes laryngopharynx
C3 disc	Common carotid arteries split into internal and external carotid arteries Carotid sinus
C3 spinous	Greater cornua of hyoid bone
C4 disc	Laryngeal prominence
C5	Vocal folds Erb's point Superior margin of lobes of thyroid gland
C6	Middle cervical ganglion Cricoid cartilage First tracheal ring Transition of larynx to trachea Transition of laryngopharynx to esophagus
C7	Inferior cervical ganglion
T1	Stellate ganglion Inferior margin of thyroid gland Subclavian and internal jugular veins unite to form brachiocephalic veins Apices of lungs
T2	Brachiocephalic veins unite to form superior vena cava
T2 disc	Suprasternal notch
T4	Aortic arch
T4 disc	Sternal angle (of Louis)
T5	Pulmonary trunk divides into right and left pulmonary arteries Pulmonary artery and primary bronchus enter right lung Trachea divides into primary bronchi Posterosuperior ends of oblique fissures of lungs
T6	Base of heart Pulmonary artery and primary bronchus enter left lung Pulmonary veins exit right lung Superior vena cava enters right atrium
T7	Pulmonary veins exit left lung Inferior vena cava enters right atrium Horizontal fissure of right lung
T8	Caval hiatus (diaphragm) Superior extent of right hemidiaphragm Superior border of liver
T9	Xiphisternal junction Fifth costal cartilage
	Inferior border of pectoralis major muscle Inferomedial angles of posterior aspects of lungs Superior extent of left hemidiaphragm Superior pole of spleen Left extent of inferior border of liver
T10	Apex of heart Anteroinferior ends of oblique fissures of lungs Esophageal hiatus (diaphragm)
T11	Lowest extent of lungs (inferolateral angles of posterior aspects of lungs) Inferior extent of esophagus Cardiac orifice of stomach Left suprarenal gland
T12	Aortic hiatus (diaphragm) Costodiaphragmatic recesses Inferior pole of spleen Tail of pancreas Orifice of gallbladder Superior poles of kidneys (right slightly lower than left) Right suprarenal gland
L1	Pyloric orifice of stomach Superior horizontal (first) part of duodenum Left colic (splenic) flexure
L1 disc	Transpyloric plane Conus medullaris Hila of kidneys (right slightly below and left slightly above)
L2	Duodenal-jejunal junction Right colic (hepatic) flexure Head of pancreas
L3	Subcostal plane (lowest portion of costal margin made up from the tenth costal cartilage) Umbilicus (inconsistent) Inferior horizontal (third) part of duodenum Right extent of lower border of liver Inferior poles of kidneys (right slightly lower than left)

L4	Beginning of sigmoid colon
	Aorta divides into common iliac arteries
L5	Common iliac veins unite to form inferior vena cava Ileocecal junction Vermiform appendix arises from cecum
L5 disc	Anterior superior iliac spine
	Superolateral end of inguinal ligament
S3	Beginning of rectum
Lower sacrum	Superior extent of uterus
Coccyx	Pubic crest Ganglion impar Superior margin of pubic symphysis Inferomedial end of inguinal ligament Bladder (empty)

The diameter of the spinal cord increases in two regions. These spinal cord enlargements are formed by the increased numbers of nerve cells necessary to innervate the limbs. The cervical enlargement includes the C4-T1 spinal cord levels and is at the level of the vertebral bodies of C4-7, or the spinous processes of C3-6 (Keogh & Ebbs, 1984). The lumbar enlargement is composed of the L2-S3 spinal cord levels and is found at the level of the T10-L1 vertebral bodies or the spinous processes of T9-12.

Vertebral Levels of Structures in the Anterior Neck and Trunk

This section describes the vertebral levels of most of the clinically important structures found in the anterior neck and trunk. Knowledge of the surface locations for the deep structures of the anterior neck and trunk is essential for relating those structures to the whole person, especially during the physical examination. This information is summarized in Table 1-1.

Visual Landmarks

The most obvious visible structure in the anterior neck region is the laryngeal prominence (Fig. 1-5). It can be seen in the midline at the level of the C4 disc and is larger in adult men than in women. Moving inferiorly, the jugular notch (or incisure) of the sternum, or suprasternal notch, is at the superior margin of the manubrium and corresponds with the horizontal plane of the T2 disc or T1-2 interspinous space. The sternal angle (of Louis) at the inferior margin of the manubrium is at the level of the T4 disc. Near the inferior end of the sternum the xiphisternal junction is found. It corresponds not only with the body of T9 but also with the inferior margin of the pectoralis major muscle and the fifth costal cartilages. These relationships are quite variable depending on body type. Laterally, the lowest portion of the costal margin consists of the tenth costal cartilages. The horizontal plane at this level is termed the subcostal plane and passes through the body of L3 (Moore & Dalley, 2006).

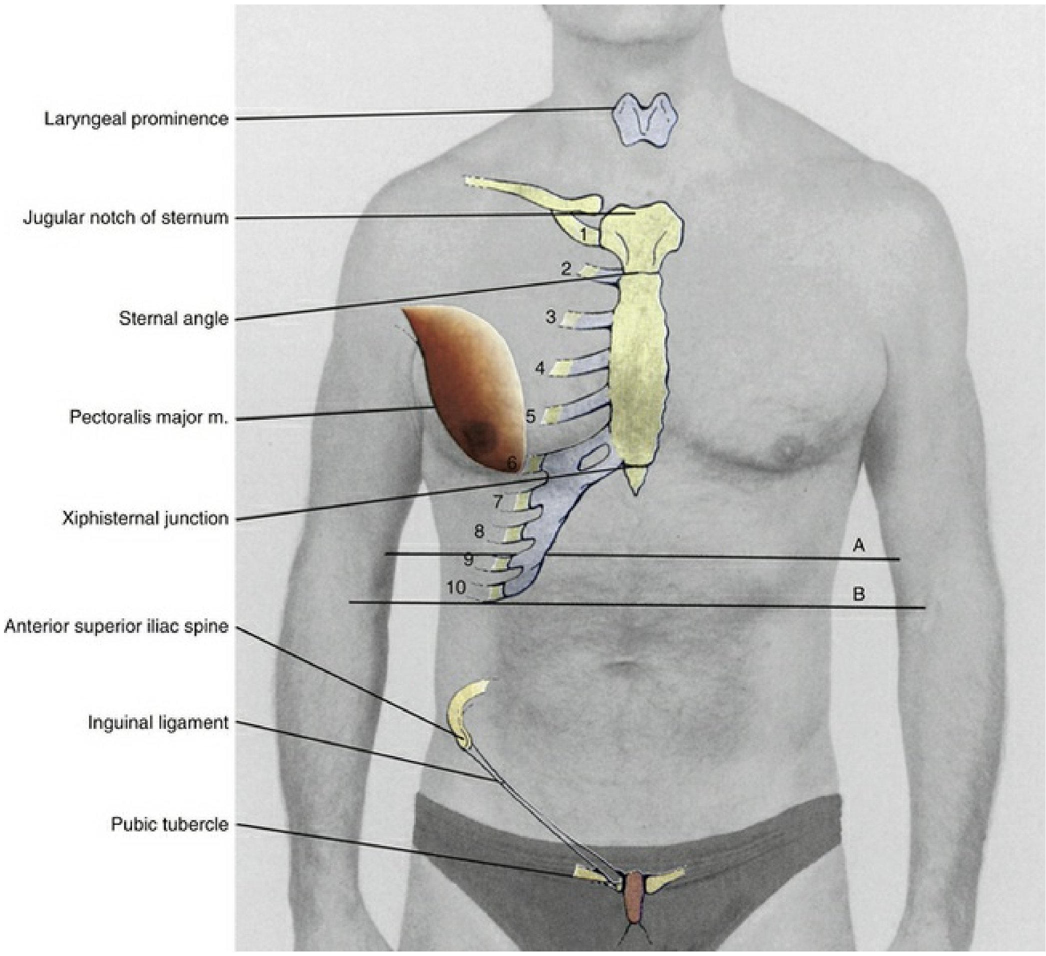


FIG. 1-5 Visual landmarks of the anterior trunk. **A,** The transpyloric plane. **B,** The subcostal plane. Note that the ribs have been numbered.

The transpyloric plane is the horizontal plane at the halfway point between the upper border of the symphysis pubis and suprasternal notch. It corresponds with the L1 disc and usually is one hand breadth (10 cm) inferior to the xiphisternal junction. The vertebral level of the umbilicus is typically at the level of L3, but this varies depending on body type and weight. The pubic crest is identified with the level of the superior margin of the pubic symphysis. It extends 2.5 cm lateral to the midline and has a prominence on its lateral aspect known as the pubic tubercle. Typically the pubic crest is in the same plane as the coccyx, but again weight and body type can alter the tilt of the pelvis and therefore this relationship. The inguinal ligament extends from the anterior superior iliac spine at the level of the L5 disc to the pubic tubercle and demarcates the beginning of the thigh region.

Deeper Structures

Neural Structures

At the level of the atlas, the gross anatomic transition of the medulla oblongata into the spinal cord occurs as it exits the cranium via the foramen magnum. The conus medullaris, the inferior tip of the spinal cord, usually is found at the L1-2 level (see previous discussion).

The sympathetic trunks (Fig. 1-6) extend along the entire anterolateral aspect of the spinal column. In the cervical region the trunks are approximately 2.5 cm lateral to the midline. They are somewhat more laterally located in the thoracic and lumbar regions. Along the anterior surface of the sacrum the trunks begin to converge until they meet as the ganglion impar on the anterior surface of the coccyx. Sympathetic ganglia are located at fairly regular intervals along these trunks. Typically there are three ganglia in the cervical region (see Fig. 1-6). The superior cervical ganglion can be found at the C2-3 interspace. The middle and inferior cervical ganglia typically are found at the C6 and C7 levels, respectively. Sometimes the inferior cervical ganglion and first thoracic ganglion unite to form the stellate (or cervicothoracic) ganglion, which is found at the T1 level. The sympathetic trunks are described in more detail in Chapters 5-8 and 10.

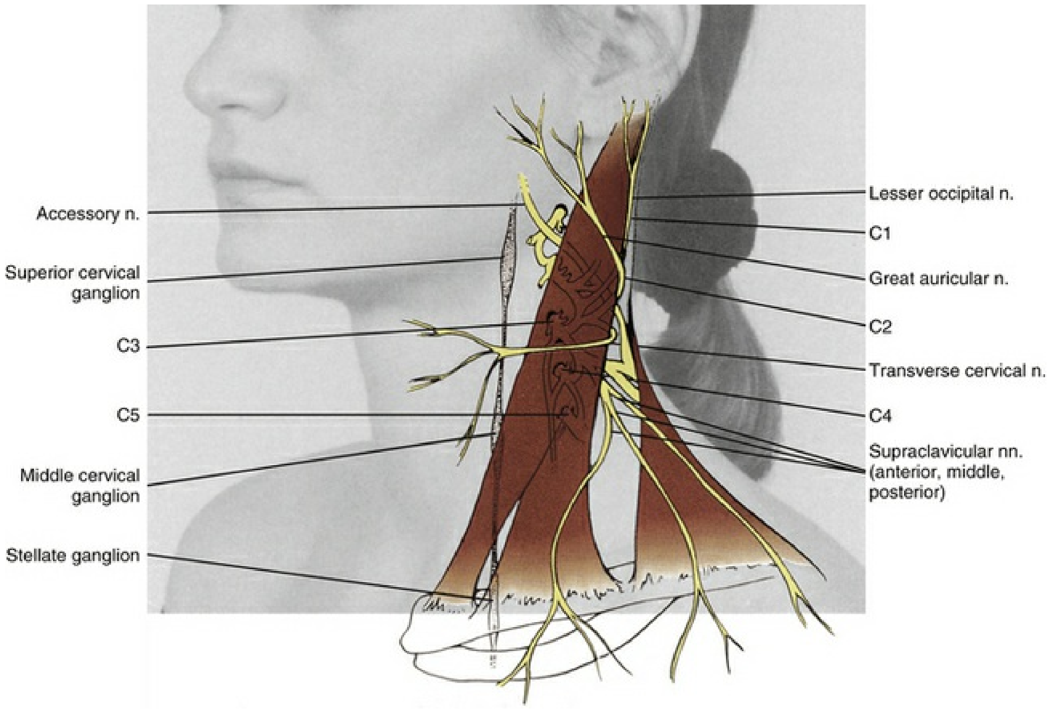


FIG. 1-6 Erb's point and the cervical sympathetic trunk. Note that Erb's point is located midway along the posterior border of the sternocleidomastoid muscle. Also note the sympathetic trunk connecting the cervical sympathetic ganglia.

Several peripheral nerves become superficial approximately midway along the posterior border of the SCM (see Fig. 1-6). This area is sometimes called Erb's point and is approximately at the C5 level. These nerves include the transverse cervical nerve, which supplies the skin of the throat region; the lesser occipital nerve, which innervates the skin in the area of the mastoid process; and the great auricular nerve, which innervates the skin in the vicinity of the ear. In addition, the supraclavicular nerves arise by a common trunk that emerges from Erb's point. This trunk divides into three branches that either are called anterior, middle, and posterior or are named medial, intermediate, and lateral; they course through the skin of the upper chest region. Finally, the accessory nerve (cranial nerve XI) becomes relatively superficial in this region after sending motor branches into the deep surface of the SCM. It then courses in a posterolateral direction, across the posterior triangle of the neck, to reach the deep surface of the trapezius muscle, which it also supplies with motor innervation.

The roots of the brachial plexus, which arise from the ventral rami of the C5-T1 spinal nerves, are located just posterior to the lower one third of the SCM (Keogh & Ebbs, 1984). The upper (or lateral) margin of the plexus runs along a line from the junction of the middle and lower thirds of the SCM to the tip of the coracoid process of the scapula. The lower (or medial) border of the plexus extends from the junction of the posterior border of the SCM with the clavicle to one finger breadth (2 cm) inferior and medial to the tip of the coracoid process of the scapula.

Vascular Structures

The shape of the heart may be thought of as an isosceles triangle with a superior base and an inferior apex directed to the left of the midline (Fig. 1-7). The base of the heart usually can be found at the level of T6. The horizontal position of the apex of the heart typically is said to be at the level of T10, but this is variable depending on the patient's body type. It may be found as high as T9 (Moore & Dalley, 2006) or as low as T11 (Gardner, Gray, & O'Rahilly, 1975).

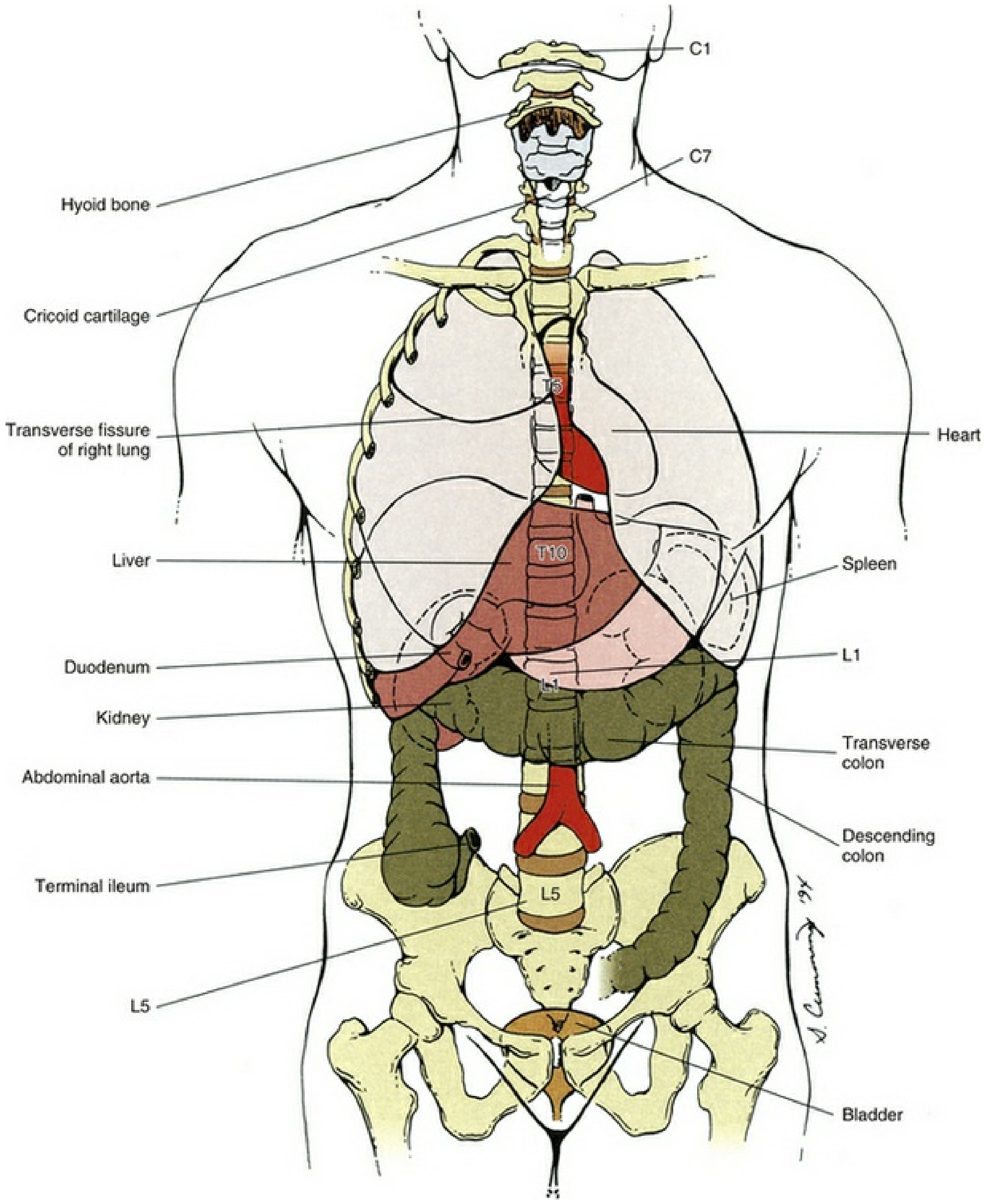


FIG. 1-7 Vertebral levels of deeper structures of the anterior neck and trunk.

The ascending aorta emerges from the left ventricle of the heart approximately in the midline and runs superiorly. It then turns to the left and forms the aortic arch that can be found at the level of the T4 body. The thoracic portion of the descending aorta begins in the plane of the T4 disc and runs inferiorly slightly left of the midline along the anterior surface of the thoracic vertebrae. It becomes the abdominal aorta as it passes through the aortic hiatus of the diaphragm in the midline at the level of T12 (Moore & Dalley, 2006). The abdominal aorta descends along the anterior surface of the lumbar vertebrae and divides into the common iliac arteries just anterior to the L4 body, slightly left of the midline.

The aortic arch has three branches. The first is the brachiocephalic trunk. This trunk gives rise to the right common carotid and right subclavian arteries. The left common carotid artery is the second branch of the aortic arch, and the left subclavian artery is the third branch of the aortic arch. The subclavian arteries supply blood to the upper extremities, and the common carotid arteries supply the head and neck region. The common carotid arteries ascend on either side of the anterolateral aspect of the neck to the level of the C3 disc, where they each split into an internal and external carotid artery. This is the region of the important carotid sinus, which monitors the blood pressure of the body. Therefore care must be taken when palpating these structures, and they should always be palpated only unilaterally.

The pulmonary trunk arises from the right ventricle of the heart and divides into the right and left pulmonary arteries in a plane with T5. The pulmonary arteries enter (and the pulmonary veins exit) their respective lungs via a hilum. The pulmonary artery of the right lung enters in the plane of T5 and that of the left lung at the level of T6 (Standring et al., 2008). The pulmonary veins exit the lungs approximately one vertebral level lower than the arteries enter. There is some variation of these levels with body type, and both of the pulmonary arteries may enter their respective lungs as low as T7 (Gardner, Gray, & O'Rahilly, 1975).

The internal jugular and subclavian veins of each side of the body unite several centimeters lateral to the midline at the level of T1 to form the brachiocephalic veins. The brachiocephalic veins then unite to form the superior vena cava slightly right of the midline at the T2 level (Standring et al., 2008). The superior vena cava courses inferiorly and ends in the upper portion of the right atrium of the heart at approximately the level of T6.

The common iliac veins unite to form the inferior vena cava at the level of the L5 body, a little to the right of the midline. The inferior vena cava then ascends in front of the vertebral column, on the right side of the abdominal aorta. Passing through the caval hiatus of the diaphragm in the horizontal plane of the body of T8 (Moore & Dalley, 2006), the inferior vena cava enters the lower portion of the right atrium just above that level at T7.

Visceral Structures

The respiratory system begins with the nasal cavity, which is separated from the oral cavity by the hard palate. The hard palate lies in the same horizontal plane as the atlas. The nasal cavity becomes continuous with the nasopharynx in the region of the soft palate also at the level of C1. The nasopharynx joins the oropharynx at the inferior border of the posterior margin of the soft palate just anterior to the C2 body, and for several centimeters the alimentary and respiratory systems share a common passageway. At the superior border of the epiglottis, the oropharynx becomes the laryngopharynx. In this region the alimentary and respiratory tracts again become separate. Anteriorly the respiratory tract continues as the larynx. Its lumen is protected during deglutition by the epiglottis, which may be found at the C3 level. The adjacent hyoid bone provides attachment sites for several muscles involved in deglutition and vocalization, and its greater cornua can be found at the C3 spinous process level. The most anterior projection of the thyroid cartilage, the laryngeal prominence, is at the level of the C4 disc, and the vocal folds, or cords, are slightly lower in the C5 plane. The cricoid cartilage, the lowest portion of the larynx, joins the first tracheal ring, the highest portion of the trachea, at the level of C6. The lobes of the thyroid gland are located anterior and lateral to the larynx and trachea and extend from the C5 to T1 levels. The trachea descends in the midline anterior to the esophagus to the level of the upper border of the T5 body, where it divides into the primary bronchi (Standring et al., 2008). The primary bronchi enter the lungs via their respective hila at around the same levels as the pulmonary arteries, which are T5 on the right and T6 on the left.

The apex of each lung extends superiorly to the level of the T1 body (see Fig. 1-7). On their posterior aspects, the inferomedial angles of both lungs are approximately at T9, and the inferolateral angles, the lowest portion of the lungs, extend inferiorly to near T11. The anteroinferior border of each lung is approximately one vertebral level higher than the posterior border. With full inspiration these levels may descend nearly two vertebral segments (Standring et al., 2008).

The left lung is divided into upper and lower lobes by an oblique fissure. This fissure extends from the T5 level posterosuperiorly to T10 anteroinferiorly. The right lung not only has an oblique fissure similar to that of the left lung, but also has a horizontal fissure at the level of T7. Therefore the right lung is divided into three lobes: upper, middle, and lower.

The diaphragm extends several vertebral levels superiorly in its center and is shaped like a dome. Therefore the diaphragm makes an impression on the inferior surface of each of the lungs. The right half of the diaphragm, often termed the right hemidiaphragm, reaches the T8 level and because of the underlying liver is approximately 1 cm higher than the level of the left hemidiaphragm (Moore & Dalley, 2006). With full inspiration, these levels may descend as much as two vertebral levels (Standring et al., 2008). Normally the pleural cavity extends slightly lower than the inferolateral angles of the lungs and forms the costodiaphragmatic recesses at the level of T12. Because of the domelike shape of the diaphragm, these recesses represent the lowest points of the thoracic cavity and are potential sites of fluid accumulation in the chest.

The alimentary canal begins as the oral cavity, which becomes the oropharynx in the region of the soft palate at the C1 level. The oropharynx, after being joined by the nasopharynx at the inferior border of the free edge of the soft palate just in front of the C2 body, turns into the laryngopharynx at the superior border of the epiglottis at the level of C3. The laryngopharynx continues inferiorly on the posterior aspect of the larynx and changes into the esophagus at the level of C6. The esophagus runs inferiorly in the chest on the anterior aspect of the vertebral column slightly anterior and to the right of the descending thoracic aorta. Passing through the diaphragm via the esophageal hiatus at the T10 level, the esophagus enters the abdomen (Standring et al., 2008) and ends at the cardiac orifice of the stomach slightly left of the midline at T11.

The stomach is the most dilated portion of the alimentary canal. Curving inferiorly and to the right, the stomach becomes continuous with the small intestine at the pyloric orifice at the level of L1. The duodenum, the first part of the small intestine, is shaped like a U lying on its side and has four parts. The first (superior horizontal) part continues from the pyloric orifice horizontally to the right at the level of L1. The second (descending) part proceeds inferiorly to the horizontal plane of L3, where it turns to the left to become the third (inferior horizontal) part. The third part continues to the left, crosses the midline, and bends slightly superiorly to give rise to the fourth (ascending) part that runs obliquely superior and ends as the duodenal-jejunal junction at the level of L2.

The rest of the small intestine continues as a series of loops and ends by connecting with the large intestine at the junction of the cecum and the ascending portion of the colon in the right lower quadrant of the abdomen at the L5 level. The proximal (oral) two fifths and the distal (aboral) three fifths of the small intestine distal to the duodenum are called the jejunum and ileum, respectively.

The large intestine begins as the cecum, which is a cul-de-sac located in the right iliac fossa (see Fig. 1-7). The ileum connects with the upper portion of the cecum at the L5 level. The vermiform appendix usually arises from the cecum approximately one finger breadth (2 cm) inferior to the ileocecal junction. The large intestine continues in a superior direction above the ileocecal junction as the ascending colon. At the level of L2 the ascending colon makes a sharp turn to the left and continues as the transverse colon. This sharp turn is termed the right colic, or hepatic, flexure, because it is just below the liver. The transverse colon continues horizontally and slightly superiorly across the midline to the left side of the abdomen, where it turns sharply inferior. This left colic flexure occurs at the L1 level, which is slightly more superior than the right colic flexure. The left colic flexure, located just below the spleen, sometimes is termed the splenic flexure. The large intestine then continues inferiorly on the left side of the abdominal cavity as the descending colon. At the L4 level, the large intestine becomes somewhat tortuous and is called the sigmoid colon. The sigmoid colon then continues into the true pelvis and becomes the rectum in the midline at the S3 level.

The head of the pancreas can be found within the curve of the duodenum. Usually it is described as being located at the level of L2 (Standring et al., 2008). The neck and body of the pancreas extend superiorly and obliquely to the left. The body of the pancreas ends as the tail of the pancreas, which can be found at the lower pole of the spleen in the left upper quadrant at T12. The superior pole of the spleen is adjacent to the left hemidiaphragm at approximately the level of T9.

The liver, the largest gland of the body, is found mostly in the upper right quadrant of the abdomen, but its left lobe does extend somewhat across the midline. Superiorly the liver is in contact with the diaphragm and fills the domelike hollow of the right hemidiaphragm. The superior border of the liver therefore extends up to the T8 level. The inferior border runs diagonally from the right side of the abdomen at the level of L3 to the left hemidiaphragm at the T9 horizontal plane (Standring et al., 2008). The gallbladder rests in a fossa in the inferior border of the right lobe of the liver. The orifice of the gallbladder is usually found at the T12 level.

The urinary system begins with the kidneys. The superior poles of the kidneys lie at the level of T12 and their inferior poles at L3. The right kidney is slightly lower than the left kidney, probably because of its relationship with the liver (Standring et al., 2008). The suprarenal, or adrenal, glands are located on the anterosuperior borders of the kidneys. As with the kidneys, the left suprarenal gland is located somewhat more superior than the right. These endocrine glands can be found at the T11 and T12 levels, respectively. The hilum of the left kidney is just above the level of the L1 disc (transpyloric plane), and that of the right kidney just below it. A ureter arises from the hilum of each kidney, and both run to the bladder in an inferior and slightly medial direction. The bladder is a midline structure in the true pelvis posterior to the pubic symphysis at the coccygeal level. The bladder may expand upward and forward into the abdominal cavity when distended.

In the female the uterus lies posterior to the bladder and anterior to the rectum. Superiorly the uterus extends above the superior border of the bladder to the lower sacral levels, and because of its anteverted and anteflexed position, the superior portion of the uterus usually lies on the posterior portion of the superior surface of the empty bladder. The ovaries are situated with one ovary located on either side of the uterus near the lateral wall of the true pelvis. The position of the ovaries is variable, especially in parous women, because they are displaced during a woman's first pregnancy and probably never return to their original position (Standring et al., 2008).

This chapter serves as a useful reference as the reader progresses through the rest of this text. Knowledge of the structures of the body that are visible and palpable through the skin and an awareness of the surface locations of deeper structures are important tools in the proper examination and evaluation of patients. Therefore this chapter is designed not only as a beginning reference point for the rest of the text, but also as a quick reference for the health care provider.

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CHAPTER 2

General Characteristics of the Spine

Gregory D. Cramer

The purpose of this chapter is to discuss the basic and clinical anatomy of the spine as a whole, that is, to introduce many of the features that are common to the major regions of the spine (cervical, thoracic, and lumbar). Some of the topics listed are discussed in more detail in later chapters.

Function and Development of the Spine

The anatomy of the human spine can be understood best if its functions are considered first. The spine has three primary functions: support of the body, protection of the spinal cord and spinal nerve roots, and movement of the trunk. The vertebral column has the ideal structure to carry out all of these functions simultaneously (Putz & Müller-Gerbl, 1996). These varied functions are performed by a series of movable bones, called vertebrae, and the soft tissues that surround these bones. A brief explanation of the development of the vertebrae and the related soft tissues is given to highlight the detailed anatomy of these structures. A more thorough discussion of spinal development is presented in Chapter 12.

Development Of The Spine

After the early development of the neural groove into the neural tube and neural crest (see Fig. 12-7), paraxial mesoderm condenses to form somites (see Figs. 12-7 and 12-9, *A*). The somites, in turn, develop into dermomyotomes and sclerotomes. Portions of the lateral aspects of the dermomyotomes develop into the dermis and subcutaneous tissue, whereas the majority of the dermomyotomes develop into the axial musculature. The sclerotomes migrate centrally to surround the neural tube and notochord (see Fig. 12-9, *B*). The sclerotomal cells then form the vertebral column and associated ligaments.

While the paraxial mesoderm is developing into somites, the more inferior portion of the neural tube differentiates into the ependymal, mantle, and marginal layers of the future spinal cord. The ependymal layer surrounds the future central canal region of the spinal cord. The mantle layer develops into the cells of the nervous system (neurons and glia), and the outer marginal layer of the tube consists of the axons of tract cells. The neural crest develops into the sensory neurons of the peripheral nervous system and the postganglionic neurons of the autonomic nervous system.

Chondrification Centers and Primary Ossification Centers

Cells of sclerotomal origin condense to form vertebral chondrification centers (one pair in the anterior aspect and at least one center in each half of the posterior aspect of the mesenchymal vertebrae). This results in the development of a cartilage model of each vertebra (see Fig. 12-11). Each vertebra then develops three primary centers of ossification (see Fig. 12-11). One primary center is located in the anterior part of the future vertebra. This region is known as the centrum and helps to form the future vertebral body. The remaining two primary ossification centers are located on each side of the portion of the vertebra that surrounds the developing neural tube. This region is known as the neural or posterior arch. The two ossification centers at the neural arch normally unite posteriorly to form the spinous process. Failure of these centers to unite results in a condition known as spina bifida. This condition is discussed in more detail in Chapter 12.

Anteriorly the left and right sides of the neural arch normally fuse to the centrum. Known as the neurocentral synchondrosis, this region actually is located within the area that becomes the posterior aspect of the vertebral body. The fusion that occurs unites the primary ossification centers of the neural arch with the centrum, consequently forming a vertebral body from both the centrum and a small part of the neural arch. Because of this unique fusion the vertebral arch is somewhat smaller than its developmental predecessor, the neural arch, and the vertebral body is somewhat larger than its predecessor, the centrum.

The precise time of fusion between the neural arch and centrum at the neurocentral synchondrosis remains a topic of investigation. Some researchers state that closure occurs by 6 years of age (Maat et al., 1996), and other investigators claim that the neurocentral cartilage may remain until as late as 16 years of age (Vital et al., 1989). Part of the function of the neurocentral cartilage is to ensure growth of the posterior arch of the vertebrae. Early fusion of the neurocentral synchondrosis has been implicated in the development of scoliosis (Vital et al., 1989). Scoliosis is discussed in more detail in Chapter 6.

Usually the vertebral body develops from two centers of chondrification, left and right. If one of these centers fails to develop, only one half of the vertebral body remains. This is known as a hemivertebra, or cuneiform vertebra, and can result in lateral curvature of the spine. Frequently a hemivertebra at one level is compensated by the same condition at another level on the opposite side.

During development the vertebral bodies may appear to be wedge shaped, narrower anteriorly than posteriorly. This can give the appearance of a compression fracture (Fesmire & Luten, 1989). Wedging that occurs in several consecutive vertebrae is seen as an indication of a normal variant. However, a compression fracture of the wedge-shaped vertebra must be considered if it occurs at only one level and the vertebrae above and below are more rectangular in appearance.

Secondary Ossification Centers

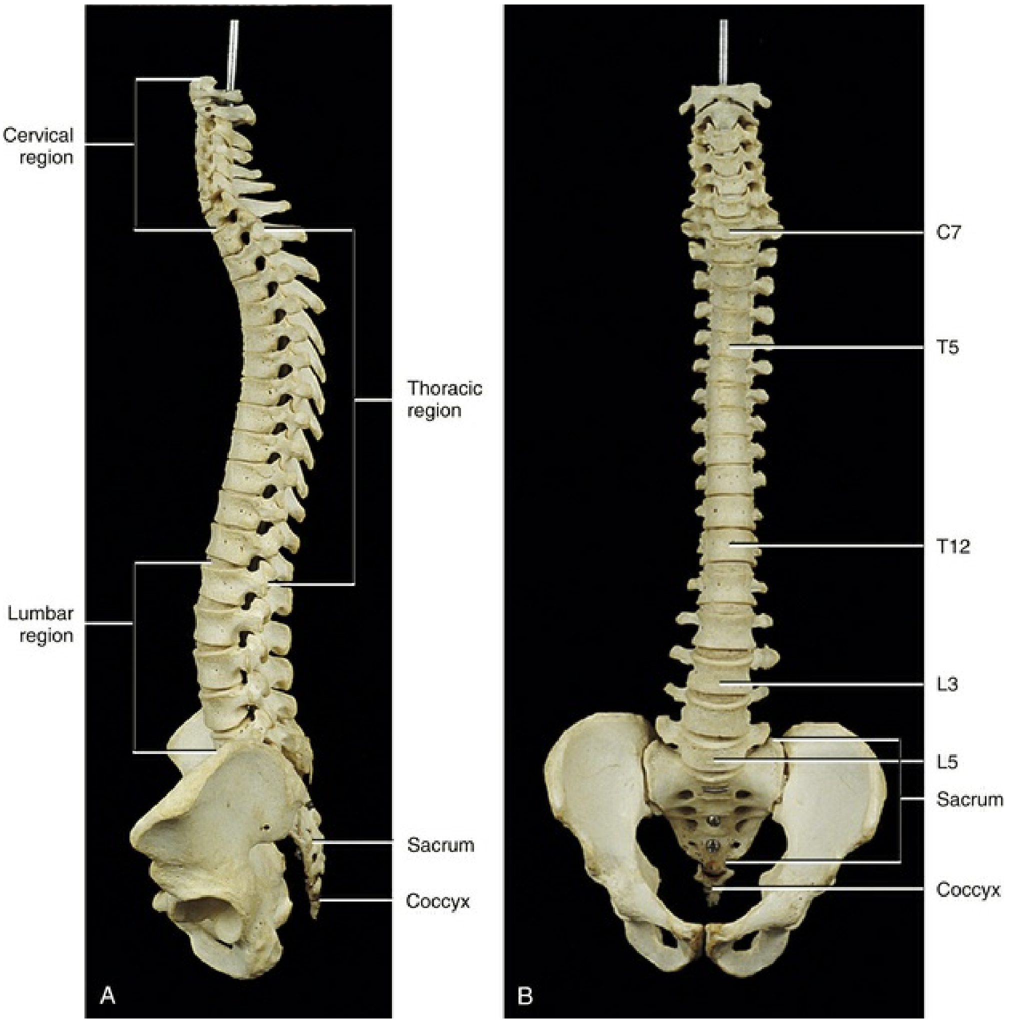
Five secondary centers of ossification appear in the vertebral column between the ages of 10 and 13 (see Fig. 12-11). One secondary center of ossification is located on each of the cartilaginous end plates of a typical vertebral body. These centers are known as the anular apophyses (singular, apophysis), ring apophyses, or anular epiphyses (Standring et al., 2008). A secondary center of ossification also is found on the tips of each of the transverse processes, and another is located on the tip of the single spinous process. The centers on the transverse processes and spinous process enable the rapid growth of these processes that occurs during adolescence.

The two centers of ossification associated with the peripheral rim of the upper and lower surfaces of the vertebral bodies (anular apophyses) do not help with the longitudinal growth of the vertebral bodies and for this reason are termed ring *apophyses* (Theil, Clements, & Cassidy, 1992; Bogduk, 2005a). These centers incorporate the outer layers of the anulus fibrosus (Fardon, 1988), which explains the bony attachment of the outer layers of the anulus, whereas the more central layers are attached to the cartilage of the vertebral end plates (Bogduk, 2005a).

All of the secondary ossification centers listed previously fuse with the remainder of the vertebrae between the ages of 14 and 25 (Bogduk, 2005a; Standring et al., 2008), and no further growth can occur after their fusion. These centers can be mistaken as sites of fracture before they have fused.

Fully Developed Vertebral Column

The first accurate description of the number of movable vertebrae in the fully developed spine was that of Galen between 100 and 200 ad (Shapiro, 1990). However, perhaps because of the many anatomic errors made by Galen in other areas, controversy ensued over the precise number of vertebrae until the publication of Vesalius' *De Humani Corporis Fabrica* in 1543 (Shapiro, 1990). This publication showed that the human vertebral column develops into 24 vertebrae (Fig. 2-1), which are divided into 7 cervical, 12 thoracic, and 5 lumbar vertebrae (expressed as C1-7, T1-12, and L1-5, respectively). The L5 vertebra rests on the bony sacrum (made of five fused segments). The coccyx (three to five fused segments) is suspended from the sacrum. All of these bones are joined by means of a series of approximately 361 joints (including synovial, symphyses, and syndesmoses; and including the joints between the vertebrae and ribs and the joints associated with the sacrum and the coccyx) to form the vertebral column. See Appendix I for a detailed list of the joints of the vertebral column.



Cervical region
Thoracic region
Lumbar region
Sacrum
Coccyx
A
C7
T5
T12
L3
L5
Sacrum
Coccyx
B

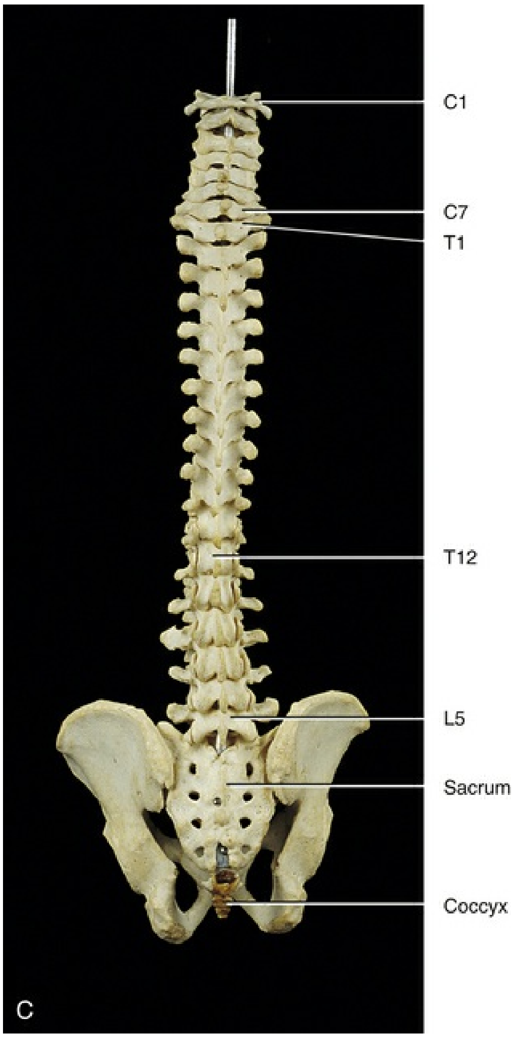


FIG. 2-1 Three views of the vertebral column. **A,** Lateral view showing the cervical, thoracic, lumbar, and sacral regions. Also notice the cervical and lumbar lordoses and the thoracic and sacral kyphoses. **B,** Anterior view. **C,** Posterior view of the vertebral column.

Curves of the Spine

The spine develops four anterior to posterior curves, two kyphoses, and two lordoses. (See introduction of text for further clarification of the terms lordosis and kyphosis.) Kyphoses are curves that are convex posteriorly (concave anteriorly), and lordoses are curves that are convex anteriorly (concave posteriorly). The two primary curves are the kyphoses. These include the thoracic and pelvic curvatures (see Fig. 2-1). They are called primary curves because they are seen from the earliest stages of fetal development. The thoracic curve extends from T2 to T12 and is created by the larger superior to inferior dimensions of the posterior portion of the thoracic vertebrae (see Chapter 6). The pelvic curve extends from the lumbosacral articulation throughout the sacrum to the tip of the coccyx. The concavity of the pelvic curve faces anteriorly and inferiorly, and is also caused by the greater superior to inferior dimensions of the posterior portion of the sacral segments.

The two secondary curves are the cervical lordosis and lumbar lordosis (see Fig. 2-1). These curves are known as secondary or compensatory curves because, even though they can be detected during fetal development, they do not become apparent until the postnatal period. The cervical lordosis begins late in intrauterine life but becomes apparent when an infant begins to lift his or her head from the prone position (approximately 3 to 4 months after birth). This forces the cervical spine into a lordotic curve. The cervical lordosis is further accentuated when the small child begins to sit upright and stabilizes his or her head while looking around in the seated position. This occurs at approximately 9 months of age. In the adult, the cervical curve is maintained by the larger superior to inferior dimensions of the anterior portion of the intervertebral discs. Because this curve is primarily created by the pliable intervertebral discs, traction of the cervical region reduces the cervical lordosis, whereas traction to the thoracic region has little effect on the thoracic kyphosis, because the thoracic curve is primarily created by the shape of the vertebrae. Further details of the cervical curvature are given in Chapter 5.

The action of the erector spinae muscles (see Chapter 4), pulling the lumbar spine erect to achieve the position necessary for walking, creates the posterior concavity known as the lumbar lordosis (see Fig. 2-1). Therefore the lumbar lordosis develops approximately 9 to 18 months after birth while the infant begins to walk upright. The lumbar lordosis extends from T12 to the lumbosacral articulation and is more pronounced in females than in males. The region between L3 and the lumbosacral angle is more prominently lordotic than the region from T12 to L2. After infancy, the lumbar lordosis is maintained by a combination of the shape of the intervertebral discs and the shape of the vertebral bodies. Each of these structures is taller anteriorly than posteriorly in the lumbar region of the spine. Therefore the lumbar lordosis is reduced when traction forces are applied to it, but the reduction is less than that found during traction of the cervical region.

A slight lateral curve normally is found in the upper thoracic region. The convexity of the curve is on the left in left-handed people and on the right in right-handed people. Such deviations are probably the result of asymmetric muscle use and tone.

The lumbar lordosis and thoracic kyphosis both increase from the supine to the standing position (Wood et al., 1996). In addition, the cervical lordosis has been found to compensate for the variations in lumbar lordosis that occur during changes in position and during normal motion. For example, lumbar lordosis increases during sitting in the erect position and cervical lordosis decreases during this activity. Lumbar lordosis decreases during lumbar forward flexion and cervical lordosis increases during lumbar flexion, and the opposite occurs during lumbar extension (Black, McClure, & Polansky, 1996).

The kyphoses and lordoses of the spine, along with the intervertebral discs, help to absorb the loads applied to the spine. These loads include the weight of the trunk, along with loads applied through the lower extremities during walking, running, and jumping. In addition, loads are applied by the carrying of objects with the upper extremities, by the pull of spinal muscles, and by the wide variety of movements that normally occur in the spine. The spinal curves, acting with the intervertebral discs and vertebral bodies, dissipate the increased loads that would occur if the spine were shaped like a straight column. Yet even with these safeguards, the vertebrae can be fractured as a result of the person falling and landing on the feet or buttocks, objects falling and landing on the head, or the person diving and landing on the head. Such injuries usually compress the vertebral bodies. Cervical compression usually occurs between C4 and C6 (Croft, 2009). When the force emanates from below, T9 through L2 are the most commonly affected through compression. Flexion injuries also can result in a compression fracture of vertebral bodies. Again, C4 through C6 are the most commonly affected in the cervical region, whereas T5 and T6 and the upper lumbar vertebrae usually are affected in the thoracic and lumbar regions (White & Panjabi, 1990).

Anatomy of a Typical Vertebra

A typical vertebra can be divided into two basic regions: a vertebral body and a vertebral arch (also called the posterior arch or dorsal arch). The bone in both regions is composed of an outer layer of compact bone and a core of trabecular bone, also known as cancellous, or spongy, bone (Fig. 2-2). The cancellous bone is composed of myriad spicules of bone, known as trabeculae (singular, trabecula). The trabeculae are oriented parallel to the lines of greatest stress (Skedros, Mason, & Bloebaum, 1994; Skedros et al., 1994). Smit and colleagues (1997) found that the trabecular architecture of the lumbar vertebral bodies was ideal for the loads placed on the spine during axial compression (loads placed on the vertebral bodies from above; for example, to resist gravity) and walking. That is, not only were the trabeculae arranged to withstand axial compression, but also they were quite strong where the pedicles of the posterior arch met the vertebral bodies. This latter finding is consistent with the transfer of loads from the articular processes of the posterior arch to the vertebral bodies during rotational movements in the horizontal plane, and anterior to posterior ("shearing") movements (most closely associated with walking).

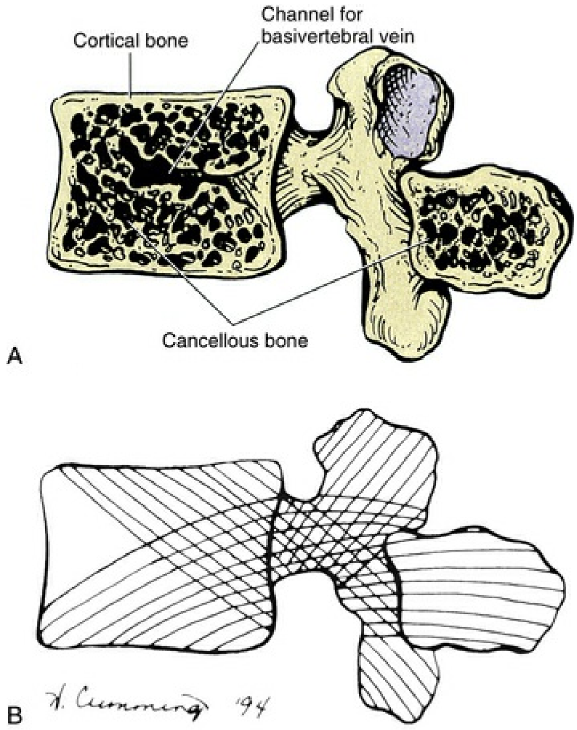


FIG. 2-2 Midsagittal view of a vertebra. **A,** The central cancellous, or trabecular, bone of the vertebral body and spinous process. Also notice the more peripheral cortical bone. **B,** The pattern of trabeculation, which develops along the lines of greatest stress.

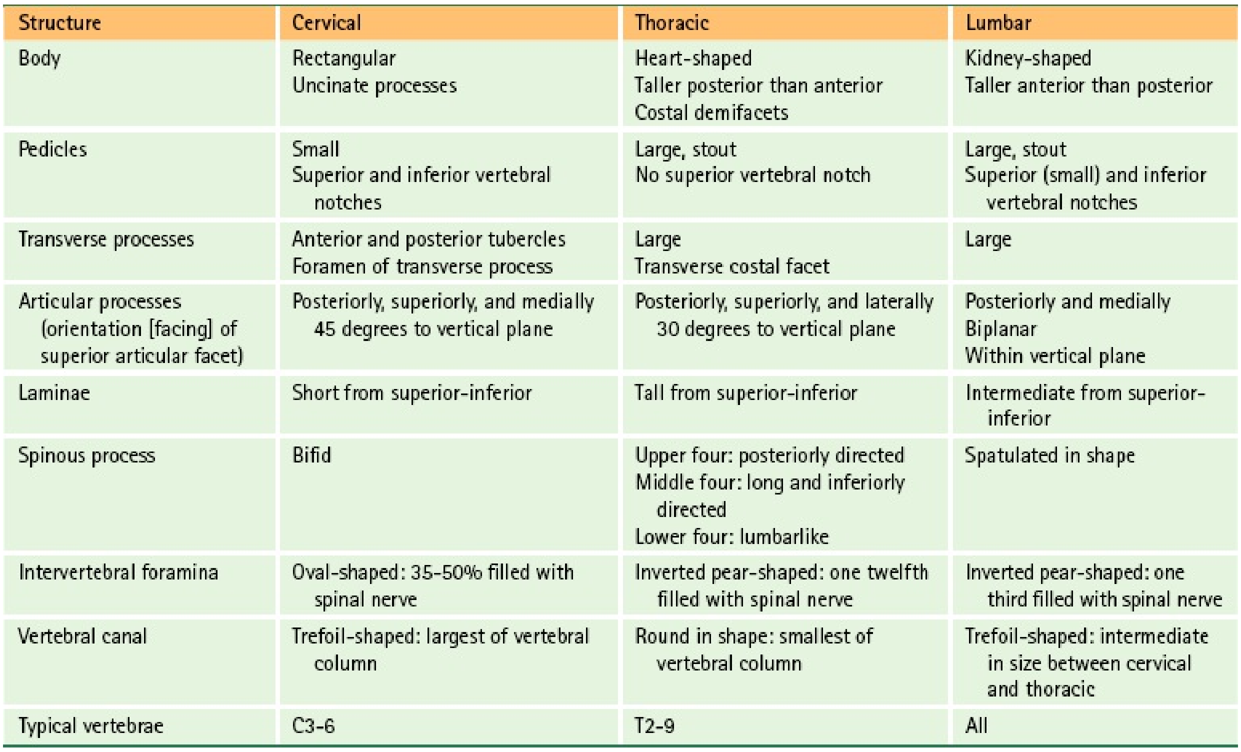
The shell of compact bone is thin on the discal surfaces of the vertebral body and is thicker in the vertebral arch and its processes. The outer compact bone is covered by a thin layer of periosteum that is innervated by nerve endings, which transmit both nociception and proprioception (Edgar & Ghadially, 1976). The outer compact bone also contains many small foramina to allow passage for numerous veins and nutrient arteries. The trabecular interior of a vertebra contains red marrow and the vertebral bodies contain one or two large canals for the basivertebral vein(s).

The density of bone in the vertebrae varies from individual to individual but seems to increase significantly in most people during puberty and reaches a peak during the mid-twenties, when closure of the growth plates of the secondary centers of ossification occurs (Gilsanz, 1988; Gilsanz et al., 1988). A decrease in bone mineral density to below normal limits is known as osteoporosis. Osteoporosis also is accompanied by a rearrangement of the trabeculae within the spongy bone (Feltrin et al., 2001). This condition is of particular clinical relevance in the spine because of the weight-bearing function of this region. A decrease in bone mineral density and a rearrangement of trabeculae lead to a loss of elasticity in the bone and an increase in bone fragility. These changes, in turn, increase the likelihood of vertebral fracture (Mosekilde & Mosekilde, 1990; Feltrin et al., 2001). Osteoporosis has been associated with aging (Mosekilde & Mosekilde, 1990) and particularly with menopause (Ribot et al., 1988). Ribot and colleagues (1988) found that spinal bone density in French women remained stable in the young adult years and in women more than 70 years of age. An average rate of apparent bone loss of approximately 1% per year was found between the ages of 45 and 65. This represented approximately 75% of the total bone loss occurring within the individuals of their sample population (510 women). Ribot and colleagues (1988) also found that the bone mineral density in their population of French women appeared to be between 5% and 10% lower than reported values in the United States. Mosekilde and Mosekilde (1990), studying the L2 and L3 vertebrae, found relatively few sex-related differences in vertebral body density. However, Mosekilde (1989) did find a sex-related difference in vertebral trabecular architecture with age. Consistent with the findings of Ribot and colleagues (1988), Mosekilde (1989) discovered that in both sexes bone density diminished by 35% to 40% from 20 to 80 years of age. She also determined that the trabecular center (cancellous bone) of the vertebral body lost more bone mass than the outer cortical rim.

The regions of the vertebral body and vertebral arch are discussed separately in the following sections of this chapter. Elaboration on each component of the vertebra, with special emphasis placed on the characteristics unique to each region of the vertebral column, is included in the chapters on the cervical, thoracic, and lumbar regions of the spine (Chapters 5 through 7). In addition, Table 2-1 compares and contrasts the different parts of cervical, thoracic, and lumbar vertebrae.

Table 2-1

Regional General Characteristics of Typical Vertebrae



Structure	Cervical	Thoracic	Lumbar
Body	Rectangular Uncinate processes	Heart-shaped Taller posterior than anterior Costal demifacets	Kidney-shaped Taller anterior than posterior
Pedicles	Small Superior and inferior vertebral notches	Large, stout No superior vertebral notch	Large, stout Superior (small) and inferior vertebral notches
Transverse processes	Anterior and posterior tubercles Foramen of transverse process	Large Transverse costal facet	Large
Articular processes (orientation [facing] of superior articular facet)	Posteriorly, superiorly, and medially 45 degrees to vertical plane	Posteriorly, superiorly, and laterally 30 degrees to vertical plane	Posteriorly and medially Biplanar Within vertical plane
Laminae	Short from superior-inferior	Tall from superior-inferior	Intermediate from superior-inferior
Spinous process	Bifid	Upper four: posteriorly directed Middle four: long and inferiorly directed Lower four: lumbarlike	Spatulated in shape
Intervertebral foramina	Oval-shaped: 35-50% filled with spinal nerve	Inverted pear-shaped: one twelfth filled with spinal nerve	Inverted pear-shaped: one third filled with spinal nerve
Vertebral canal	Trefoil-shaped: largest of vertebral column	Round in shape: smallest of vertebral column	Trefoil-shaped: intermediate in size between cervical and thoracic
Typical vertebrae	C3-6	T2-9	All

Vertebral Body

The vertebral body (Fig. 2-3) is the large anterior portion of a vertebra that acts to support the weight of the human frame. Each vertebral body is designed to provide the greatest amount of strength with the least amount of bone mass (Feltrin et al., 2001). The vertebral bodies are connected to one another by fibrocartilaginous intervertebral discs, and when the bodies are combined with their intervening discs, they create a flexible column or pillar that supports the weight of the trunk and head. The vertebral bodies also must be able to withstand additional forces from contraction of the axial and proximal limb muscles. The bodies are cylindric in shape and have unique characteristics in each named region of the spine. The transverse diameter of the vertebral bodies increases from C2 to L3. This probably results from the fact that each successive vertebral body carries a slightly greater load. There is variation in the width of the last two lumbar vertebrae, but the width steadily diminishes from the first sacral segment to the apex (inferior tip) of the coccyx.

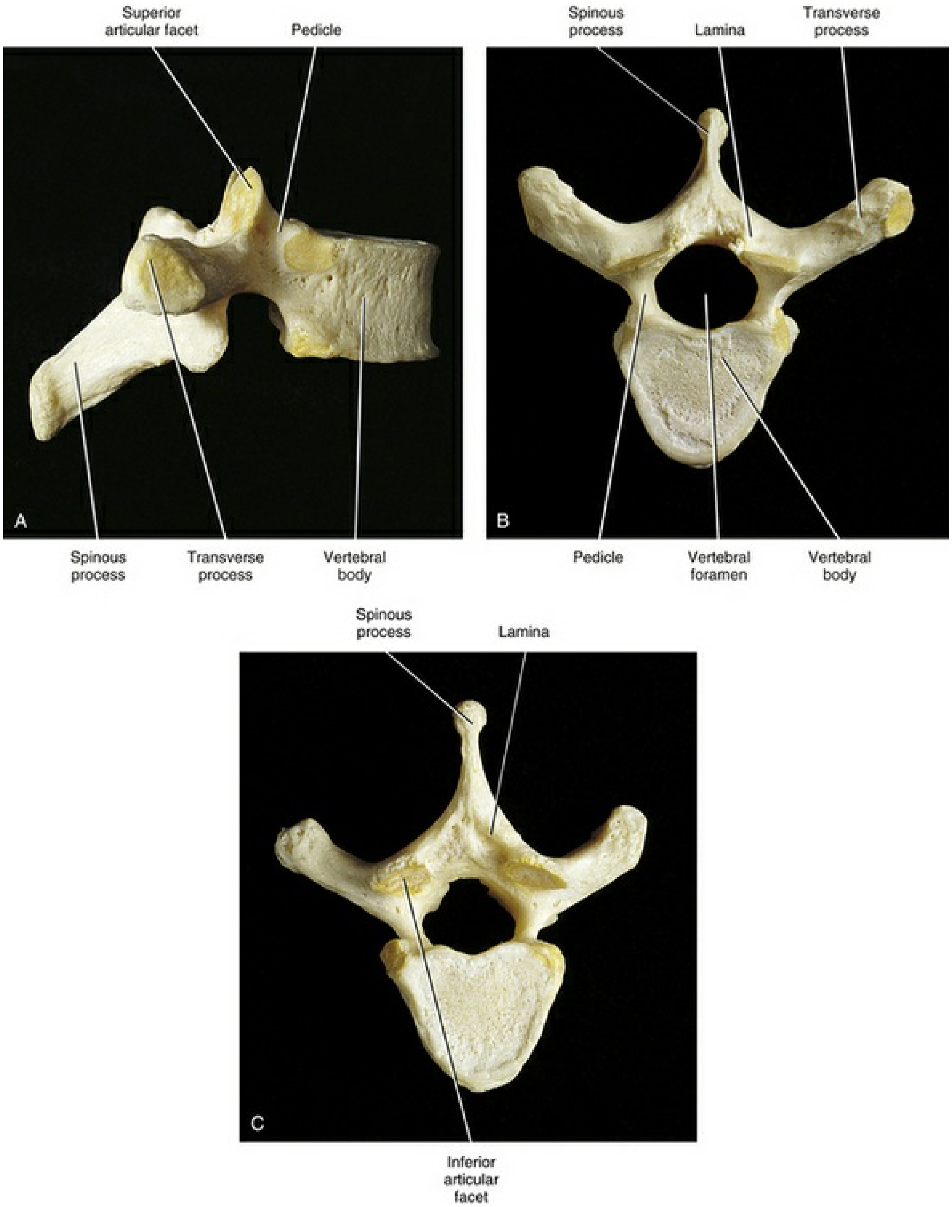


FIG. 2-3 Typical vertebra. **A,** Lateral view. **B,** Superior view. **C,** Inferior view.

Vertical trabeculae predominate in the vertebral bodies. The vertical trabeculae are supported by horizontal trabeculae that function much like the struts or support beams in the frame of a building. Animal studies have shown that both the vertical and the horizontal trabeculae of a vertebral body increase in number after prolonged (weeks) and increased loading by superior-inferior compression (Issever et al., 2003).

Osteoporosis is associated with a decrease in mass primarily of the horizontal trabeculae, leaving less support for the vertical trabeculae when loads are placed on an osteoporotic vertebral body. This lack of horizontal support results in a weakening of the vertebral body beyond that anticipated by the percent reduction in bone mineral content. In fact, a 25% reduction in bone mass is accompanied by a 50% reduction in the ability of a vertebral body to resist loads applied to the spine.

Bone mineral density can vary significantly from one vertebra to another (Curylo et al., 1996). Although determining the presence or absence of osteoporosis by means of x-ray bone densitometry to measure bone mineral density is reliable, fractal analysis of the trabecular pattern within vertebral bodies as imaged by computed tomography (CT) also shows promise (Kim and Nah, 2007).

The vertebral bodies have been found to change (remodel) after degeneration of the intervertebral discs, by adding bone to the region adjacent to the intervertebral disc. This addition of bone is known as subchondral sclerosis, and allows the vertebral bodies to more effectively absorb the additional compressive loads received by the vertebral bodies after intervertebral disc degeneration (Moore et al., 1996a,b).

Mosekilde and Mosekilde (1990) found that the cross-sectional area of vertebral bodies is larger in men than in women. They also found that the cross-sectional area of the vertebral body increases with age in men, but no similar finding was discovered in women.

The superior and inferior surfaces of vertebral bodies range from flat, but not parallel (Standring et al., 2008), to interlocking (see Chapter 5). A raised, smooth region around the edge of the vertebral body is formed by the anular apophysis. The superior and inferior surfaces of the vertebral body are rougher inside the anular apophyses.

Most vertebral bodies are concave posteriorly (in the transverse plane), where they help to form the vertebral foramina. Small foramina for arteries and veins appear on the front and sides of the vertebral bodies. Posteriorly there are small arterial foramina and one or two large, centrally placed foramina for the exiting basivertebral vein(s) (Standring et al., 2008).

A series of relatively large arteries pierce the center of the vertebral bodies along their entire circumference (Fig. 2-4). On entering a vertebral body, these large nutrient arteries form a dense plexus of arteries within the central horizontal plane of the vertebral body. From this central plexus, many small branches ascend and descend to reach the superior and inferior margins of the vertebral bodies; these margins are adjacent to the cartilaginous end plates of the intervertebral discs.

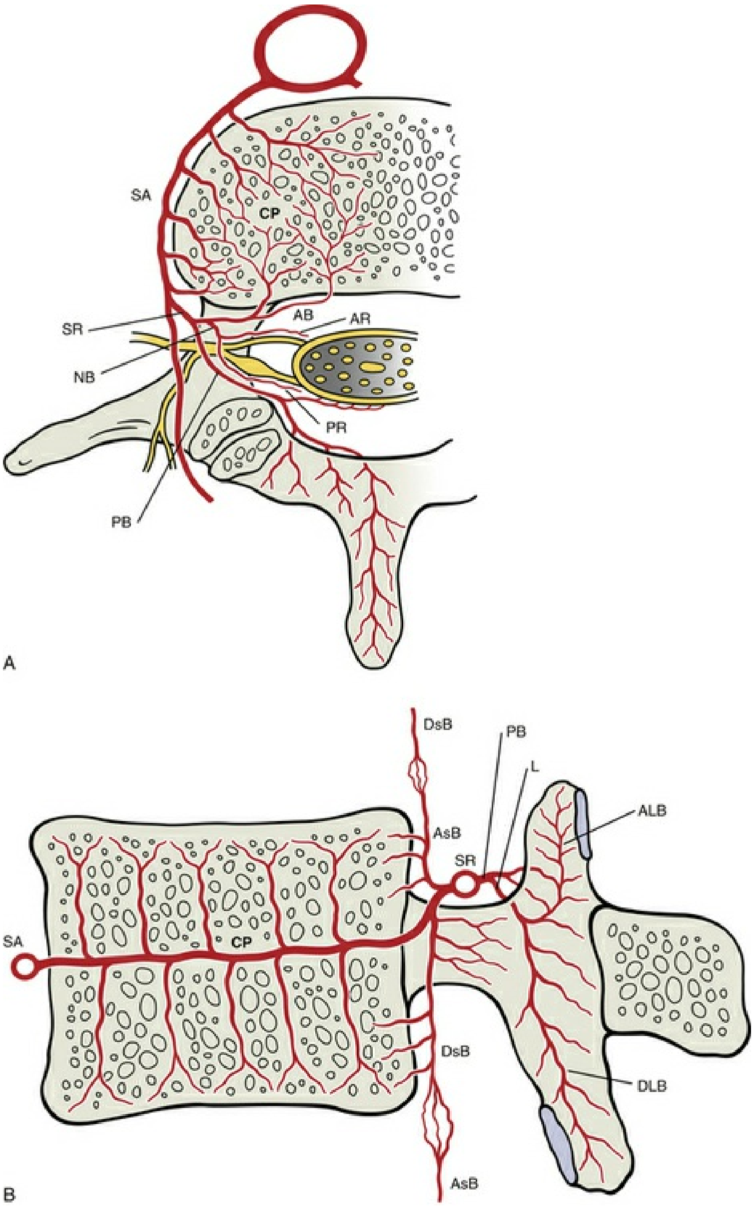


FIG. 2-4 Arterial supply to a typical vertebra and related tissues. **A,** Superior view of a horizontal section through the level of the vertebral body showing a lumbar segmental artery *(SA)* branching from the abdominal aorta and sending many branches to feed the dense central plexus *(CP)* of arteries formed within this plane of the vertebral body. From this central plexus many small branches ascend and descend to reach the superior and inferior margins of the vertebral bodies (see panel **B**). Also, notice that the spinal ramus of the segmental artery *(SR)* forms an anterior branch *(AB)* to the vertebral body and anterior tissues of the vertebral canal, a posterior branch *(PB)* to the posterior arch structures and posterior tissues of the vertebral canal, and a neural branch *(NB)* that divides into anterior *(AR)* and posterior *(PR)* radicular arteries to feed the ventral and dorsal roots (and rootlets), respectively. **B,** Midsagittal section showing the superior and inferior branches of the central arterial plexus of the vertebral body. These branches feed the arterial plexuses located subjacent to the cartilaginous end plates. Also notice that the anterior branch (not labeled here) of the spinal ramus provides an artery to the center of the vertebral body that helps supply the central arterial plexus as well. The anterior branch also produces an ascending *(AsB)* and a descending *(DsB)* branch, each of which anastomoses with a corresponding artery of adjacent vertebral levels. The posterior branch of the spinal ramus is shown dividing into a large laminar artery *(L)* that enters the lamina and then provides ascending *(ALB)* and descending *(DLB)* laminar branches to supply the superior and inferior articular processes, respectively, including the subchondral bone of the articular facets. See Arterial Supply to the Spine for further details.

Large numbers of small veins drain the superior and inferior margins of the vertebral bodies. These very small veins enter into large tributaries that are oriented in the horizontal plane very close to each superior and inferior vertebral margin. These large tributaries have been called the horizontal subarticular collecting vein system (Crock & Yoshizawa, 1976). Branches of the horizontal subarticular collecting vein system, in turn, drain into large, vertically oriented channels that course toward the central horizontal plane of the vertebral body, where a dense venous network is formed. The dense network is drained by the basivertebral vein (occasionally there are two basivertebral veins in the same vertebral body). The subarticular collecting vein system also sends small tributaries laterally. These small tributaries leave the vertebral body and drain into veins of the external vertebral venous plexus (see later information).

Items of Clinical Significance: Of clinical interest are the findings of Esses and Moro (1992), who found that long-term intraosseous hypertension within the vessels of the vertebral bodies is associated with an increase of pain and severity of osteoarthritis.

Occasionally a vertebral body compression fracture occurs some time (days to years) after an individual suffers trauma to the spine. This condition is known as “delayed posttraumatic vertebral collapse,” or Kümmell disease, and is probably the result of damage to the nutrient arteries of the vertebral body during the original injury. Damage to the nutrient arteries then leads to necrosis (ischemic necrosis) of the vertebral body and subsequent vertebral collapse (Van Eenenaam & El-Khoury, 1993).

Osteophytes of the vertebral bodies are protrusions of the superior or inferior aspects of the vertebral bodies that are composed of compact bone and extend toward the adjacent intervertebral disc and vertebral body. Anterior osteophytes of the vertebral bodies generally are more common than posterior ones and usually are larger. A large proportion of vertebral columns have osteophytes by the second decade of life, and by the fourth decade osteophytes are present in almost 100% of vertebral columns. The size of the osteophytes increases with age. There is no significant difference between osteophyte formation on the anterior aspect of the vertebral bodies and gender; however, males have more anterior osteophytes than females. Osteophytes on the posterior aspect of the vertebral bodies are most common in the lower cervical and lower lumbar regions and are more common in white than in black males and females. No significant difference exists in the prevalence of posterior osteophytes between males and females of the same racial background (Nathan, 1962).

Osteophytes develop slightly earlier in life in the thoracic and lumbar regions than in the cervical and sacral regions. However, in the fifth decade cervical osteophytes develop more rapidly than in the other regions of the spine, and by the seventh decade the incidence is nearly equal among cervical, thoracic, and lumbar osteophytes; osteophytes of the sacral region (only found on the first sacral segment) are the least common (Nathan, 1962).

Anterior osteophytes can result in complete interbody fusion. Such fusion is most common in the mid- to lower-thoracic region and in the lower-cervical region; however, fusion is extremely rare between C7 and T1 and between L5 and the first sacral segment (Nathan, 1962).

Osteophytes are much less common in the region of a vertebral body in contact with the aorta, and they usually develop in the region of the vertebral body that receives the greatest compressive loads during normal stance or common movements. For example, osteophytes tend to develop on the concave side of the normal curves of the spine. Anterior osteophytes, which generally are the most numerous, are most common in the thoracic region, and posterior osteophytes are most common in the cervical and lumbar regions of the spine (Nathan, 1962).

Bony End Plates

The ring apophyses, also known as the ring epiphyses, are secondary centers of ossification that develop along the periphery of the superior and inferior aspects of the vertebral bodies before puberty (see Chapter 12). These regions fuse with the remainder of the vertebral bodies usually by the age of 25 years. Some authors refer to the superior- and inferior-most regions of the vertebral body, including the area associated with the superior and inferior ring apophyses (both before and after their fusion with the remainder of the vertebral body), as the vertebral end plates. However, this terminology is confusing because the vertebral end plates (also known as the cartilaginous end plates) refer to the parts of each intervertebral disc that are found superior and inferior to the nucleus pulposus and anulus fibrosus. Therefore the term "bony end plate" is used in this text to describe the superior- and inferior-most regions of the vertebral bodies. During the time of puberty these regions are also associated with the ring apophyses, and the term bony end plate applies to the region of the ring apophyses as well, both before and after their fusion with the remainder of the vertebral bodies. The term vertebral end plate, or cartilaginous end plate, is used in this text to refer to the superior and inferior aspects of each intervertebral disc.

The central region of each bony end plate has a mottled appearance from birth to 6 months of age. This appearance results from vascular markings (holes) formed by small blood vessels that at this early age extend to the cartilaginous end plate from deep within the vertebral body.

Between 6 months and 2.5 years of age the mottled appearance of the central bony end plate diminishes (as the blood vessels disappear), and the end plate retains this somewhat smoother appearance for the remainder of the life of the vertebra. However, between 6 months and 25 years of age the peripheral margins of the end plates become prominently scalloped, showing prominent ridges and sulci. This scalloping results in a denticulate, or toothlike, appearance along the vertebral margins, having an appearance similar to that of the outer margins of the epiphyseal plates of other bones of the body. The scalloping of the bony end plate is variable from one vertebra to the next and is most prominent in the lower thoracic and upper lumbar regions, and less pronounced in the cervical and thoracic regions. The scalloping is thought to increase stability during the application of shear forces to the spine (forces that tend to slide one vertebra over the vertebra immediately inferior to it). Resistance to shear forces also explains why the scalloping is less prominent in the majority of the thoracic region and the entire cervical region, where the ribs and uncinate processes (see Chapter 5), respectively, resist shear forces in these areas. The ridges and sulci of the bony end plates become more prominent until approximately 12 to 25 years of age when the bone from the anular apophysis is laid down, creating an enlarging smooth ridge of bone that follows the peripheral margins of the superior and inferior surfaces of the vertebral bodies (Edelson & Nathan, 1988). The cortical bone of the central region of the superior and inferior bony end plates (i.e., the region of each end plate adjacent to the nucleus pulposus) is thinnest, and the end plates increase in thickness from this central region to the periphery (Grosland & Goel, 2007). Consequently, the periphery of the bony end plates can withstand more loads before failure than the more central regions of the end plates (Bailey et al., 2011).

Items of Clinical Significance: Beginning in the latter aspect of the third decade, osteophytes develop on the vertebral bodies, usually just adjacent to the bony end plate. That is, an osteophyte usually spares the bony end plate (there is usually a distinct sulcus between each osteophyte and the related bony end plate). The osteophytes then arch across the bony end plate, extending toward the adjacent vertebra (Edelson & Nathan, 1988).

Osteoporotic changes also can occur in the bony end plate. These changes usually begin toward the end of the fifth decade and progress until death. Osteoporotic changes in the bony end plates assume the appearance of lytic, or "punched out," areas of the bone (Edelson & Nathan, 1988).

Vertebral Arch

The vertebral (posterior) arch has several unique structures (see Fig. 2-3). These include the pedicles, laminae, and superior articular, inferior articular, transverse, and spinous processes. Each of these subdivisions of the vertebral arch is discussed separately in the following sections.

Pedicles

The pedicles (see Fig. 2-3) create the narrow anterior portions of the vertebral arch. They are short, thick, and rounded and attach to the posterior and lateral aspects of the vertebral body. They also are placed superior to the midpoint of a vertebral body. Because the pedicles are smaller than the vertebral bodies, a groove, or vertebral notch, is formed above and below the pedicles. These are known as the superior and inferior vertebral notches, respectively. The superior vertebral notch is more shallow and smaller than the inferior vertebral notch.

The percentage of compact bone surrounding the inner cancellous bone of the pedicles varies from one region of the spine to another and seems to depend on the amount of motion that occurs at the given region (Pal et al., 1988). More compact, stronger bone is found in regions with more motion. Therefore the pedicles of the middle cervical and upper lumbar regions contain more compact bone than the relatively immobile thoracic region. The thoracic pedicles are made primarily of cancellous bone (Pal et al., 1988).

There are significant differences in the relative size of various parts of vertebrae among various ethnic populations, with those from Western populations generally having larger structures than those from Asia. This is true for the pedicles (Chadha et al., 2003).

Laminae

The laminae (singular, lamina) are continuous with the pedicles. They are flattened from anterior to posterior and form the broad posterior portion of the vertebral arch (see Fig. 2-3). They curve posteromedially to unite with the spinous process, completing the vertebral foramen. Xu and colleagues (1999) performed a detailed morphometric study of the laminae of the entire vertebral column. They concluded that, generally speaking, the laminae of males are slightly larger than those of females. The laminae generally increase in height from C4, which are the shortest (10.4 ± 1.1 mm), to T11, which are the tallest (25.1 ± 2.5 mm). The height of the laminae then begin to decrease slowly from T12 to L4, and then more markedly at L5. However, the laminae are widest at L5 (15.7 ± 2.0 mm) and narrowest at T4 (5.8 ± 0.8 mm). The cervical laminae are wide (rivaling those of L5), the thoracic laminae (with the exception of T11 and T12) are narrow, and the width steadily increases from T11 to L5. The laminae are thickest at T2 (5.0 ± 0.2 mm) and least thick at C5 (1.9 ± 0.6 mm), with the thickness of the laminae decreasing from the upper to the lower thoracic regions. The lower cervical laminae are the least thick of the vertebral column, and the lumbar laminae are of intermediate thickness (Xu et al., 1999).

Spinous Process

The spinous process (spine) of each vertebra (see Fig. 2-3) projects posteriorly and often inferiorly from the laminae. The size, shape, and direction of this process vary greatly from one region of the vertebral column to the next (see individual regions). A spinous process also may normally deviate to the left or right of the midline, and this can be a source of confusion in clinical practice. Therefore a deviated spinous process seen on x-ray film or palpated during a physical examination frequently is *not* associated with a fracture of the spinous process or a malposition of the entire vertebra.

The spinous processes throughout the spine function as a series of levers both for muscles of posture and for muscles of active movement (Standring et al., 2008). Most of the muscles that attach to the spinous processes act to extend the vertebral column. Some muscles attaching to the spinous processes also rotate the vertebrae to which they attach.

Lateral to the spinous processes are the vertebral grooves. These grooves are formed by laminae in the cervical and lumbar regions. They are much broader in the thoracic region and are formed by both the laminae and transverse processes. The left and right vertebral grooves serve as gutters. These gutters are filled with the deep back muscles that course the entire length of the spine.

The spinous process of a specific vertebra frequently can be identified by its relationship to other palpable landmarks of the back. Chapter 1 provides a detailed account of the relationship between the spinous processes and other anatomic structures.

Vertebral Foramen and the Vertebral Canal

The vertebral foramen is the opening within each vertebra that is bounded by the structures discussed thus far. Therefore the vertebral body, the left and right pedicles, the left and right laminae, and the spinous process form the borders of the vertebral foramen in a typical vertebra (see Fig. 2-3). The size and shape of the vertebral foramina vary from one region of the spine to the next and even from one vertebra to the next. The vertebral canal is the composite of all of the vertebral foramina. This region houses the spinal cord, nerve roots, meninges, and many vessels. The vertebral canal is discussed in more detail later in this chapter.

Transverse Processes

The transverse processes project laterally from the junction of the pedicle and lamina (pediculolaminar junction) (see Fig. 2-3). Like the spinous processes, their exact direction varies considerably from one region of the spine to the next. The transverse processes of typical cervical vertebrae project obliquely anteriorly between the sagittal and coronal planes and are located anterior to the articular processes and lateral to the pedicles. The left and right cervical transverse processes are separated from those of the vertebrae above and below by successive intervertebral foramina. The thoracic transverse processes are different and project obliquely posteriorly and are located behind the articular processes, pedicles, and intervertebral foramina (see Fig. 6-1). They also articulate with the ribs. The lumbar transverse processes (see Fig. 7-2) lie in front of the lumbar articular processes and posterior to the pedicles and intervertebral foramina.

The transverse processes serve as muscle attachment sites and are used as lever arms by spinal muscles. The muscles that attach to the transverse processes maintain posture and induce rotation and lateral flexion of single vertebrae and the spine as a whole.

Each transverse process is composed of the “true” transverse process (diapophysis) and a costal element. Each costal element (pleurapophysis) develops as part of the neural arch (see Fig. 12-13). The costal elements of the thoracic region develop into ribs. Elsewhere the costal elements are incorporated with the diapophysis and help to form the transverse process of the fully developed vertebra. The cervical costal elements are composed primarily of the anterior tubercle but also include the intertubercular lamella and a part of the posterior tubercle. The lumbar costal elements are the anterior aspects of the transverse processes, and the left and right sacral alae represent the costal processes of the sacrum. The cervical and lumbar costal processes occasionally may develop into ribs. This occurs most frequently in the lower cervical and upper lumbar regions. These extra ribs may be a cause of discomfort in some individuals. This is particularly true of cervical ribs (see Chapter 5).

Superior Articular Processes

Like the transverse processes, the superior articular processes (zygapophyses) and facets also arise from the pediculolaminar junction (see Fig. 2-3). The left and right superior articular processes project superiorly, and the articular surface (facet) of each articular process faces posteriorly, although the precise direction varies from posteromedial in the cervical and lumbar regions to posterolateral in the thoracic region. (The superior and inferior articular facets are discussed in more detail later in this chapter under Zygapophysial Joints.)

Inferior Articular Processes

The left and right inferior articular processes (zygapophyses) and facets project inferiorly from the pediculolaminar junction, and the articular surface (facet) faces anteriorly (see Fig. 2-3). Again, the precise direction in which they face varies from anterolateral (cervical region) to anteromedial (thoracic and lumbar regions).

Adjoining zygapophyses form zygapophysial joints (Z joints), which are small and allow for limited movement. Mobility at the Z joints varies considerably between vertebral levels. The Z joints also help to form the posterior border of the intervertebral foramina. The anatomy of the Z joint is discussed after the next section.

Functional Components Of A Typical Vertebra

Each region of a typical vertebra is related to one or more of the functions of the vertebral column mentioned at the beginning of this chapter (support, protection of the spinal cord and spinal nerve roots, and movement) (Fig. 2-5). In general, the vertebral bodies help with support, whereas the pedicles and laminae protect the spinal cord. The superior and inferior articular processes help determine spinal movement by the facing of their facets. The transverse and spinous processes aid movement by acting as lever arms on which the muscles of the spine act.

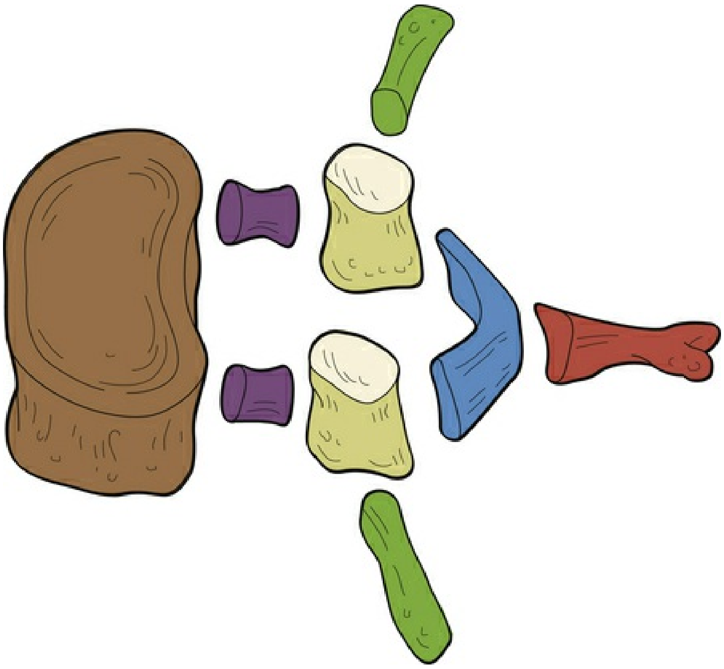


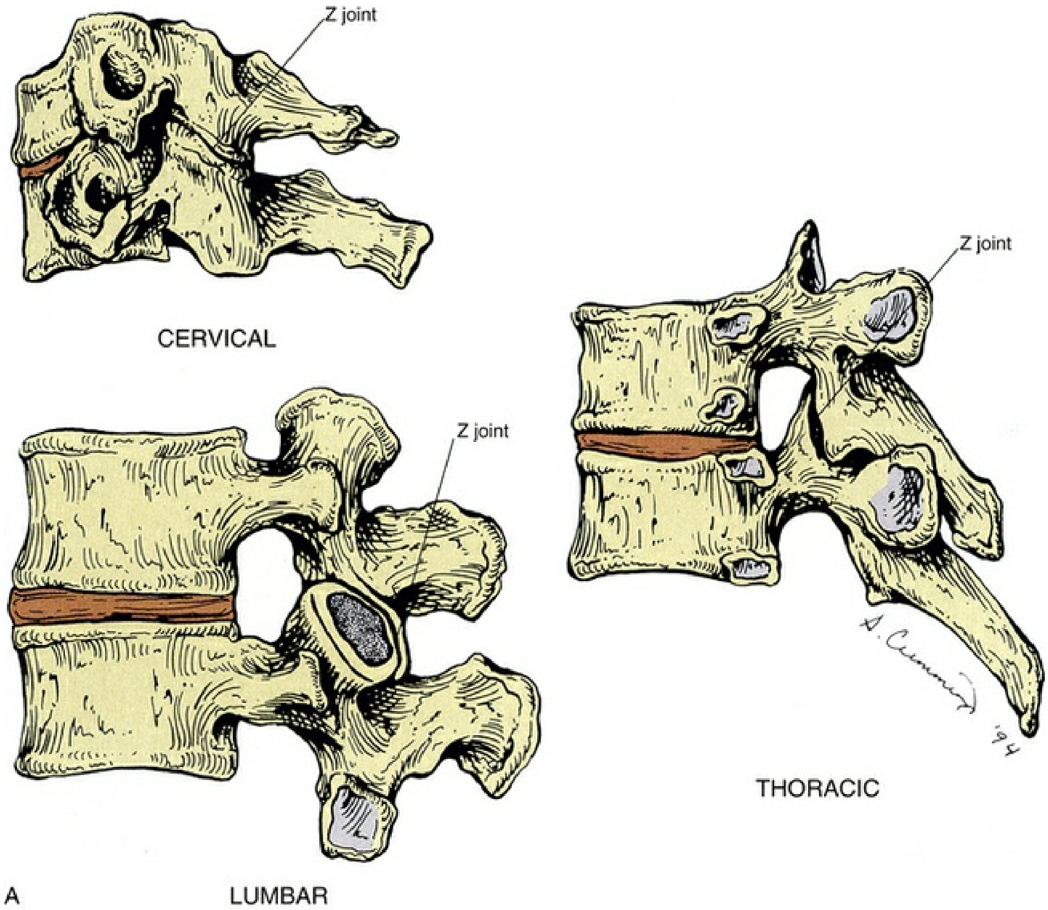
FIG. 2-5 Functional components of a typical vertebra. The vertebral body *(brown)* serves the function of support. The pedicles *(purple)* and laminae *(blue)* serve the function of protection of the spinal cord (cervical and thoracic regions) or cauda equina (below the level of L1). The spinous process *(red)*, transverse processes *(dark green)*, articular processes *(tan)*, and particularly the articular facets *(cream)* serve the function of movement (see text).

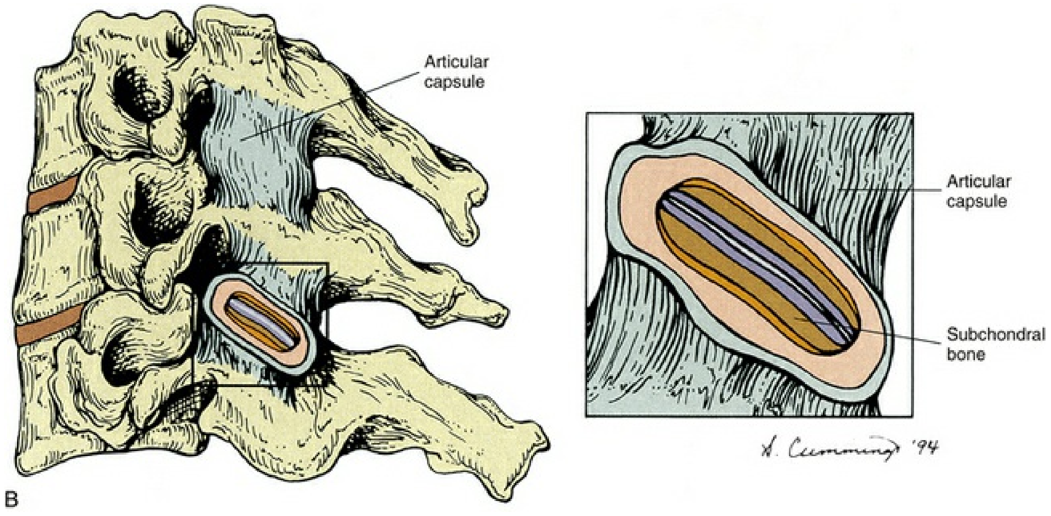
The posterior arches also function to support and transfer weight (Pal et al., 1988), and the articular processes of the cervical region form two distinct pillars (left and right) that bear weight. In addition, the laminae of C2, C7, and the upper thoracic region (T1 and T2) help to support weight. Therefore a laminectomy at these levels results in marked cervical instability (Pal et al., 1988), whereas a laminectomy from C3 to C6 is relatively safe.

The pedicles also act to transfer weight from the posterior arch to the vertebral body, and vice versa in the cervical region (Pal et al., 1988), but only from the posterior arch to the vertebral bodies in the thoracic region. The role of the pedicles in the transfer of loads is yet to be completely determined in the upper lumbar region, but the trabecular pattern of the L4 and L5 pedicles seems to indicate that the majority of load may be transferred from the vertebral bodies to the region of the posterior arch in these two vertebrae. This is discussed in further detail in Chapter 7, which is devoted to the lumbar spine.

Zygapophysial Joints

The articulating surface of each superior and inferior articular process (zygapophysis) is covered with a 1- to 2-mm-thick layer of hyaline cartilage. This hyaline-lined portion of a superior and inferior articular process is known as the articular facet. The junction found between the superior and inferior articular facets on one side of two adjacent vertebrae is known as a zygapophysial joint. Therefore, a left Z joint and a right Z joint are between each pair of vertebrae. Figure 2-6, *A*, shows the Z joints of the cervical, thoracic, and lumbar regions. These joints also are called facet joints or interlaminar joints (Giles, 1992). The Z joints (Fig. 2-6, *B* to *D*) are classified as synovial (diarthrodial), planar joints. They are rather small joints, and although they allow motion to occur, they are perhaps more important in their ability to determine the direction and limitations of movement that can occur between vertebrae. In addition, the Z joints (more specifically, the articular processes) help to carry the loads placed on the spine, particularly during extension and rotation (Schultz et al., 1973). The Z joints are of added interest to those who treat spinal conditions because they have been found to be a source of back pain (Dreyer & Dreyfuss, 1996). Z joint pain may be generated as a result of direct injury to the joints, or as is the case with any synovial joint, loss of motion or aberrant motion of the Z joints may result in pain (Paris, 1983). In addition, degeneration of the hyaline cartilage that composes the articular facets can result in pain (Lewinnek & Warfield, 1986). In fact, the Z joints have been found to be a source of pain in 39% of chronic cervical pain patients, and in 34% and 27% of patients with chronic thoracic and lumbar pain, respectively (Manchukonda et al., 2007).


Z joint
CERVICAL
Z joint
Z joint
THORACIC
A. Cummings '94
A
LUMBAR


Articular capsule
Articular capsule
Subchondral bone
A. Cummings '94
B

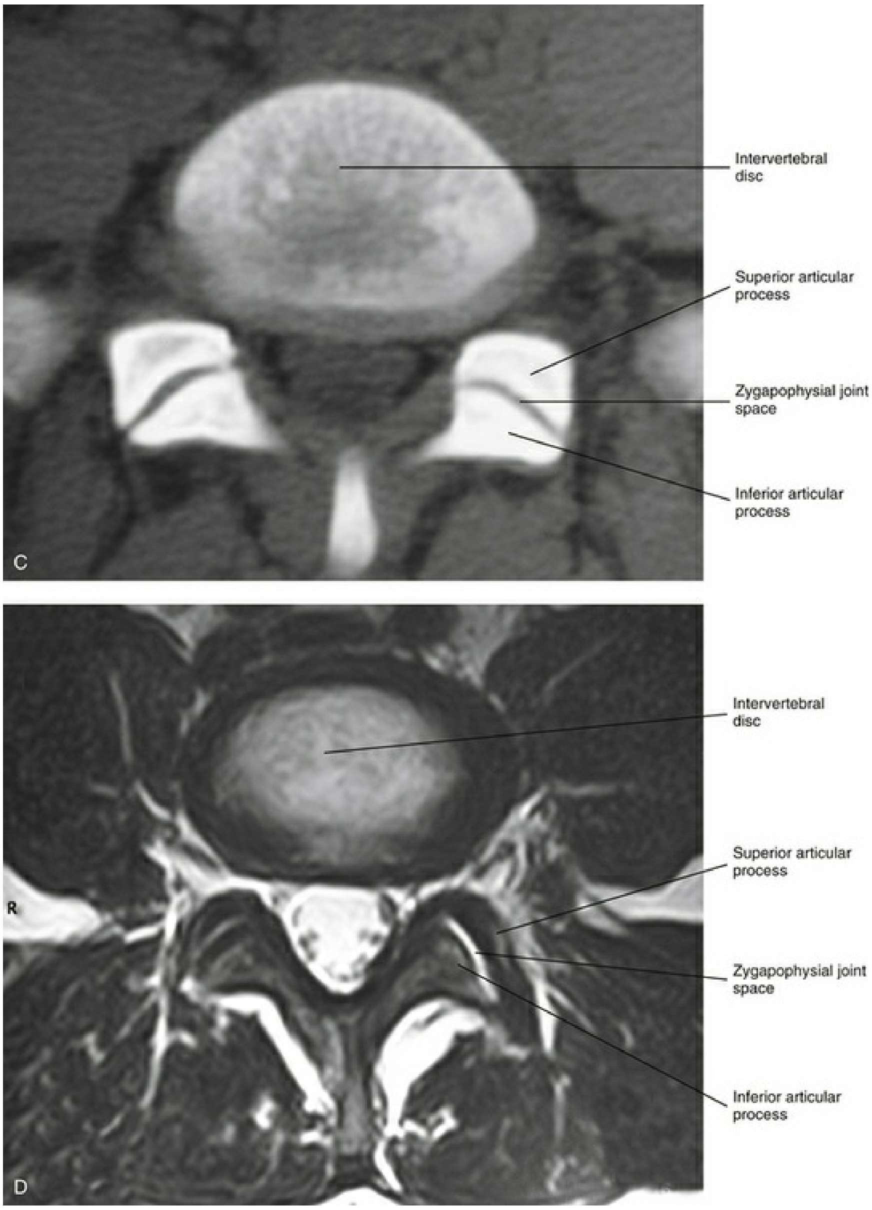


FIG. 2-6 **A,** Typical Z joints of each vertebral region. **B,** Typical Z joint. The layers of the Z joint as seen in parasagittal section *(inset)* are color coded as follows: *light blue*, joint space; *violet*, articular cartilage; *brown*, subchondral bone; *orange*, synovial lining of articular capsule; *peach*, vascularized, middle layer of the articular capsule; *turquoise*, fibrous, outer layer of the articular capsule. **C,** Horizontal computed tomography (CT) showing lumbar Z joints. **D,** Magnetic resonance imaging (MRI) scan through the left and right Z joints of typical lumbar vertebrae. (Images courtesy Dr. Dennis Skogsbergh.)

Each Z joint is surrounded posterolaterally by a capsule. The outer capsule and inner layers of the capsule differ significantly in composition; this is possibly unique to Z joints (Yamashita et al., 1996). The capsule consists of an outer layer of dense fibroelastic connective tissue, a vascular central layer made up of areolar tissue and loose connective tissue, and an inner layer consisting of a synovial membrane (Giles & Taylor, 1987). Figure 2-6, *B,* shows the previously listed regions of the capsule. The anterior and medial aspects of the Z joint are covered by the ligamentum flavum. The synovial membrane lines the articular capsule, the ligamentum flavum (Xu et al., 1991), and the synovial joint folds (see the following), but not the hyaline articular cartilage that covers the joint surfaces of the articular processes (Giles, 1992).

The Z joint capsules throughout the vertebral column are thought to do little to limit motion (Onan, Heggeness, & Hipp, 1998), although the capsules probably help to stabilize the Z joints during motions (Boszczyk et al., 2001).

Generally, the Z joint capsules are relatively thin and loose and are attached to the margins of the opposed superior and inferior articular facets of the adjacent vertebrae (Standring et al., 2008). Superior and inferior external protrusions of the joint capsules, known as recesses, bulge from the joint and are filled with adipose tissue. The inferior recess is larger than the superior one (Jeffries, 1988). The capsules are longer and looser in the cervical region than in the lumbar and thoracic regions.

Innervation of the Zygapophysial Joints

The Z joint capsule receives significant sensory innervation (Cavanaugh, Kallakuri, & Özaktay, 1995; Vandenabeele, Creemers, & Lambrichts, 1996). Ahmed and colleagues (1993) found both sensory and autonomic fibers in the synovial layer of the Z joint capsules of rats. They also found evidence of nociceptive innervation in the ligamentum flavum proper (that portion of the ligamentum flavum adjacent to the Z joint). The authors concluded that both sensory and autonomic innervations could play a collaborative role in the pathophysiology of Z joint pain, inflammation, and inflammatory joint disease.

The sensory nerve supply to each Z joint (Fig. 2-7) is derived from the medial branch of the posterior primary division (dorsal ramus) at the level of the joint, and each joint also receives innervation from the medial branch of the posterior primary division of the level superior and the level inferior (Jeffries, 1988). This multilevel innervation is probably one reason why pain from a Z joint frequently has a very broad referral pattern (Jeffries, 1988). Chapters 5, 6, and 7 describe features unique to innervation of the cervical, thoracic, and lumbar Z joints, respectively; and Chapter 11 discusses the phenomenon of referred pain in more detail.

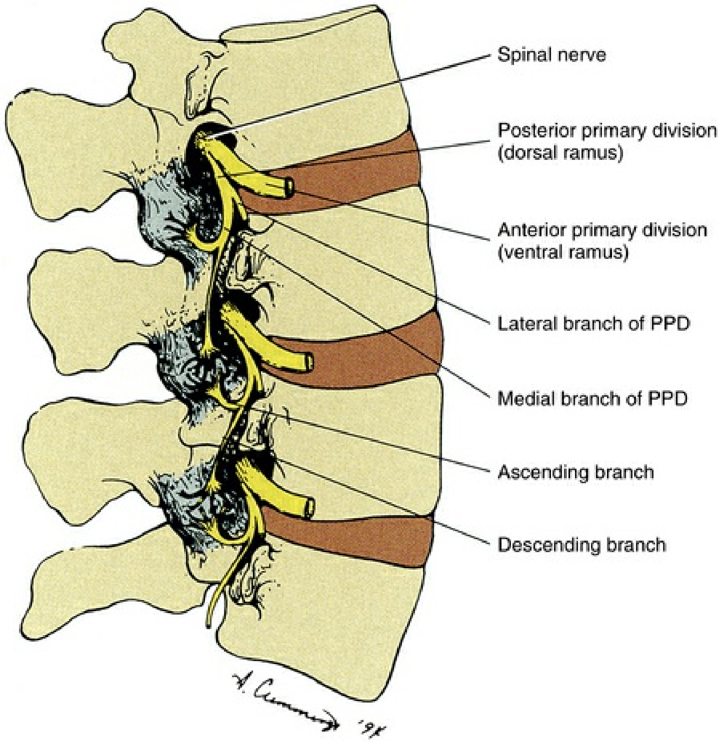


FIG. 2-7 Innervation of the Z joints. Each spinal nerve divides into a medial and a lateral branch. The medial branch has an ascending division, which supplies the Z joint at the same level, and a descending division, which supplies the Z joint immediately below. Jeffries (1988) states that each lumbar medial branch also sends a branch to the Z joint of the level above (not shown in illustration). *PPD*, Posterior primary division.

The medial branches of the posterior primary divisions innervating a Z joint terminate as one of three types of sensory receptors: free nerve endings (nociceptive), complex-unencapsulated nerve endings, and encapsulated nerve endings (Yamashita et al., 1990; Beaman et al., 1993; Cavanaugh, Kallakuri, & Özaktay, 1995). The latter two types are thought to be associated with proprioceptive sense and the modulation of protective muscular reflexes. The free nerve endings are associated with nociception (i.e., signaling potential or real tissue damage). The ultrastructure of these receptors has been described (Vandenabeele et al., 1997; McLain & Pickar, 1998).

In addition, Wyke (1985) categorized the types of sensory receptors in Z joints by their function. These categories are as follows:

- Type I: Very sensitive static and dynamic mechanoreceptors that fire continually, even to some extent when the joint is not moving
- Type II: Less sensitive mechanoreceptors that fire only during movement
- Type III: Mechanoreceptors found in joints of the extremities (Wyke [1985] did not find these in the Z joints.)
- Type IV: Slow-conducting nociceptors

Wyke (1985) asserts that type I and II receptors have a pain suppressive effect (a Melzack and Wall gate control type of mechanism). He also states that there is a reflexogenic effect created by type I and II fibers that causes a normalization of muscle activity on both sides of the spinal column when stimulated. This reflexogenic effect is thought to occur at the level of the site of stimulation, as well as at the levels superior and inferior to this site. Of possible interest is the fact that Isherwood and Antoun (1980) found similar nerve endings within the interspinous and supraspinous ligaments and the ligamentum flavum. These ligaments are respectively discussed in Chapters 5 and 6 on the cervical and thoracic regions.

Innervation by mechanoreceptors is denser in the cervical Z joint capsules than in those of the thoracic and lumbar regions (McLain, 1994; McLain & Pickar, 1998). This may be because the increased mobility of the cervical region may require more proprioceptive input to ensure smooth and accurate head movement and positioning, and also to help prevent injury from inappropriate motions or muscle responses to sudden movements. Innervation by free nerve endings associated with nociception is abundant in all regions of the spine (McLain & Pickar, 1998).

Beaman and colleagues (1993) found nerves that stained with substance P (associated with pain) in the bone underlying the articular facets of the articular processes (subchondral bone) from specimens of Z joints taken during surgical procedures of patients with low back pain and accompanying degeneration of the Z joints, but not in control specimens. This indicates that the subchondral bone may be an additional source of pain in individuals with arthritis of the spine (including degenerative joint disease, also known as osteoarthritis, or common degenerative arthritis) or with injury to the spine. Because degeneration of the spine can result in an increase in the loads placed on the Z joints by 3% to 47%, depending on the severity of the degeneration, the presence of nociceptive (pain) nerve endings in the subchondral bone of the Z joint articular facets indicates that the subchondral bone in this region may play an active role in back pain. The combined innervation of the Z joint capsules and subchondral bone provides further strong evidence implicating the Z joints as an important source of back pain in many individuals.

Zygapophysial Joint Synovial Folds

Z joint synovial folds are synovium-lined extensions of the capsule that protrude into the joint space to cover part of the hyaline cartilage. Although the function of the synovial folds has not been definitively determined, they are thought to provide lubrication to the Z joints, through the secretion of synovial fluid, and also to protect the margins of the articular cartilage (Uhrenholt et al., 2008). The synovial folds vary in size and shape in the different regions of the spine. Figure 2-8 shows a photomicrograph by Singer and colleagues (1990) demonstrating a large Z joint synovial fold. Chapters 5, 6, and 7 discuss the unique characteristics of Z joint synovial folds in the cervical, thoracic, and lumbar regions, respectively.