Spine Essentials Handbook

A Bulleted Review of Anatomy, Evaluation, Imaging, Tests, and Procedures

Kern Singh

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Kern Singh, MD
Professor
Department of Orthopaedic Surgery
Co-Director, Minimally Invasive Spine Institute
Rush University Medical Center
Chicago, Illinois

165 illustrations

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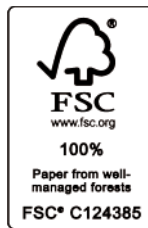
I dedicate this book to my father. As I now progress into parenthood, I realize the sacrifices you made for me. Never ending patience, bountiful amounts of time, and a dedication to giving me every opportunity to succeed.

- K. Singh

Associate Editors

Brittany E. Haws, MD
Orthopedic Surgery Resident
University of Rochester
Rochester, New York

Fady Y. Hijji, MD
Orthopedic Surgery Resident
Wright State University
Dayton, Ohio

Benjamin Khechen, BA
Research Coordinator
Rush University Medical Center
Chicago, Illinois

Ankur S. Narain, MD
Orthopedic Surgery Resident
University of Massachusetts
Boston, Massachusetts

Dil V. Patel, BS
Research Coordinator
Rush University Medical Center
Chicago, Illinois

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Preface

The *Spine Essentials Handbook* was produced as a portable resource that is easily accessible to all medical professionals. The detailed information, ranging from basic neuroanatomy to spinal pathology to surgical intervention, allows the reader to fully grasp the complexity of the spine. This holistic compilation helps the audience become comfortable with the intricacy of the spine before entering a clinic or the operating room. The clear depiction of complex spinal anatomy overlaid with real-time intraoperative pictures facilitates an understanding of the nuances associated with spine surgery. As any surgery demands efficiency, the accompanying text provides an in-depth coverage of technique as well as pearls to help execute the operation expeditiously. Lastly, the handbook outlines possible complications associated with spine surgery with suggestions for prevention.

The text offers up-to-date knowledge in the quickly advancing field of spinal anatomy, pathology, and surgery. With comprehensive images, cross-sectional illustrations, and emphasis on potential difficulties, this handbook allows for improved expertise on surgical procedures and postoperative care. Clinical questions included at the end of this e-book are provided to help test and solidify your knowledge and comprehension about the complexities of spine and spinal surgery.

This handbook will be of value to not only surgeons and surgical trainees, but also for the other surgical staff involved in the medical care of spine surgery patients. We are optimistic that the *Spine Essentials Handbook* will grant readers a better understanding of the delicacies of spine surgery.

Kern Singh, MD

Acknowledgements

We would like to thank all of those who assisted in the creation of this book. In particular, we would like to acknowledge Brittany Haws and Benjamin Khechen for their efforts in seeing this book to completion.

Contributors

Ikechukwu Achebe, BS
Department of Orthopaedic Surgery
Rush University Medical Center
Chicago, Illinois

Junyoung Ahn, MD
Department of Orthopaedic Surgery
Rush University Medical Center
Chicago, Illinois

Daniel D. Bohl, MS, MD
Department of Orthopaedic Surgery
Rush University Medical Center
Chicago, Illinois

Jacob V. DiBattista, BS
Department of Orthopaedic Surgery
Rush University Medical Center
Chicago, Illinois

Melissa G. Goczalk, BFA
Department of Orthopaedic Surgery
Rush University Medical Center
Chicago, Illinois

Brittany E. Haws, MD
Orthopedic Surgery Resident
University of Rochester
Rochester, New York

Fady Y. Hijji, MD
Orthopedic Surgery Resident
Wright State University
Dayton, Ohio

Benjamin Khechen, BA
Research Coordinator
Rush University Medical Center
Chicago, Illinois

Suzanne Labelle, BS
Rush Medical College
Chicago, Illinois

William W. Long, BA
Department of Orthopaedic Surgery
Rush University Medical Center
Chicago, Illinois

Philip K. Louie, MD
Department of Orthopaedic Surgery
Rush University Medical Center
Chicago, Illinois

Catherine Maloney, BS
Department of Orthopaedic Surgery
Rush University Medical Center
Chicago, Illinois

Jonathan Markowitz, BS
Department of Orthopaedic Surgery
Rush University Medical Center
Chicago, Illinois

Dustin H. Massel, BS
Department of Orthopaedic Surgery
Rush University Medical Center
Chicago, Illinois

Benjamin C. Mayo, BA
Department of Orthopaedic Surgery
Rush University Medical Center
Chicago, Illinois

Krishna D. Modi, BS
Department of Orthopaedic Surgery
Rush University Medical Center
Chicago, Illinois

Ankur S. Narain, MD
Orthopedic Surgery Resident
University of Massachusetts
Boston, Massachusetts

Dil V. Patel, BS
Research Coordinator
Rush University Medical Center
Chicago, Illinois

Lauren M. Sadowsky, BA
Rush Medical College
Rush University
Chicago, Illinois

Kern Singh, MD
Professor
Department of Orthopaedic Surgery
Co–Director, Minimally Invasive Spine
    Institute
Rush University Medical Center
Chicago, Illinois

Antonios Varelas, BA
Department of Orthopaedic Surgery
Rush University Medical Center
Chicago, Illinois

1 Neuroanatomy and Physiology

Jacob V. DiBattista, Ankur S. Narain, Fady Y. Hijji, Philip K. Louie, Daniel D. Bohl, and Kern Singh

1.1 Neuron Anatomy

- Basic components (**Table 1.1, Fig. 1.1**).
- Synaptic junction and signal transmission:
  - Mechanism of basic chemical synapses (**Fig. 1.3**).
    - Action potential (depolarization) reaches terminal branch of the presynaptic neuron.
    - N-type Ca^{2+} channels open, Ca^{2+} influx.
      - *Associated pathologies:* Lambert–Eaton myasthenic syndrome.
    - Ca^{2+} facilitates vesicle docking, neurotransmitter released into synaptic cleft.
      - *Associated pathologies:* botulism, tetanus (lockjaw).
    - Neurotransmitter binds neurotransmitter receptor (postsynaptic neuron).
      - *Associated pathologies:* myasthenia gravis.
    - Depending on its function, the neurotransmitter receptor creates either an excitatory postsynaptic potential (EPSP) or an inhibitory postsynaptic potential (IPSP).

Table 1.1 Basic anatomy of the neuron

Component	Function
Dendrites	Receive signals from other neurons for transfer toward the cell body
Cell body (soma)	Contains cell nucleus. Site of protein and ATP production
Axon hillock	Portion of cell body that connects to axon. Final site of action potential summation (trigger zone)
Axon	Carries action potential from cell body to terminal branches
Myelin sheath	Fatty insulating layer around axon that facilitates action potential through saltatory conduction. • Oligodendrocytes myelinate neurons of the central nervous system (CNS). A single oligodendrocyte myelinates multiple neurons (**Fig. 1.2a**). • Schwann's cells myelinate neurons of the peripheral nervous system (PNS). Multiple Schwann's cells myelinate a single neuron (**Fig. 1.2b**).
Nodes of Ranvier	Occasional interruptions in the myelin sheath that expose the axonal membrane. Contain a high density of voltage-gated Na^+ and K^+ channels and Na^+/K^+ ATPases, which act to regenerate the action potential.
Terminal branches (boutons) of axon	Branched terminal portion of an axon. Site of neurotransmitter release into the synaptic cleft. Often referred to as the presynaptic terminal.
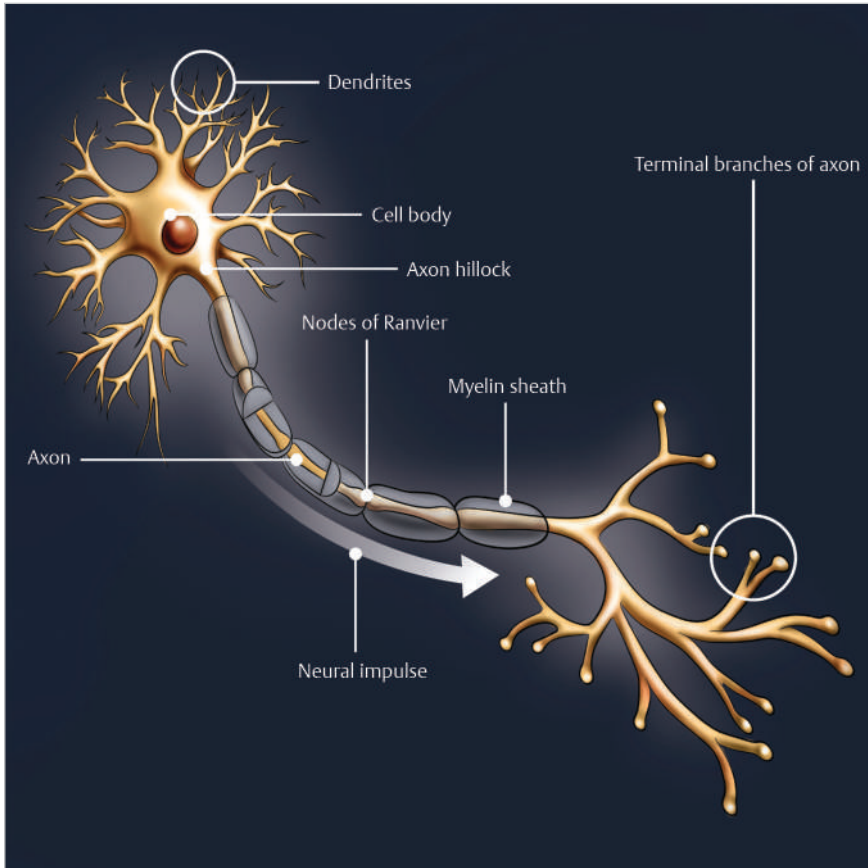
Fig. 1.1 Basic components of the neuron.

- EPSPs depolarize the postsynaptic neuron and increase the probability of action potential formation.
- IPSPs either hyperpolarize or resist depolarization of the postsynaptic neuron and decrease the probability of action potential formation.
  - The potentials across all dendrites are integrated in the cell body and axon hillock, determining whether or not an action potential will fire in the postsynaptic neuron.
  - A variety of mechanisms, including enzymatic degradation (i.e., acetylcholine) and presynaptic reuptake (i.e., serotonin), remove neurotransmitters from the synaptic cleft to end the postsynaptic stimulus.
- Neuromuscular junction:
  - Specialized chemical synapse between motor neuron and muscle fiber.
  - Cholinergic synapse containing mainly nicotinic acetylcholine receptors.
  - Nerve impulse results in contraction of muscle fiber(s).
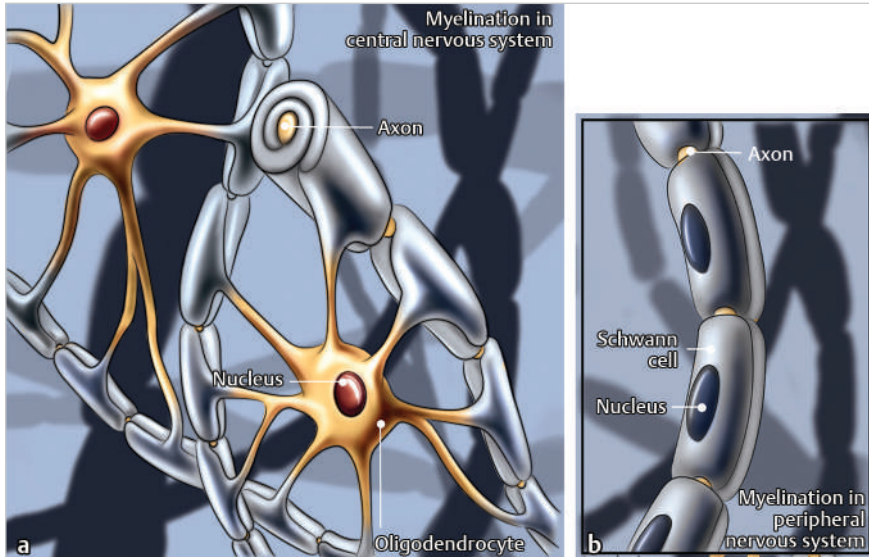
Fig. 1.2 **(a)** Oligodendrocyte (central nervous system). **(b)** Schwann's cell (peripheral nervous system).

- Motor unit:
  - A *single* motor neuron and all muscle fibers that it innervates.
    - A small motor unit contains three to six muscle fibers and controls muscles of fine control.
    - A large motor unit contains 100 to 1,000 muscle fibers and controls muscles of crude control and strength (i.e., biceps, quadriceps).
  - All muscle fibers of a single motor unit are of the same fiber type (types 1, 2a, and 2b).
- Neuron types (**Table 1.2**).
- Nerve fiber organization (**Table 1.3, Fig. 1.4**).
- Nervous system organization (**Fig. 1.5**).
- Afferent and efferent nerves (**Table 1.4, Fig. 1.6**):
  - Afferent nerve fibers carry sensory information and arrive at the spinal cord through dorsal roots.
  - Efferent nerve fibers carry motor information and exit the spinal cord through ventral roots.
  - Efferent motor neurons (**Table 1.5, Fig. 1.7**):
    - Upper motor neurons (UMNs)
      - Cell bodies originate within the primary motor cortex or brainstem nuclei.
      - Convey motor information by synapsing with lower motor neurons (LMNs, or interneurons) in the brainstem or spinal cord.
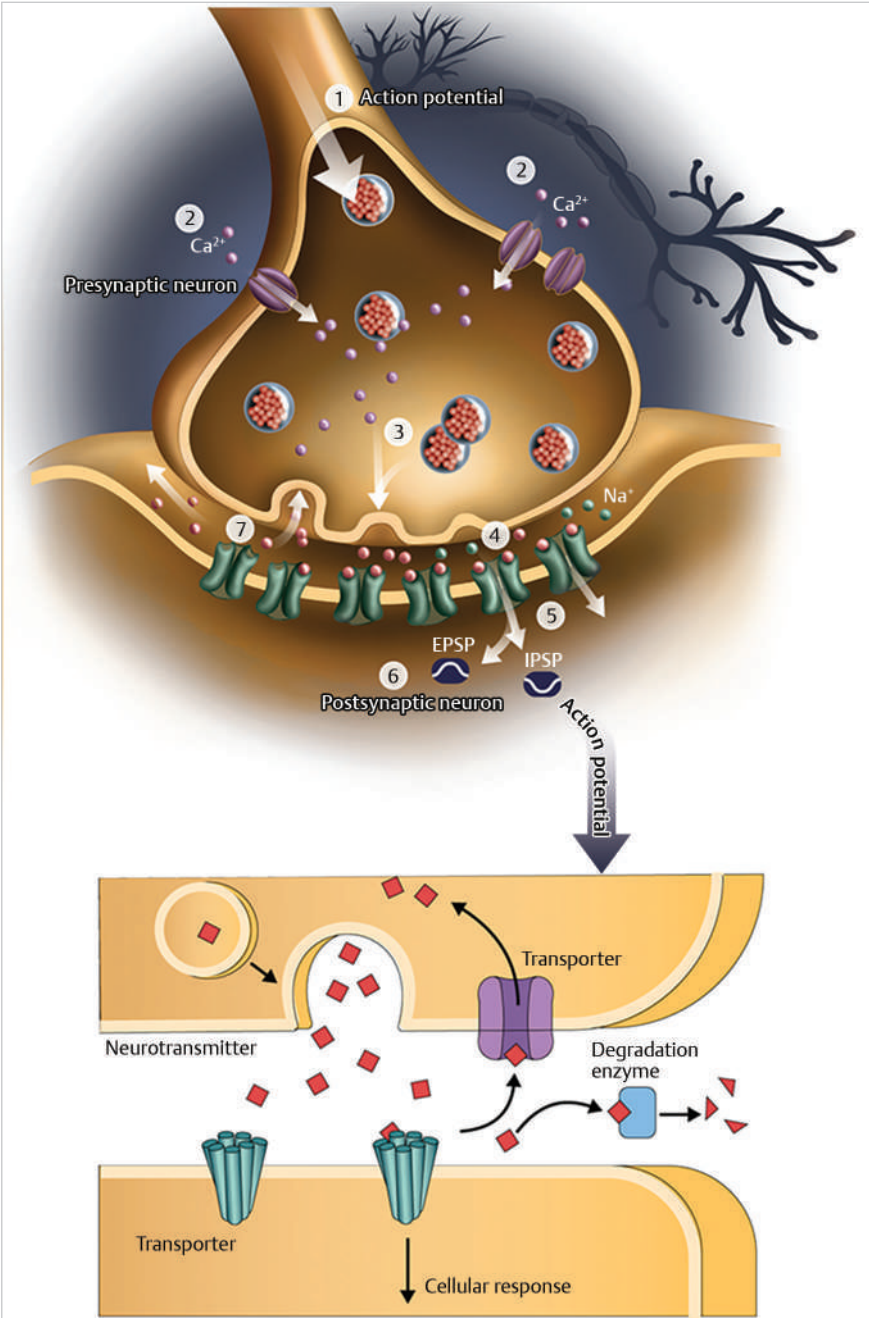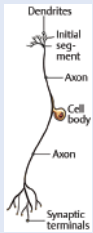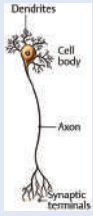
Fig. 1.3 Synaptic transmission at a chemical synapse.

Table 1.2 Basic neuron types

Type	Image	Description	Examples
Pseudounipolar	Dendrites Initial segment Axon Cell body Axon Synaptic terminals	A single axon split into two branches with an *adjacent* cell body: • *Peripheral branch*: periphery to cell body (contains dendrites) • *Central branch*: cell body to spinal cord (contains synaptic terminals) Transmits sensory information from the periphery to the CNS	• Sensory neurons of dorsal root ganglia • Sensory ganglia of cranial nerves V, VII, IX, and X
Bipolar	Dendrites Cell body Axon Synaptic terminals	Cell body centrally located between a: • *Dendrite:* transmits signals toward cell body • *Axon:* transmits signals away from cell body Specialized sensory neurons for the transmission of special senses (i.e., vision, hearing)	• Bipolar cells, ganglion cells, horizontal cells, and amacrine cells of the retina • Cochlear and vestibular ganglia of the inner ear
Multipolar	Dendrites Cell body Axon Synaptic terminals	Cell body contains multiple dendrites and a single axon Able to receive and integrate abundant nerve impulses	• Motor neurons (ventral horn of spinal cord) • Interneurons (spinal cord gray matter) • Purkinje's cells (cerebellum) • Pyramidal cells (cerebral cortex)

Abbreviation: CNS, central nervous system.

Table 1.3 Hierarchical organization of nerve fibers

Component	Covering
Deep	
Axon (of individual neuron)	Endoneurium
Fascicle (bundle of axons)	Perineurium
Nerve (bundle of fascicles)	Epineurium
Superficial	
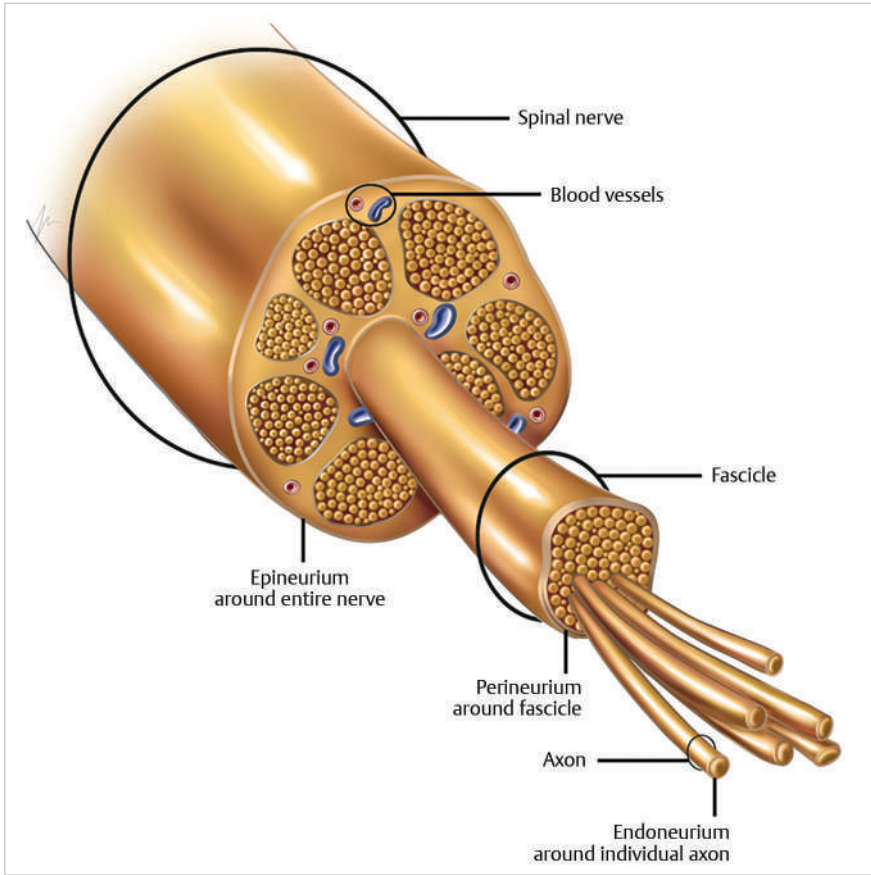
Fig. 1.4 Nerve fiber structure.

- ○ LMNs:
  - ▪ Cell bodies originate in brainstem nuclei or the ventral horn of spinal cord gray matter.
  - ▪ Convey motor information from UMNs by synapsing with skeletal muscle in the periphery via neuromuscular junctions.
- – Afferent sensory receptors (**Table 1.6**).
- – Afferent sensory neurons (**Table 1.7**).
- • Reflex arcs (**Table 1.8**):
  - – General principles:
    - ○ A reflex arc is a neural pathway that controls a reflex action.
    - ○ It involves the spinal cord only, allowing for a fast, subconscious response.
    - ○ Sensory information is processed by the brain *after* the reflex has occurred.
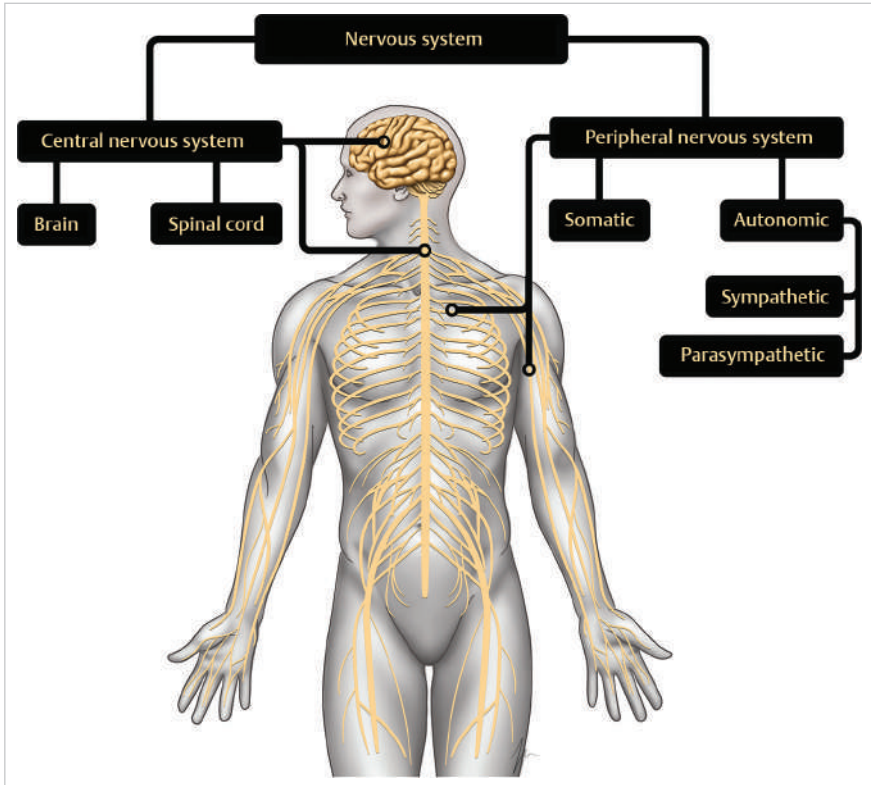
Fig. 1.5 Summary of central and peripheral nervous systems.

Table 1.4 Afferent and efferent nerve organization

Type	Root	Cell body location	Information conveyed
Afferent:	Dorsal	Dorsal root ganglion	Sensory
General somatic afferent (GSA)			*Skin, muscles, tendons, joints*
General visceral afferent (GVA)			*Visceral organs*
Efferent:	Ventral	Spinal cord gray matter	Motor
General somatic efferent (GSE)		*Ventral horn*	*Skeletal muscle*
General visceral efferent (GVE)		*Lateral horn*	*Smooth and cardiac muscle, glands*

Note: In spinal nerves and dorsal and ventral rami, GSA, GVA, GSE, and GVE fibers are mixed.
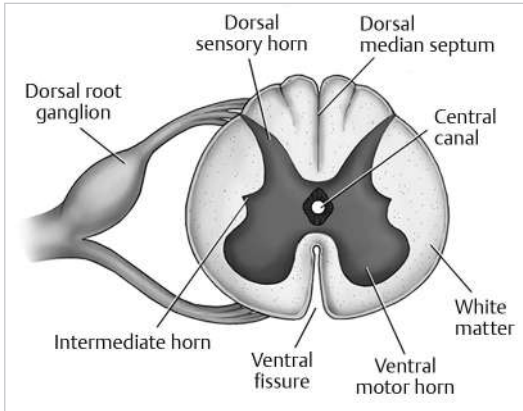
Fig. 1.6 Components of spinal nerves. (Reproduced with permission from Baaj AA, Mummaneni PV, Uribe JS, Vaccaro AR, Greenberg MS, eds. Handbook of Spine Surgery. 2nd ed. New York, NY: Thieme; 2016.)

Table 1.5 General signs of upper motor neuron and lower motor neuron lesions

Clinical sign	Upper motor neuron lesion presentation		Lower motor neuron lesion presentation
	Acute	Chronic	
Weakness	Yes	Yes	Yes
Atrophy	No	Some	Severe
Tone/paralysis	Decreased/flaccid	Increased/spastic	Decreased
Fasciculations	No[a]	No[a]	Yes
Reflexes	Decreased	Increased	Decreased
Babinski's sign[b]	No	Yes	No

[a]May see slight fasciculations at spinal level of UMN lesions due to partial damage of LMN cell bodies in the ventral horn.
[b]Babinski's sign is considered normal response in children younger than 1 year.

- Types:
  - Monosynaptic: contains two neurons (sensory and motor) with a single chemical synapse (**Fig. 1.9**):
    - That is, patellar reflex, Achilles reflex.
  - Polysynaptic: contains one or more interneurons that connect a sensory neuron to a motor neuron:
    - Represents the majority of reflex arcs.
    - Allows for higher order processing and control.
    - That is, pain withdrawal reflex.
  - Somatic: affects skeletal muscle.
  - Autonomic: affects internal viscera.
- Components:
  - Stimulus (muscle stretch, pain, temperature, stretch, etc.).
  - Sensory receptor (muscle spindle, free nerve ending, etc.).
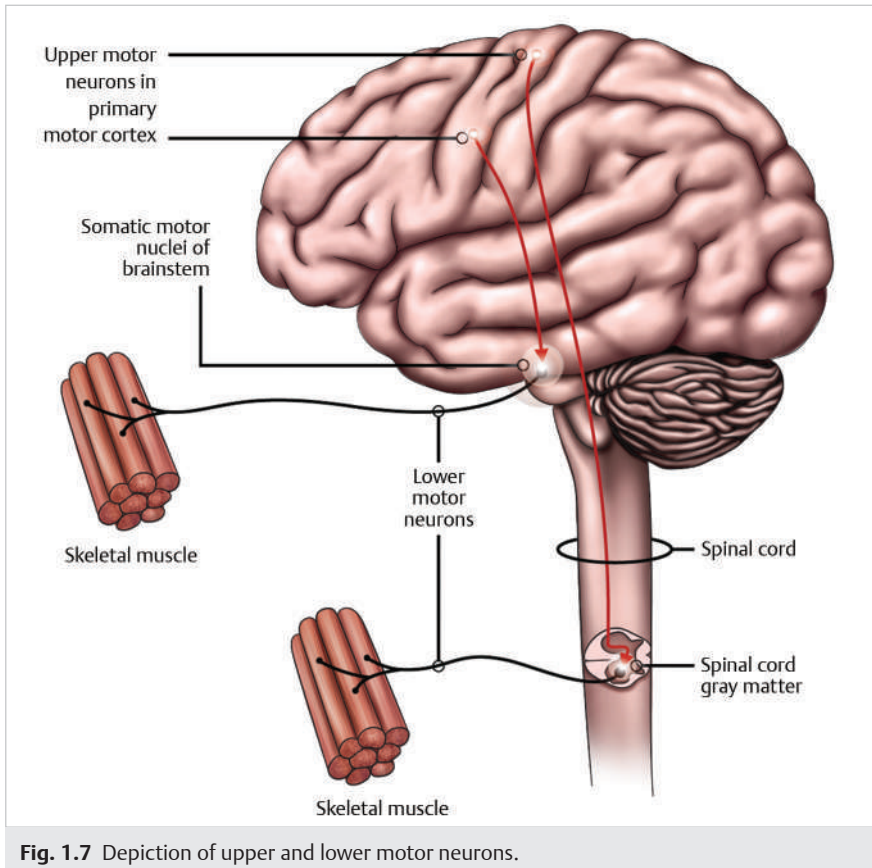
Fig. 1.7 Depiction of upper and lower motor neurons.

- Afferent pathway: sensory neuron (dorsal root ganglia).
- Interneuron(s) (dorsal horn):
  - Polysynaptic reflex arcs only.
- Efferent pathway: motor neuron (ventral horn).
- Skeletal muscle:
  - Effector response → muscle contraction.
- Inhibitory interneurons:
  - Activated by sensory neurons of a reflex arc.
  - Inhibit LMNs that act on antagonistic muscle groups:
    - That is, during biceps reflex, inhibitory interneurons will cause the triceps to relax.
- UMN effects:
  - Inhibits the magnitude of LMN responses in a reflex arc:
    - This is a conscious process, and is the basis of the Jendrassik maneuver:

Table 1.6 Sensory receptor types

Receptor type	Modality	Adaption rate	Fiber class
Cutaneous mechanoreceptors			
Meissner's corpuscle	Touch (superficial)	Rapid	II
Merkel's cell	Touch (superficial)	Slow	II
Hair follicle receptor	Touch, vibration	Rapid and slow	II
Pacinian corpuscle	Touch (deep), vibration	Rapid	II
Ruffini's ending	Touch (deep), stretch, proprioception	Very slow	II
Stretch receptors			
Muscle spindle			
Nuclear bag fibers	Proprioception (muscle stretch)	Slow	I
Nuclear chain fibers	Proprioception (muscle tone)	Slow	II
Golgi's tendon organ	Proprioception (muscle tension)	Slow	I
Pain and temperature receptors			
Free nerve endings	Nociception (fast)	_	III
	Nociception (slow)	_	IV
	Temperature (cool)	_	III
	Temperature (warm)	_	IV

Table 1.7 Types of sensory neuron fibers

Sensory fiber type	Myelinated	Sensory modality	Sensory receptor
A-α[a]	Yes	Proprioception	Muscle spindle Golgi's tendon organ
A-β	Yes	Proprioception Superficial touch Touch, vibration Deep touch, vibration Deep touch, stretch	Muscle spindle Meissner's corpuscle Merkel's cell Hair follicle receptor Pacinian corpuscle Ruffini's ending
A-δ	Yes	Nociception (fast) Temperature (cool)	Free nerve endings Free nerve endings
C[b]	No	Nociception (slow) Temperature (warm)	Free nerve endings Free nerve endings

[a]A-α fibers have the lowest threshold for stimulation.
[b]C fibers have the highest threshold for stimulation.

Table 1.8 Commonly tested deep tendon reflexes

Deep tendon reflex	Spinal cord level tested
Biceps reflex	C5–C6
Brachioradialis reflex	C6
Triceps reflex	C6–C8
Patellar reflex (knee jerk)	L2–L4
Achilles reflex (ankle jerk)	S1–S2

Fig. 1.8 **(a)** Location of different sensory receptor types in skin tissue. **(b)** Location of Type I and Type II fibers within muscle tissue.

❷ Afferent pathway: sensory neuron

To brain

❶ Stimulus: muscle stretch

❺ Efferent response: muscle contraction & relaxation of antagonistic muscle

❸ Spinal cord: synapse with motor neuron & inhibitory interneuron

Spinal nerve

❹ Efferent pathway: motor neuron

a

1 Arrival of stimulus & activation of receptor

2 Activation of a sensory neuron

Dorsal root

Receptor

Interneuron

Sensation relayed to the brain by axon collaterals

Reflex arc

Stimulus

Ventral root

3 Information processing in the CNS

Effector

4 Activation of a motor neuron

5 Response by effector

b

Fig. 1.9 (a,b) Components of a monosynaptic reflex arc.

❖ Useful to determine the effect of UMNs on clinically observed hyporeflexia.
❖ Can reduce the effect of UMNs on a reflex arc by having a patient clench their teeth and hold their interlocked fingers in a hooklike configuration.
❖ These maneuvers reduce the conscious activity of UMNs by providing a distraction.

– Lesions

◦ UMN lesions → hyperreflexia due to loss of inhibition.
◦ LMN lesions → hyporeflexia due to loss of effector response.

Suggested Readings

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2 General Spine Anatomy and Long Tract Pathways

Jacob V. DiBattista, Ankur S. Narain, Fady Y. Hijji, Philip K. Louie, Daniel D. Bohl, and Kern Singh

2.1 Topographical Anatomy

2.1.1 General Vertebral Column Anatomy

• Overview of the vertebral column (**Table 2.1, Fig. 2.1**).
• Column classification:
  – Vertebral column divided into three anatomical classifications (**Table 2.2, Fig. 2.2**).
  – Moderate reliability for determining clinical degree of stability.
• Surface landmarks (**Table 2.3, Fig. 2.3**).

2.1.2 General Spinal Cord Anatomy

• Vertebral canal:
  – Spans from foramen magnum (cranial) to the sacral hiatus (caudal).
  – Formed by the vertebral foramina of each vertebra.
  – Contents (**Table 2.4, Fig. 2.4**).
• Spinal cord regions and spinal nerves:
  – Five divisions and 31 spinal nerves (**Fig. 2.5**):
    ◦ Cervical: C1–C8 spinal nerves.
    ◦ Thoracic: T1–T12 spinal nerves.

Table 2.1 Regions of the vertebral column

Region	Vertebral levels	Curvature[a]	Function
Cervical	C1–C7	Lordosis, 20–40 degrees	Supports and moves head Transmits spinal cord and vertebral vessels between head and neck
Thoracic	T1–T12	Kyphosis, 20–40 degrees	Supports and protects thorax
Lumbar	L1–L5	Lordosis, 40–60 degrees	Supports abdomen
Sacral	S1–S5 (fused)	Kyphosis, fused	Transmits weight to lower limbs through the pelvic bones Forms boundary and framework of posterior pelvis
Coccyx	Co	Kyphosis	Vestigial, no apparent function

[a]Kyphosis: concave anteriorly and convex posteriorly. Lordosis: convex anteriorly and concave posteriorly.
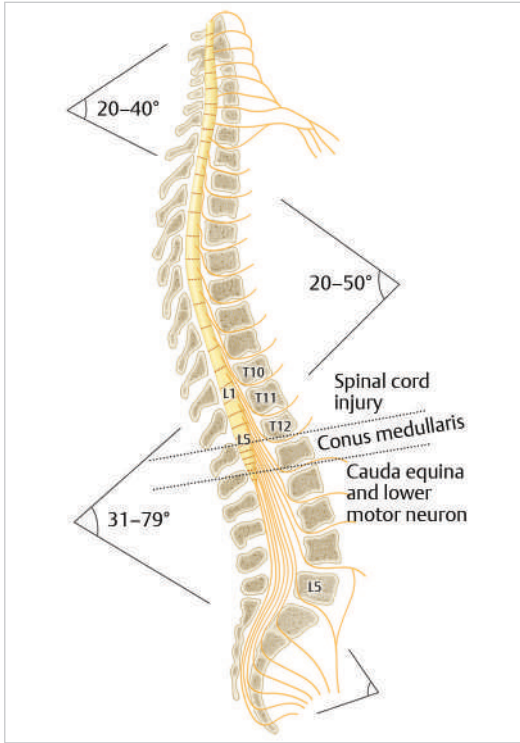
Fig. 2.1 Vertebral column. (Reproduced with permission from An HS, Singh K, eds. Synopsis of Spine Surgery. 3rd ed. New York, NY: Thieme; 2016.)

Table 2.2 Column classification

Classification	Anterior boundary	Posterior boundary
Anterior column	Anterior longitudinal ligament (ALL)	Anterior two-thirds of vertebral body and intervertebral disk
Middle column	Posterior one-third of vertebral body and intervertebral disk	Posterior longitudinal ligament (PLL)
Posterior column	Immediately posterior to PLL	Ligamentum nuchae (C1–C7) or supraspinous ligament (inferior to C7)

- Lumbar: L1–L5 spinal nerves.
- Sacral: S1–S5 spinal nerves.
- Coccyx: coccygeal nerve.
  - Spinal nerves exit vertebral canal through intervertebral foramina.
  - Spinal nerve numbering:
    - C1–C7 spinal nerves exit *above* their respective vertebrae.
    - C8 spinal nerve exits *below* C7 vertebrae (C7/T1 intervertebral foramen).
    - All remaining spinal nerves exit *below* their respective vertebrae.
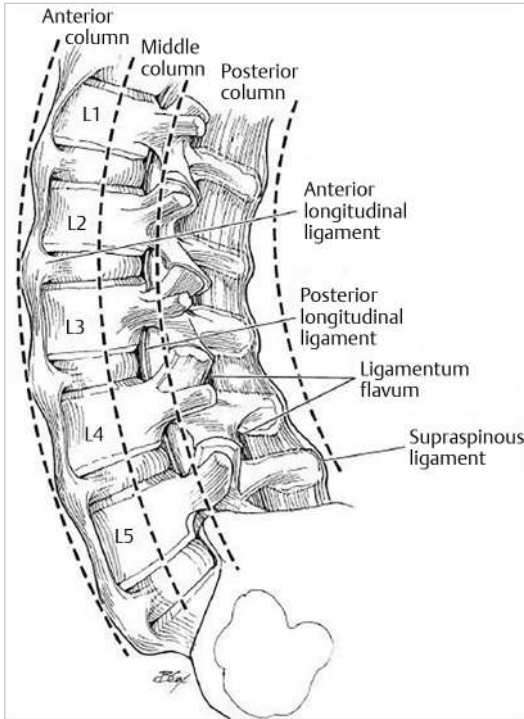
Fig. 2.2 Column classification. (Reproduced with permission from Baaj AA, Mummaneni PV, Uribe JS, Vaccaro AR, Greenberg MS, eds. Handbook of Spine Surgery. 2nd ed. New York, NY: Thieme; 2016.)

Table 2.3 Palpable surface landmarks and association with vertebral level

Anterior		Posterior	
Vertebral level	Surface landmark	Vertebral level	Surface landmark
C2/C3	Body of mandible	C7	Most prominent
T2/T3	Jugular notch	T3	Spine of scapula (medial portion)
T9/T10	Xiphoid process	T7	Inferior tip of scapula
L3/L4	Umbilicus	L4	Superior aspect of iliac crests
S1	Anterior superior iliac spine (ASIS)	S2	Posterior superior iliac spine (PSIS)

• General features of the spinal cord:
  – Adult spinal cord is two-thirds the length of the vertebral column:
    ◦ Origin: medulla (brainstem) at the foramen magnum.
    ◦ Termination: conus medullaris (L2).
  – Thecal sac comprises a dura-surrounded sac that extends from the spinal cord and contains cerebrospinal fluid (CSF), nerve roots, and the cauda equina.
  – Features (**Table 2.5, Figs. 2.5, 2.6**).
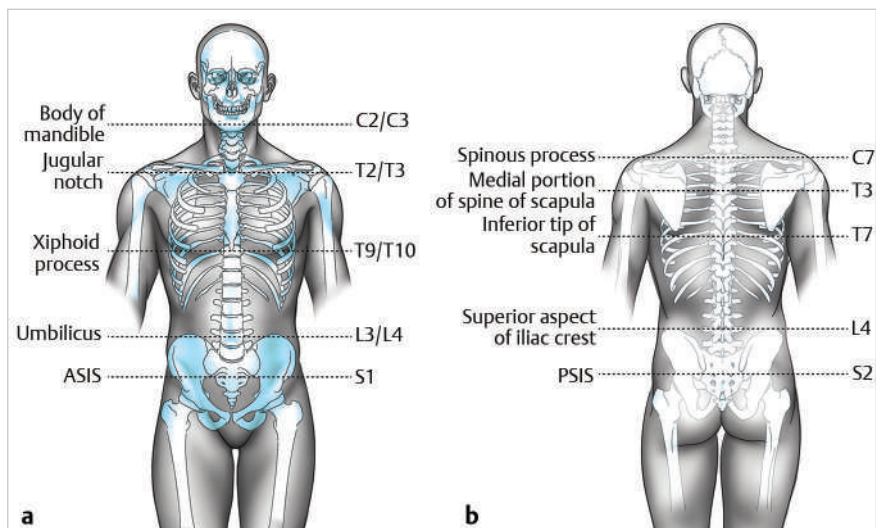
Fig. 2.3 Palpable surface landmarks to determine vertebral level. **(a)** Anterior. **(b)** Posterior.

Table 2.4 Contents of the vertebral canal

Structure	Description
Superficial	
Extradural (epidural) space	Contains adipose tissue and internal vertebral venous plexus
Internal vertebral venous plexus (anterior and posterior divisions)	Drains spinal cord and connects with external vertebral plexus. Lack of valves can lead to bidirectional blood flow
Meningeal layers	
• Dura mater (most superficial)	Composed of fibrous tissue. Continuous with the epineurium of spinal nerves
Subdural space	Potential space between dura and arachnoid mater that can open secondary to trauma (i.e., subdural hematoma)
• Arachnoid mater (middle)	Adherent to dura mater. Avascular and translucent
Subarachnoid space	Between arachnoid and pia mater. Contains cerebrospinal fluid (CSF)
• Pia mater (deepest)	Composed of thin fibrous tissue. Impermeable to CSF
Denticulate ligaments	Reflections of pia mater that attach to the arachnoid and dura mater. 21 pairs, spanning craniovertebral junction to T12, provide stability to the spinal cord
Spinal cord	
Deep	
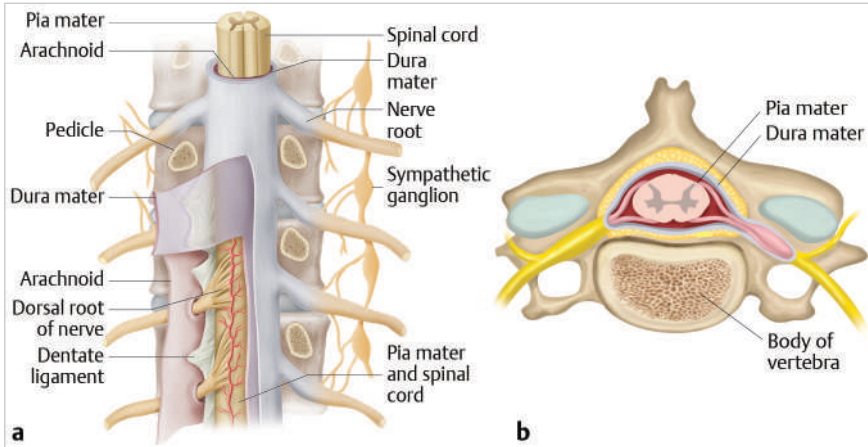
Fig. 2.4 (a,b) Contents of the vertebral canal. (Reproduced with permission from Baaj AA, Mummaneni PV, Uribe JS, Vaccaro AR, Greenberg MS, eds. Handbook of Spine Surgery. 2nd ed. New York, NY: Thieme; 2016.)

• Spinal cord anatomy (**Tables 2.6–2.7**).
• Regional variation in spinal cord white and gray matter composition (**Figs. 2.7, 2.8**):
  – Cervical region:
    ◦ Abundant gray matter for innervation of upper extremities.
    ◦ Region of most abundant white matter.
    ◦ Presence of both the fasciculus gracilis and cuneatus.
  – Thoracic region:
    ◦ Reduced size of gray matter (no innervation to extremities).
    ◦ Less white matter than cervical region.
    ◦ Intermediolateral (IML) cell column:
      ▪ Small outpocketing of gray matter from lateral horn containing cell bodies of preganglionic sympathetic neurons.
    ◦ Fasciculus cuneatus only present superior to T6, while fasciculus gracilis is present over the entire length.
  – Lumbar region:
    ◦ Abundant gray matter for innervation of lower extremities.
    ◦ Less white matter than superior regions.
    ◦ Presence of the fasciculus gracilis only.
    ◦ Presence of cauda equina.
  – Sacral region:
    ◦ Comparatively little white or gray matter.
    ◦ Contains an IML cell column:
      ▪ Cell bodies of parasympathetic preganglionic neurons.
    ◦ Presence of cauda equina.

Fig. 2.5 Spinal cord regions, features, and spinal nerve. (Reproduced with permission from Albert TJ, Vaccaro, AR, eds. Physical Examination of the Spine. 2nd ed. New York, NY: Thieme; 2016.)

2.2 Long Tract Pathways

• Descending tracts (motor information; **Tables 2.8, 2.9, Fig. 2.9**).
• Ascending tracts (sensory information; **Tables 2.10, 2.11**).

Table 2.5 General features of the spinal cord

Feature and vertebral level	Description
Cervical enlargement (C4–T1)	Overabundance of nerve fibers for the innervation of upper extremities
Lumbosacral enlargement (L1–L3)	Overabundance of nerve fibers for the innervation of lower extremities
Cauda equina (T12/L1–Co)	Collection of lumbar, sacral, and coccygeal nerve roots that arise from the conus medullaris Travel inferiorly within vertebral canal to exit at their respective vertebral levels
Termination of dural sac (S2)	Termination of dura mater
Filum terminale	Continuation of pia mater from conus medullaris (L2) to the coccyx. Helps anchor spinal cord in place
Internum (L2–S2)	Filum terminale within the dural sac
Externum (S2–Co)	Filum terminale outside the dural sac
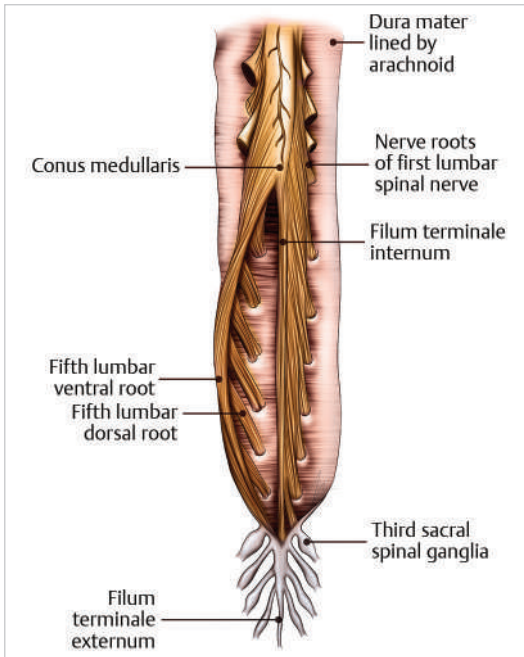
Fig. 2.6 Terminal ending of the spinal cord.

Table 2.6 Spinal cord anatomy: surface structures

Structure	Function
Root	
Ventral	Carries **motor** information from the spinal cord. Contains general somatic efferent (GSE) and general visceral efferent (GVE) fibers
Dorsal	Carries **sensory** information to the spinal cord. Contains general somatic afferent (GSA) and general visceral afferent (GVA) fibers
Rootlet	
Ventral	Branched portion of ventral root that attaches to spinal cord
Dorsal	Branched potion of dorsal root that attaches to spinal cord
Dorsal root ganglion	Site of GSA and GVA neuron cell bodies
Spinal nerve	Aggregation of ventral and dorsal roots (GSA, GVA, GSE, and GVE fibers). 31 pairs, which exit vertebral canal at intervertebral foramina
Ramus	
Ventral	Anterior division of a spinal nerve. Innervates the ventral trunk and upper and lower limbs. Much larger than the dorsal mini
Dorsal	Posterior division of a spinal nerve. Most levels divide into medial and lateral branches to innervate skin and muscles of back (dorsal trunk)
Meningeal branches	Branch from spinal nerve prior to rami. Re-enter intervertebral foramen to innervate vertebrae and vertebral canal structures
Anterior median fissure	Runs length of ventral spinal cord, dividing it into right and left halves. Creates a groove where the anterior spinal artery lies
Anterolateral sulcus	Site where ventral rootlets exit the spinal cord
Posterior median sulcus	Runs length of dorsal spinal cord, dividing it into right and left halves. Less prominent than anterior median sulcus
Posterior intermediate sulcus	Small furrow that separates the fasciculus gracilis (medial) from the fasciculus cuneatus (lateral). Only located superior to T6
Posterolateral sulcus	Site where dorsal rootlets enter the spinal cord

2.3 Intervertebral Disk Anatomy (Fig. 2.10)

- Description:
  - Nonsynovial (symphysis) joint located between vertebral bodies:
    - Layer of hyaline cartilage separates the disk and vertebral body (end plates).
- Composition:
  - Fibrocartilaginous.
  - Nucleus pulposus: inner core, remnant of the embryological notochord:
    - Composed of type II collagen.
  - Annulus fibrosus: outer ring arranged in lamellar fashion:
    - Composed of type I collagen.

Table 2.7 Spinal cord anatomy: cross section

White matter: myelinated neurons. Contains ascending and descending tracts (pathways).	
Structure[a]	Function (tracts)
Anterior funiculus	*Ascending:* anterior spinothalamic *Descending:* anterior corticospinal, medial reticulospinal, tectospinal, and medial vestibulospinal
Lateral funiculus	*Ascending:* lateral spinothalamic and anterior and posterior spinocerebellar *Descending:* lateral corticospinal, lateral reticulospinal, rubrospinal, and lateral vestibulospinal
Posterior funiculus	*Ascending:* dorsal column (fasciculus gracilis and cuneatus) *Descending:* none
Anterior white commissure	Site where certain fibers cross in the midline. Located between the anterior median fissure and gray matter commissure. Connects two halves of spinal cord
Gray matter: unmyelinated neurons. Contains interneurons and cell bodies.	
Structure	Function
Ventral horn	Site of GSE cell bodies (lower motor neurons)
Lateral horn	Site of GVE (autonomic) cell bodies
Dorsal horn	Site of interneuron cell bodies (receive GSA and GVA fibers)
Gray commissure	Surrounds central canal. Connects two halves of spinal cord
Other structures	
Structure	Function
Central canal	Cerebrospinal fluid–filled space within the center of the spinal cord. Continuous with the ventricular system of the brain. Gradually occludes with age

[a]A fasciculus refers to a bundle of parallel axons in the central nervous system (carry same information/modality), while a funiculus refers to a grouping of fasciculi. Both are located within spinal cord white matter.
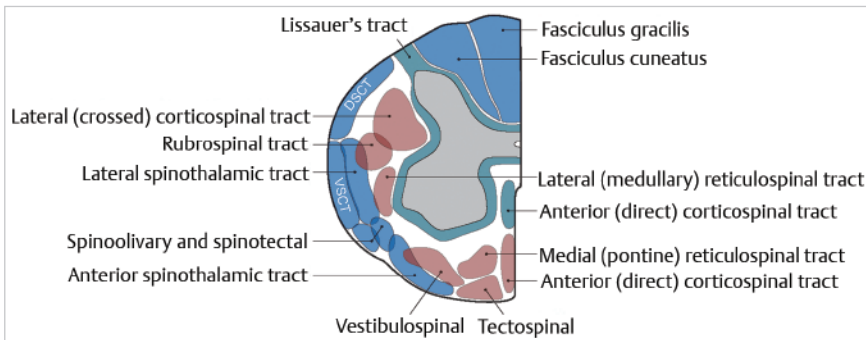
Fig. 2.7 Divisions of spinal cord white matter and gray matter. (Reproduced with permission from Fehlings MG, Vaccaro AR, Maxwell Boakye M, Rossignol S, Ditunno DF, Burns AS, eds. Essentials of Spinal Cord Injury: Basic Research to Clinical Practice. New York, NY: Thieme; 2012.)
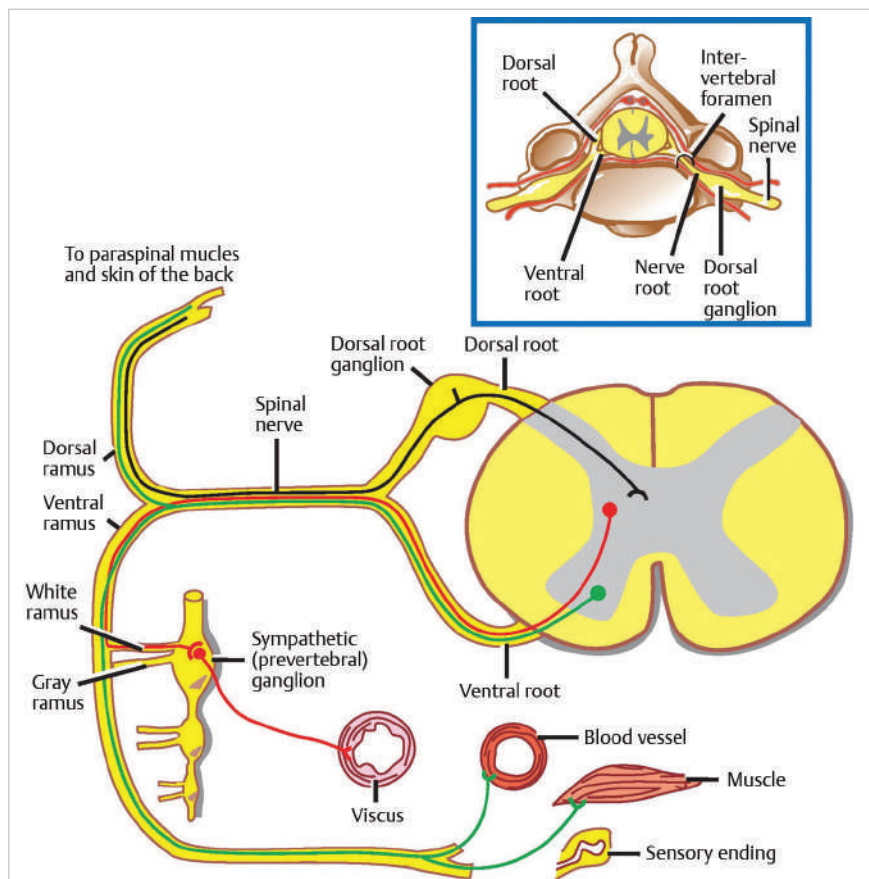
Fig. 2.8 Functional organization of spinal cord gray matter. (Reproduced with permission from Albertstone CD, Benzel EC, Najm IM, Steinmetz M, eds. Anatomic Basis of Neurologic Diagnosis. New York, NY: Thieme; 2009.)

• Mechanics:
  – Allows limited movement and holds vertebrae in close association.
  – Help resist compression of the vertebral column.
• Anatomy:
  – Twenty-three pairs of disks in the vertebral column:
    ◦ First intervertebral disk: C2/C3.
    ◦ Last functional intervertebral disk: L5/S1.

Table 2.8 Overview of the descending (motor) tracts

Pyramidal tracts: UMN fibers that travel from the cerebral cortex to the spinal cord. Control voluntary movement by acting directly (or indirectly via interneurons) on lower motor neuron (LMN) cell bodies of the ventral horn.

Tract	Location	
	Spinal cord white matter	Spinal cord region
Corticospinal		
Anterior	Anterior funiculus	Entire length
Lateral	Lateral funiculus	Entire length

Extrapyramidal tracts: upper motor neuron (UMN) fibers that travel from brainstem areas to the spinal cord. Control involuntary movements by modulating and regulating LMN cell bodies of the ventral horn (i.e., posture, balance, etc.).

Tract	Location	
	Spinal cord white matter	Spinal cord region
Reticulospinal		
Medial	Anterior funiculus	Entire length
Lateral	Lateral funiculus	Entire length
Rubrospinal	Lateral funiculus	Cervical/upper thoracic only
Tectospinal	Anterior funiculus	Cervical only
Vestibulospinal		
Medial	Anterior funiculus	Cervical only
Lateral	Lateral funiculus	Entire length

2.4 Dermatomes

• Dermatome:
  – Distinct area of skin supplied by a single spinal cord level.
  – That is, pain sensation from a pinprick on the third finger is carried through the median nerve and enters the spinal cord at C7.
• Radiating pain:
  – Pain that migrates from the origin of the painful stimulus; can be cutaneous or deep.
  – That is, sciatica is caused by L5 spinal nerve entrapment, leading to lower back pain that radiates down the thigh to the leg and foot.
• Referred pain:
  – Pain perceived at a different site than origin of the painful stimulus.
  – Follows dermatomal pattern (based on autonomics).
  – That is, a myocardial infarction often causes pain in the left shoulder, neck, and back because general visceral afferent (GVA) fibers from the heart are of the same spinal level and dermatome as those cutaneous areas.

Table 2.9 Descending (motor) tract pathway details

Tract	Function	Pathway		Site of decussation
		Origin	Final destination	
Corticospinal				
Anterior[a]	Control of proximal muscles (trunk and neck)	Cerebral cortex (precentral gyrus)	Lower motor neuron (LMN) cell bodies	Some in anterior white commissure, at level of synapse (bilateral innervation)
Lateral	Control of fine movement in (primarily) distal flexor muscles	Cerebral cortex (precentral gyrus)	LMN cell bodies	Caudal medulla (contralateral innervation)
Reticulospinal				
Medial	Regulation of voluntary movement in (primarily) extensors of limbs and trunk	Pontine reticular formation	Interneurons (dorsal horn)	None (ipsilateral innervation)
Lateral	Regulation of voluntary movement in (primarily) flexors of limbs	Medullary reticular formation	Interneurons (dorsal horn)	Some in caudal medulla (bilateral innervation)
Rubrospinal	Facilitation of voluntary movement in flexors of upper limbs. Inhibition of voluntary movement in extensors of upper limbs. Important for balance	Red nucleus (midbrain)	Interneurons and LMN cell bodies	Midbrain (contralateral innervation)
Tectospinal	Reflex movement of head and neck due to visual stimuli	Superior colliculus (midbrain)	Interneurons and LMN cell bodies	Midbrain (contralateral innervation)
Vestibulospinal				
Medial	Maintain upright head positioning in response to vestibular stimuli	Medial vestibular nucleus (medulla)	Interneurons and LMN cell bodies	Some in caudal medulla (bilateral innervation)
Lateral	Maintain posture in response to vestibular stimuli	Lateral vestibular nucleus (pons)	LMN cell bodies	None (ipsilateral innervation)

[a]The anterior corticospinal pathway represents approximately 15% of neurons that do not decussate in the lower medulla (which form the lateral corticospinal pathway).
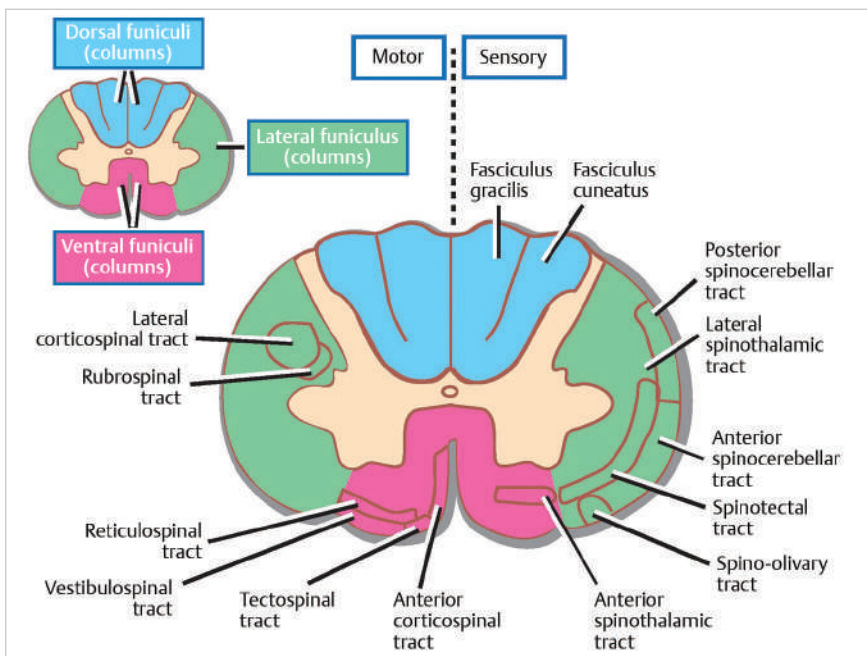
Fig. 2.9 Descending (motor) and ascending (sensory) tracts. (Reproduced with permission from Albertstone CD, Benzel EC, Najm IM, Steinmetz M, eds. Anatomic Basis of Neurologic Diagnosis. New York, NY: Thieme; 2009.)

Table 2.10 Overview of the ascending (sensory) tracts

Tract	Location	
	Spinal cord white matter	**Spinal cord region**
Dorsal column		
Fasciculus cuneatus	Posterior funiculus	Cranially to T6 only
Fasciculus gracilis	Posterior funiculus	Entire length
Spinothalamic		
Anterior	Anterior funiculus	Entire length
Lateral	Lateral funiculus	Entire length
Spinocerebellar		
Anterior	Lateral funiculus	Entire length
Posterior	Lateral funiculus	Entire length

Table 2.11 Ascending (sensory) tract pathway details

Tract	Sensory modality	Cell body location and pathway				Site of decussation
		1-degree neuron	2-degree neuron	3-degree neuron	Terminal destination	
Dorsal column						
Fasciculus gracilis	Conscious proprioception, 2-point discrimination, touch, pressure, and vibration caudal to T6	Dorsal root ganglia. Ascends within fasciculus gracilis (medial portion of posterior funiculus)	Nucleus gracilis of medulla. Decussates and ascends within medial lemniscus	Ventral posterolateral (VPL) nucleus of thalamus. Ascends within internal capsule	Cerebral cortex (postcentral gyrus)	Lower medulla (contralateral sensation)
Fasciculus cuneatus	Conscious proprioception, 2-point discrimination, touch, pressure, and vibration cranial to T6	Dorsal root ganglia. Ascends within fasciculus cuneatus (lateral portion of posterior funiculus)	Nucleus cuneatus of medulla. Decussates and ascends within medial lemniscus	Same as above	Same as above	Same as above
Spinothalamic						
Anterior	Light touch	Dorsal root ganglia. Either enters dorsal horn at same level or travels 1–2 levels cranially or caudally via Lissauer's tract	Substantia gelatinosa or nucleus proprius of dorsal horn. Decussates via the anterior white commissure and ascends in the anterior funiculus	VPL nucleus of thalamus. Ascends within internal capsule	Cerebral cortex (postcentral gyrus)	Anterior white commissure, at either same spinal level or 1–2 cranially or caudally (contralateral sensation)
Lateral	Pain and temperature	Same as above	Same as above, but ascends in the lateral funiculus	Same as above	Same as above	Same as above

(Continued)

Table 2.11 (*Continued*)

Tract	Sensory modality	Cell body location and pathway				Site of decussation
		1-degree neuron	2-degree neuron	3-degree neuron	Terminal destination	
Spinocerebellar						
Anterior	Unconscious proprioception	Dorsal root ganglia. Enters dorsal horn at same level	Nucleus proprius. Decussates via the anterior white commissure and ascends in the lateral funiculus	None	Cerebellum (via superior cerebellar peduncle of midbrain)	Anterior white commissure at same level, then again in the cerebellum (net ipsilateral sensation)
Posterior	Unconscious proprioception	Same as above	Nucleus of Clarke. Ascends ipsilaterally in the lateral funiculus	None	Cerebellum (via inferior cerebellar peduncle of midbrain)	None (ipsilateral sensation)
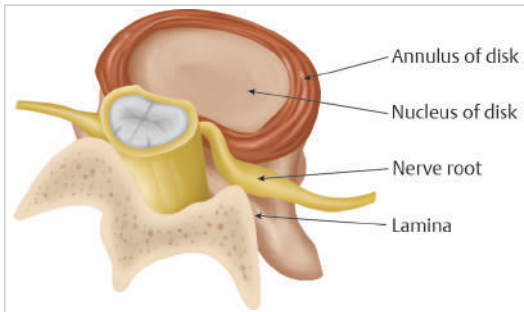
Fig. 2.10 (a,b) Components of the intervertebral disks. (Reproduced with permission from An HS, Singh K, eds. Synopsis of Spine Surgery. 3rd ed. New York, NY: Thieme; 2016.)

- Annulus of disk
- Nucleus of disk
- Nerve root
- Lamina

Suggested Readings

1. Haines DE. Fundamental Neuroscience for Basic and Clinical Applications. 4th ed. Philadelphia, PA: Churchill Livingstone/Elsevier; 2013
2. Haines DE. Neuroanatomy in Clinical Context: An Atlas of Structures, Sections, and Systems. 9th ed. Baltimore, MD: Lippincott, Williams, and Wilkins; 2014
3. Drake RL, Vogl AW, Mitchell AW. Gray's Anatomy for Students. 2nd ed. Philadelphia, PA: Churchill Livingstone; 2014
4. Gilroy AM, MacPherson BR, Ross LM, Schuenke M, Schulte E, Schumacher U. Atlas of Anatomy. 2nd ed. New York, NY: Thieme; 2012
5. Martini FH, Timmons MJ, Tallitsch RB. Human Anatomy. 8th ed. Boston, MA: Pearson; 2014

3 Atlanto-Occipital Anatomy

Suzanne Labelle, Fady Y. Hijji, Ankur S. Narain, Philip K. Louie, Daniel D. Bohl, and Kern Singh

3.1 Bony Anatomy

3.1.1 Occipital Bone (Fig. 3.1)

• External occipital protuberance.
• Superior nuchal line.
• Inferior nuchal line.
• Occipital condyle:
  – Articulate with superior facets of the atlas vertebra.
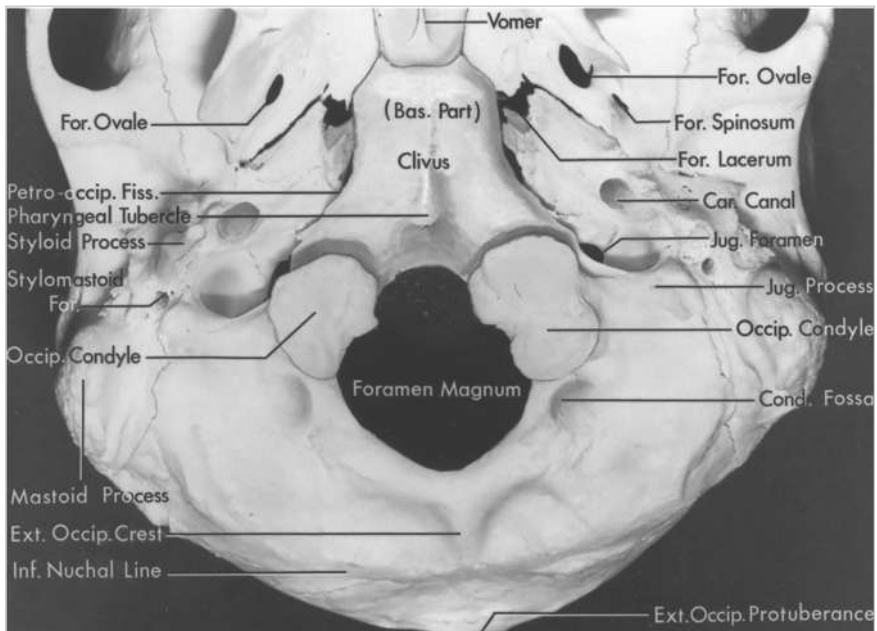
Fig. 3.1 Bony anatomy of occipital bone. (Reproduced with permission from Bambakidis NC, Dickman CA, Spetzler RF, Sonntag VKH, eds. Surgery of the Craniovertebral Junction. 2nd edition. New York, NY: Thieme; 2012)

3.1.2 Atlas: First Cervical Vertebra (C1; Fig. 3.2)

• Foramen magnum:
  – Allows passage of spinal cord.
• Anterior arch:
  – Anterior tubercle.
  – Articular facet for dens on posterior surface.
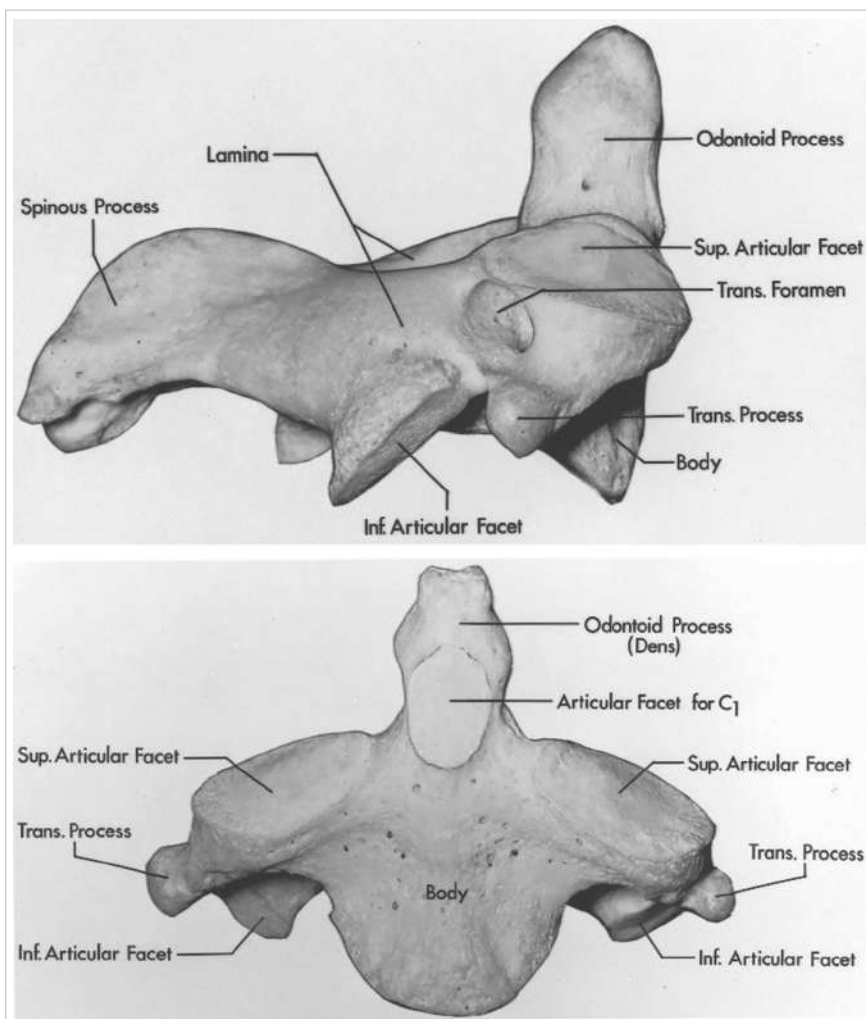
Fig. 3.2 Bony anatomy of atlas and axis. (Reproduced with permission from Bambakidis NC, Dickman CA, Spetzler RF, Sonntag VKH, eds. Surgery of the Craniovertebral Junction. 2nd edition. New York, NY: Thieme; 2012)

- Posterior arch:
  - Equivalent to lamina of other cervical vertebrae.
  - Posterior tubercle:
    - Equivalent to spinous process.
- Transverse process:
  - Contains transverse foramen:
    - Allows for passage of vertebral artery.
    - Vertically oriented.
- Lateral masses:
  - Equivalent to vertebral body (no formal vertebral body).
  - Contains tubercle for attachment of cruciate ligament.
  - Superior articular surface:
    - Horizontally oriented.
    - Articulates with occipital condyle forming atlanto-occipital joint:
      - Biaxial condyloid synovial joint: fluid-filled articulations involving occipital condyles that allow movement in two planes.
      - Permits flexion and extension; minimal lateral bending and rotation.
  - Inferior articular surface:
    - Horizontally oriented.
    - Articulates with lateral mass of axis forming atlanto-axial joint.

3.1.3 Axis: Second Cervical Vertebra (C2; Fig. 3.2)

- Dens:
  - Unique to only C2.
  - Anterior articular facet:
    - Articulates with anterior arch of atlas.
    - Forms median pivot joint (**Fig. 3.3**).
  - Posterior articular facet:
    - Serves as articulating surface for the transverse ligament of the cruciate ligament:
      - Prevents subluxation between C1 and C2.

C1-C2, Axial Rotation   C1-C2, Lateral Bending
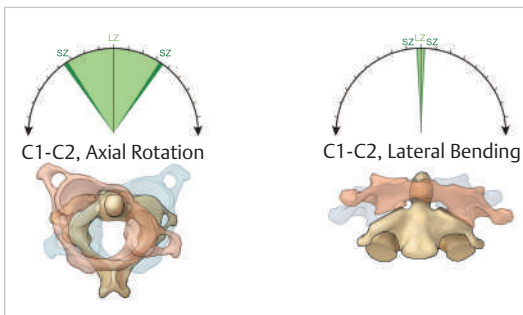
Fig. 3.3 Atlantoaxial joint side-to-side rotation. (Reproduced with permission from Bambakidis NC, Dickman CA, Spetzler RF, Sonntag VKH, eds. Surgery of the Craniovertebral Junction. 2nd edition. New York, NY: Thieme; 2012)

- – Small vertebral body beneath dens:
  - ◦ Small pedicles attaching to lateral masses.
- • Transverse process:
  - – Contains transverse foramen:
    - ◦ Vertebral artery exits here:
      - ▪ Makes a 45-degree turn and re-enters cervical spine at transverse foramen of C1.
- • Spinous process:
  - – Small and bifid.
- • Lateral masses:
  - – Superior articular facet:
    - ◦ Horizontally oriented.
    - ◦ Articulates with atlas forming atlantoaxial joint:
      - ▪ Uniaxial synovial joint: fluid-filled joint that allows movement in one plane.
      - ▪ Plane joints between both superior articular facets of axis and corresponding inferior articular facets of atlas.
      - ▪ Median pivot joint between dens and anterior arch of atlas.
      - ▪ Permits side-to-side head rotation (50% of cervical rotation).
      - ▪ Permits small degree of flexion/extension (10 of 110 degrees of the cervical spine).
  - – Inferior articular facet:
    - ◦ Horizontally oriented.
    - ◦ Articulates with C3 (**Table 3.1**).

Table 3.1 Comparison to other cervical vertebrae

Vertebra	Similarities	Differences
Atlas (C1)		Posterior arch in place of lamina Posterior tubercle in place of spinous process Anterior arch with anterior process
Axis (C2)	Spinous process Vertebral body	Articular processes in place of lamina Dens/odontoid process
Both	Transverse processes with foramina for vertebral artery Articular surfaces on lateral masses	No uncinate processes Lateral masses in place of body

3.2 Ligamentous Anatomy (Tables 3.2, 3.3; Figs. 3.4, 3.5)

3.3 Muscular Anatomy (Tables 3.4, 3.5; Figs. 3.6, 3.7)

3.4 Vascular Anatomy

Table 3.2 Atlanto-occipital ligaments (**Figs. 3.5, 3.6**)

Ligament	Origin	Insertion	Function
Anterior			
Anterior atlanto-occipital membrane (AAO)	Anterior aspect of atlas	Anterior rim of foramen magnum	Limits extension of head
Barkow's ligament	Anteromedial aspect of occipital condyle anterior to alar ligament	Anteromedial aspect of occipital condyle anterior to alar ligament	Limits extension of atlanto-occipital joint
Lateral atlanto-occipital ligament (LAO)	Anterolateral transverse process of axis	Jugular process of occipital bone	Limits lateral flexion of the head
Posterior			
Posterior atlanto-occipital membrane (PAO)	Posterior arch of atlas	Posterior rim of foramen magnum	Posterior reinforcement of joint
Tectorial membrane	Posterior axis	Upper surface of occipital bone anterior to foramen magnum	Restricts extension at atlanto-occipital joint (continuation of posterior longitudinal ligament)
Posterior atlanto-occipital membrane (PAO)	Posterior arch of atlas	Posterior rim of foramen magnum	Posterior reinforcement of joint
Nuchal ligament	Spinous process of C7	Inferior projection of occipital bone	Restricts hyperflexion of cervical spine (continuation of supraspinous ligament)

Table 3.3 Atlantoaxial ligaments

Ligament	Origin	Insertion	Function
Anterior			
Cruciate ligament (transverse atlantal ligament)	Lateral tubercle of atlas	Lateral tubercle of atlas of opposite site	Maintains stability of atlantoaxial junction by locking odontoid process against anterior arch of C1 Strongest ligament of the atlantoaxial joint
Alar ligaments	Lateral aspect of odontoid process	Base of skull	Limits hyperrotation and lateral bending on contralateral side
Transverse occipital ligament (TOL)	Inner aspect of occipital condyle	Inner aspect of occipital condyle	Sits posterosuperiorly to alar ligaments and assists them in support of craniocervical junction
Posterior			
Accessory atlantoaxial ligament	Medial dorsal surface of axis	Posterior to transverse ligament on lateral mass of atlas	Protection and support for branches of vertebral artery that supply the dens
Tectorial membrane	Posterior axis	Upper surface of occipital bone anterior to foramen magnum	Restricts flexion/extension at atlantoaxial joint
Nuchal ligament	Spinous process of C7	Inferior projection of occipital bone	Restricts hyperflexion of cervical spine

- Vertebral artery: arterial supply of C1 and C2:
  - Four segments (V1–V4).
  - Originates from subclavian artery:
    - Ascends between anterior scalene and longus colli muscles.
    - Reaches C6 vertebrae and enters transverse foramen.
  - Four segments (V1–V4): progresses superiorly:
    - V1: preforaminal:
      - Subclavian artery to transverse foramen of C6:
        - Despite a vertebral foramen in C7, the vertebral artery does not travel through it in a majority of individuals.
    - V2: foraminal:
      - Transverse foramen (C6) to C2 vertebrae.
  - Segments at the craniocervical junction:
    - V3: above C2:
      - C2 to dura mater.
    - V4: intradural:
      - Intradural to basilar artery (brainstem).
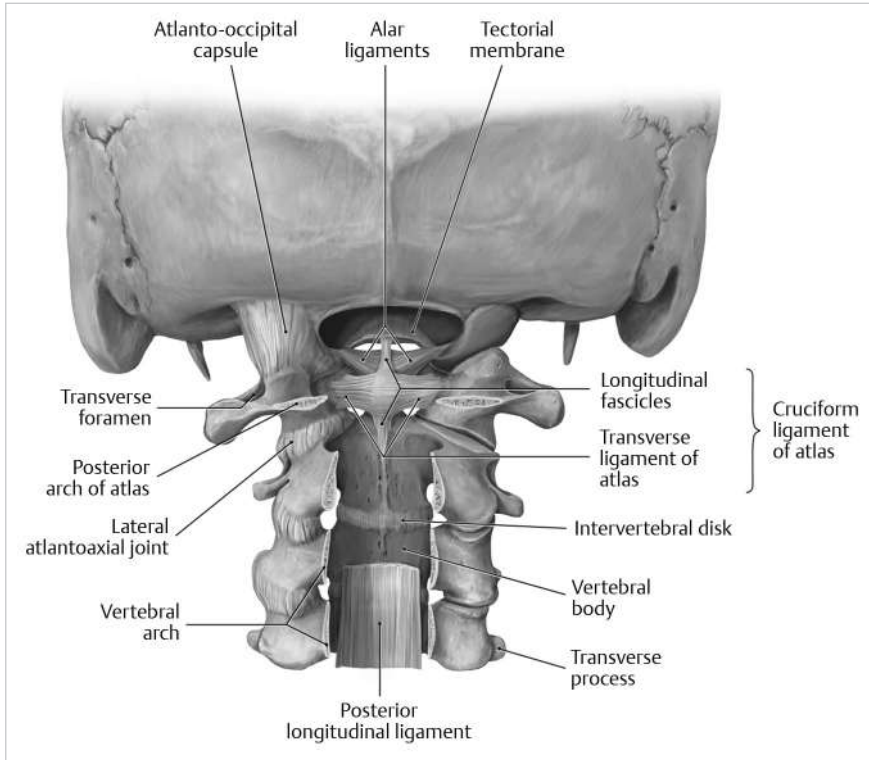
Fig. 3.4 Internal ligaments of craniocervical junction. (Reproduced with permission from Baaj AA, Mummaneni PV, Uribe JS, Vaccaro AR, Greenberg MS, eds. Handbook of Spine Surgery. 2nd edition. New York, NY: Thieme; 2016)

- Feeding branches to C1 and C2:
  - Anterior spinal artery:
    - Single midline vessel.
    - Supplies anterior two-thirds of spinal cord within C1 and C2.
  - Posterior spinal artery:
    - Supplies posterior one-third of spinal cord within C1 and C2.
  - Anterior ascending artery:
    - Branch off vertebral arteries immediately caudal to axis.
    - Primary supply to odontoid.
    - Forms collateral system with posterior ascending artery.
  - Posterior ascending artery:
    - Branch off vertebral arteries caudal to axis.
    - Primary supply to odontoid.
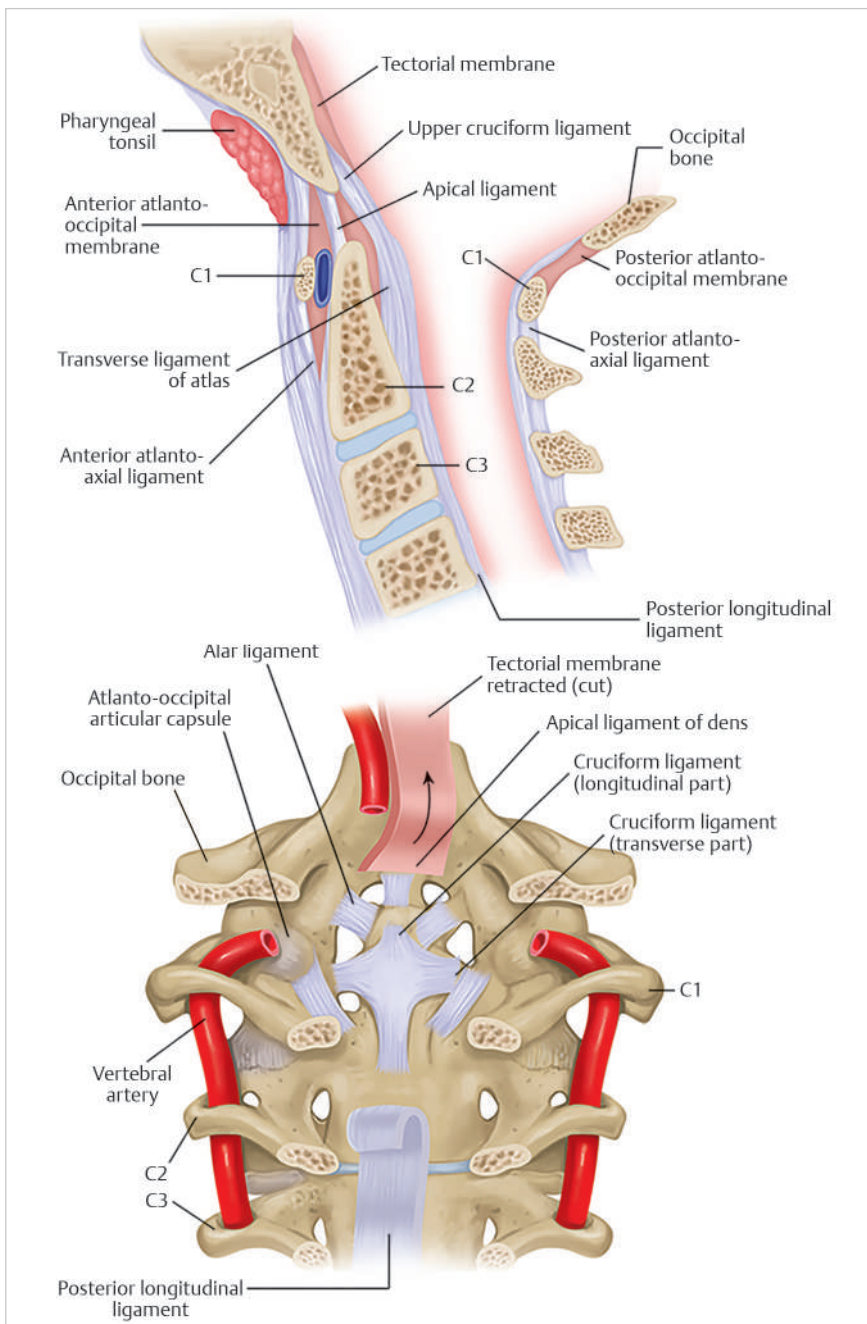
Fig. 3.5 Sagittal view of external ligaments of craniocervical junction. (Reproduced with permission from An HS, Singh K, eds. Synopsis of Spine Surgery. 3rd ed. New York, NY: Thieme; 2016)

Table 3.4 Suboccipital triangle (**Fig. 3.6**)

Muscle	Origin	Insertion	Action	Innervation
Rectus capitis posterior (major)	Spine of C2 vertebrae (axis)	Inferior nuchal line	Extend, rotate, and laterally flex head	Suboccipital nerve (dorsal ramus of C1)
Rectus capitis posterior (minor)	Posterior tubercle of C1 vertebrae (C1)	Occipital bone	Extend and laterally flex head	Suboccipital nerve
Obliquus capitis	Transverse process of atlas	Occipital bone	Extend and laterally flex head	Suboccipital nerve
Obliquus capitis inferior	Spine of axis	Transverse process of atlas	Extend and laterally flex head	Suboccipital nerve

Table 3.5 Deep anterior neck muscles (**Fig. 3.7**)

Muscle	Origin	Insertion	Action	Innervation
Longus capitis	Transverse process of C3–C6	Basilar part of occipital bone	Flexion of neck at atlanto-occipital joint	C1–C4 nerve roots
Longus colli	Transverse process of C5–T3	Anterior arch of atlas	Flexes head and neck	C2–C6 nerve roots
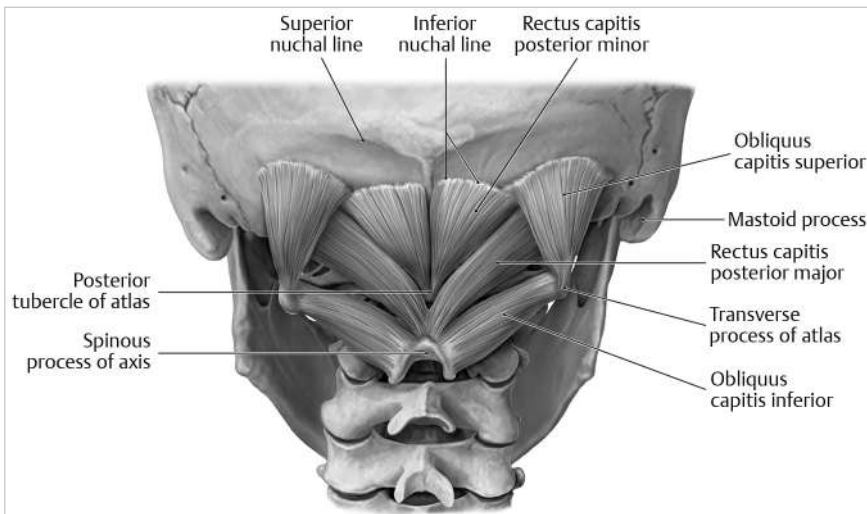
Fig. 3.6 Muscular anatomy of the suboccipital triangle. (Reproduced with permission from Baaj AA, Mummaneni PV, Uribe JS, Vaccaro AR, Greenberg MS, eds. *Handbook of Spine Surgery*. 2nd ed. New York, NY: Thieme; 2016)
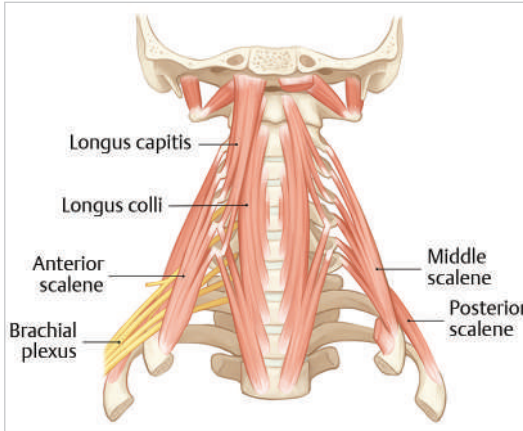
Fig. 3.7 Deep anterior muscles of the neck.

- Posterior ascending arteries connect to form apical arcade at top of odontoid process.
- Forms collateral system with anterior ascending artery.
  - Anterior segmental medullary artery:
    - Small branches penetrating cervical vertebrae and spinal cord.
  - Posterior segmental medullary artery:
    - Small branches penetrating cervical vertebrae and spinal cord.

3.5 Neural Anatomy

- C1 and C2 nerve roots:
  - Exit above respective vertebrae.
  - Exhibit both ventral and dorsal rami:
    - Ventral rami: motor innervation for strap muscles.
    - Dorsal rami: motor innervation for suboccipital triangle muscles and sensation of the posterior scalp (**Fig. 3.8**).
- Cervical plexus:
  - Anterior rami of C1–C4.
  - Gives rise to ansa cervicalis.
    - Ventral rami of C1 form superior root:
      - Gives off branches to infrahyoid anterior neck muscles (strap muscles): omohyoid, sternohyoid, and sternothyroid.
    - Ventral rami of C2 join C3 to form inferior root:
      - Gives off branches to strap muscles: omohyoid, sternohyoid, and sternothyroid.
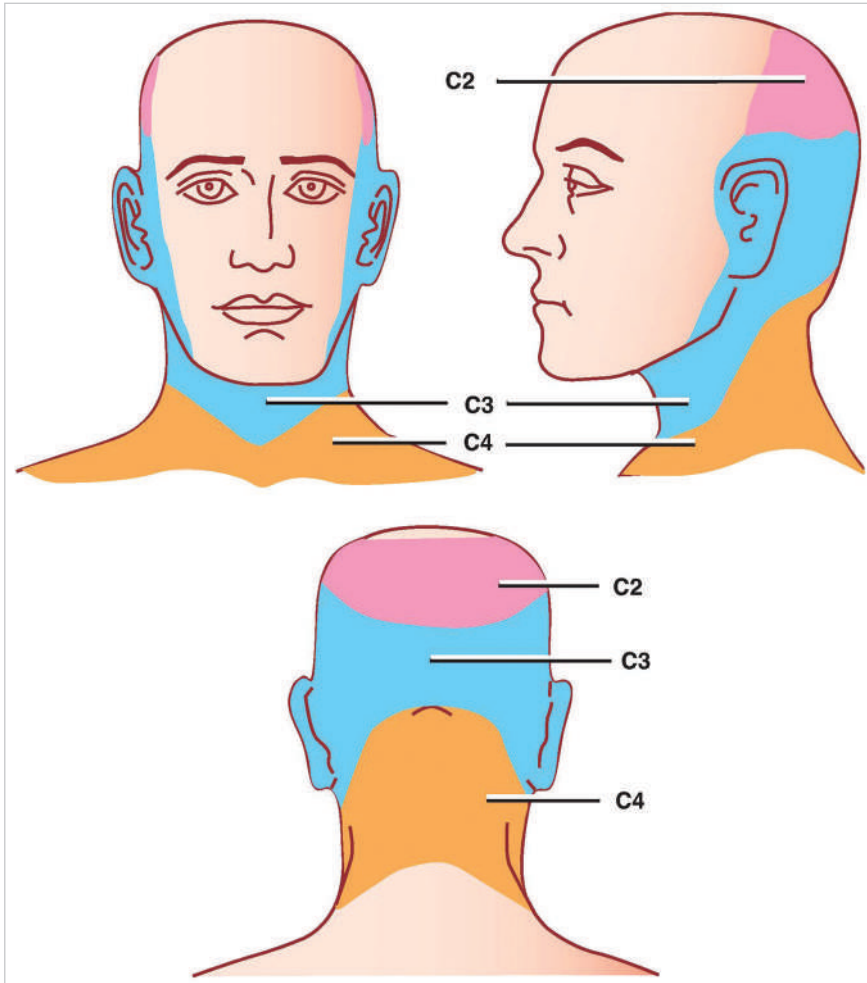
Fig. 3.8 Occipital dermatomes. (Reproduced with permission from Albertstone CD, Benzel EC, Najm IM, Steinmetz M, eds. *Anatomic Basis of Neurologic Diagnosis.* New York, NY: Thieme; 2009)

3.6 Clinical and Surgical Pearls

- C1 and C2 nerve roots can be sacrificed with minimal consequences in occipital–cervical fusion and risk of occipital neuralgia.
- High-energy forces such as motor vehicle collisions can result in atlanto-occipital ligamentous injury:
  - Separates spinal column from occiput, frequently damaging the brainstem.

- Anomalous fusion of cervical vertebrae most commonly occurs between C1 and C2 or between C5 and C6.
- 3–15% of the population has an arcuate foramen:
  - Bony bridge covering the groove for vertebral artery (V3) entering C1:
    - Caused by calcification of atlanto-occipital ligaments.
- C2 pedicles are narrow, increasing the risk for screw breach into the neural canal during occipitocervical fusion procedures.

Suggested Readings

1. An HS, Singh K. Synopsis of Spine Surgery. 3rd ed. New York, NY: Thieme; 2016
2. Althoff B, Goldie IF. The arterial supply of the odontoid process of the axis. Acta Orthop Scand 1977;48(6):622–629
3. Netter FH. Atlas of Human Anatomy. 6th ed. Philadelphia, PA: Saunders; 2014
4. Tubbs RS, Hallock JD, Radcliff V, et al. Ligaments of the craniocervical junction. J Neurosurg Spine 2011;14(6):697–709

4 Cervical Spine Anatomy

Fady Y. Hijji, Ankur S. Narain, Philip K. Louie, Daniel D. Bohl, and Kern Singh

4.1 General Information

- C3–C7 are defined as the subaxial spine.
- Majority of flexion/extension of the neck and lateral bending occur here:
  - Maximal flexion occurs at C4/C5 and C5/C6.
  - Maximal lateral bending occurs at C2/C3, C3/C4, and C4/C5.
- Lordotic curvature: 16 to 25 degrees.
- Landmarks:
  - C2/C3: lower border of mandible.
  - C3: hyoid bone.
  - C4: thyroid cartilage.
  - C6: cricoid cartilage.

4.2 Bony Anatomy (Fig. 4.1)

- Vertebral body:
  - Concave superiorly.
  - Convex inferiorly.
- Uncinate process:
  - Directly interacts with adjacent vertebral body above.
  - Contain articular surfaces.
- Pedicle:
  - Angled medially and superiorly.
  - Pedicles smaller than those in thoracic and lumbar spine.
- Transverse process:
  - Contains transverse foramen:
    - **All** cervical vertebrae have transverse foramen.
    - Anterior to nerve root groove.
    - Allow for passage of vertebral artery.
  - C6 transverse process (Chassaignac's tubercle) is palpable.
- Lamina:
  - Bridge between lateral masses and spinous process.
- Lateral mass:
  - Lateral to junction between pedicle and lamina.
  - Contains the superior and inferior articular processes:
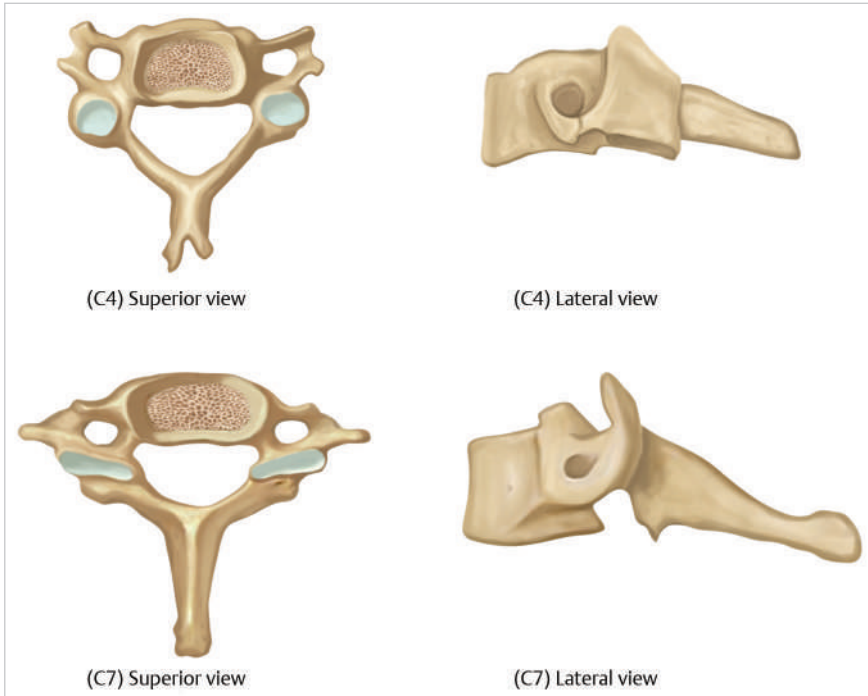
Fig. 4.1 Bony anatomy of cervical vertebrae. (Reproduced with permission from An HS, Singh K, eds. Synopsis of Spine Surgery. 3rd ed. New York, NY: Thieme; 2016.)

- ◦ Creates the facet joint with the adjacent vertebral articular processes.
- ◦ Superior articular facets exhibit posteromedial orientation, transitioning to posterolateral with caudal progression:
  - ▪ Supports more flexion/extension.
- Spinous process:
  - – Bifid from C3 to C5.
  - – C7 exhibits largest spinous process.

4.3 Ligamentous Anatomy

- Anterior ligamentous complex:
  - – Anterior longitudinal ligament (ALL):
    - ◦ Traverses along anterior surface of vertebral bodies.
    - ◦ Resists extension.
  - – Annulus fibrosis of the intervertebral disk.
- Middle ligamentous complex:
  - – Posterior longitudinal ligament (PLL):
    - ◦ Traverses along posterior surface of vertebral bodies.
    - ◦ Resists flexion.

- – Annulus fibrosis.
- Posterior ligamentous complex:
  - – Facet capsules:
    - ◦ Support facet joint for adjacent vertebra articulation and resist distractive forces.
  - – Interspinous and supraspinous ligament:
    - ◦ Traverse between spinous processes:
      - ▪ Midline avascular plane.
    - ◦ Continuous with the ligamentous nuchae above C7.
  - – Ligamentum flavum:
    - ◦ Deepest structure posteriorly prior to reaching spinal canal.
    - ◦ Connects the laminas of adjacent vertebrae.

4.4 Muscular Anatomy

- Fascial layers (**Fig. 4.2**):
  - – Platysma:
    - ◦ Superficial muscle.
  - – Superficial layer of deep cervical fascia:
    - ◦ Contains anterior neck muscles (except longus colli) and trapezius posteriorly.
  - – Prevertebral layer of deep cervical fascia:
    - ◦ Contains all posterior neck muscles deep to trapezius.
    - ◦ Covers ALL and longus colli.
  - – Pretracheal fascia:
    - ◦ Contains thyroid and trachea.
  - – Carotid sheath:
    - ◦ Contains carotid artery, internal jugular vein, and vagus nerve (cranial nerve X).
- Muscular layers:
  - – Anterior neck muscles (**Fig. 4.3; Tables 4.1 and 4.2**):
    - ◦ Divided into two regions: anterior neck and anterior cervical triangle:
      - ▪ Anterior cervical triangle primarily functions to move the hyoid bone.
  - – Posterior neck muscles:
    - ◦ Divided into three regions: posterior neck, occipital triangle, and suboccipital triangle:
      - ▪ Posterior neck (**Table 4.3, Figs. 4.4, 4.5**).
      - ▪ Occipital triangle (**Table 4.4, Fig. 4.6**):
        - ❖ Borders: sternocleidomastoid (SCM; anterior), trapezius (posterior), and omohyoid (inferior).
      - ▪ Suboccipital triangle:
        - ❖ Borders: formed by the muscles it contains.
        - ❖ See Chapter 3.

Trachea
Thyroid gland
Recurrent laryngeal nerve
Esophagus
Retropharyngeal
space
Internal jugular vein
Common carotid artery
Longus colli muscle
Fat in posterior
cervical triangle
Subcutaneous tissue
Skin
Alar fascia
Cervical vertebra (C7)

Sternohyoid muscle
Sternothyroid muscle
Omohyoid muscle
Platysma muscle
Sternocleidomastoid
muscle
Vagus nerve (X)
Sympathetic trunk
Phrenic nerve
Anterior scalene muscle
Spinal nerve
Middle and posterior
scalene muscle
Levator scapulae muscle
Trapezius muscle
Deep cervical muscles

a

Retropharyngeal
space
Alar fascia
Trachea
Esophagus
Aorta

Pharynx
Mandible
Geniohyoid fascia
Geniohyoid muscle
Thyroid gland
Suprasternal space
Manubrium of sternum
Pericardium

| Superficial fascia | Infrahyoid fascia | Buccopharyngeal fascia |
| Prevertebral fascia | Pretracheal fascia | Carotid sheath |

b

Fig. 4.2 (a,b) Fascial layers containing muscular compartments of the cervical spine.
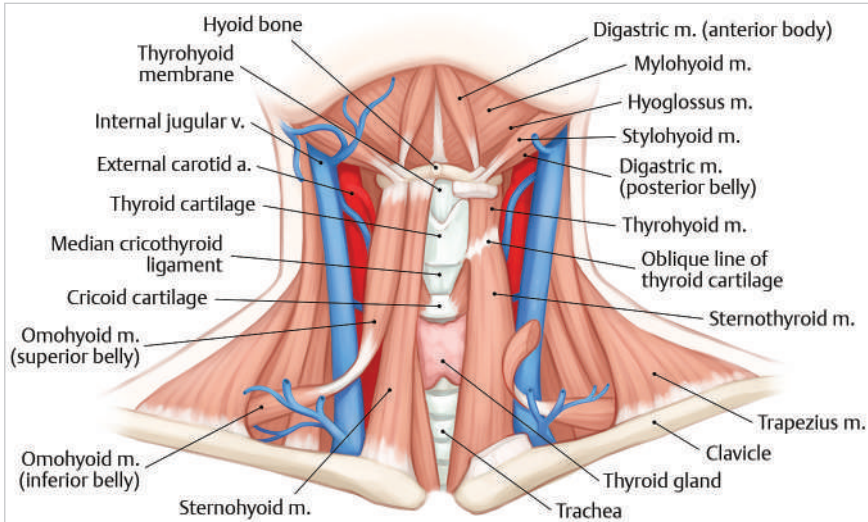
Fig 4.3 Muscular anatomy of anterior neck.

Table 4.1 Anterior neck

Muscle	Origin	Insertion	Action	Innervation
Platysma	Deltoid and pectoralis major	Mandible	Lower jaw	Cranial nerve VII
Sternocleidomastoid (SCM)	Manubrium of sternum and clavicle	Mastoid process of skull	Turn head (left SCM turns head to the right)	Cranial nerve XI

4.5 Vascular Anatomy

• Cervical region rich in vascular structures.
• Carotid sheath:
  – Within carotid triangle of anterior neck:
    ◦ Formed by SCM laterally, digastric superiorly, and omohyoid anteriorly.
  – Contains carotid artery (anteromedial), internal jugular vein (anterolateral), and vagus nerve (posterior between artery and vein).

Table 4.2 Anterior cervical triangle

| Muscle	Origin	Insertion	Action	Innervation
Suprahyoid				
Digastric	Mandible (anterior belly); mastoid notch of temporal bone (posterior belly)	Hyoid bone	Depresses mandible and elevates larynx	Cranial nerve V (anterior belly); cranial nerve VII (posterior belly)
Mylohyoid	Mandible	Hyoid bone	Depresses mandible, elevated hyoid	Cranial nerve V
Stylohyoid	Styloid process	Hyoid bone	Elevate hyoid	Cranial nerve VII
Geniohyoid	Mandible	Hyoid bone	Elevate hyoid	C1
Infrahyoid (superficial)				
Sternohyoid	Manubrium and clavicle	Hyoid bone	Depress hyoid	Ansa cervicalis (C1–C3)
Omohyoid	Suprascapular notch	Hyoid bone	Depress hyoid	Ansa cervicalis
Infrahyoid (deep)				
Thyrohyoid	Thyroid cartilage	Hyoid bone	Depress hyoid	C1
Sternothyroid	Manubrium of sternum	Hyoid bone	Depress hyoid and larynx	Ansa cervicalis

Table 4.3 Posterior neck

Muscle	Origin	Insertion	Action	Innervation
Superficial (extrinsic)				
Trapezius	Spinous processes of C7–T12	Clavicle and scapula	Rotate and raise scapula	Cranial nerve XI
Superficial (intrinsic)				
Splenius capitis	Ligamentum nuchae	Mastoid and nuchal line	Laterally flex and rotate neck	Dorsal rami of C4, C5, C6
Deep (intrinsic)				
Semispinalis capitis	Transverse process T1–T6	Nuchal ridge	Extend head	Dorsal rami

- Subclavian artery (**Fig. 4.7**):
  - Originates from aorta (left) or brachiocephalic trunk (right):
    - Traverses between anterior and middle scalene muscles.
  - Branches:
    - Vertebral artery:
      - Bilateral.
      - Primary arterial supply to cervical vertebrae and cord.
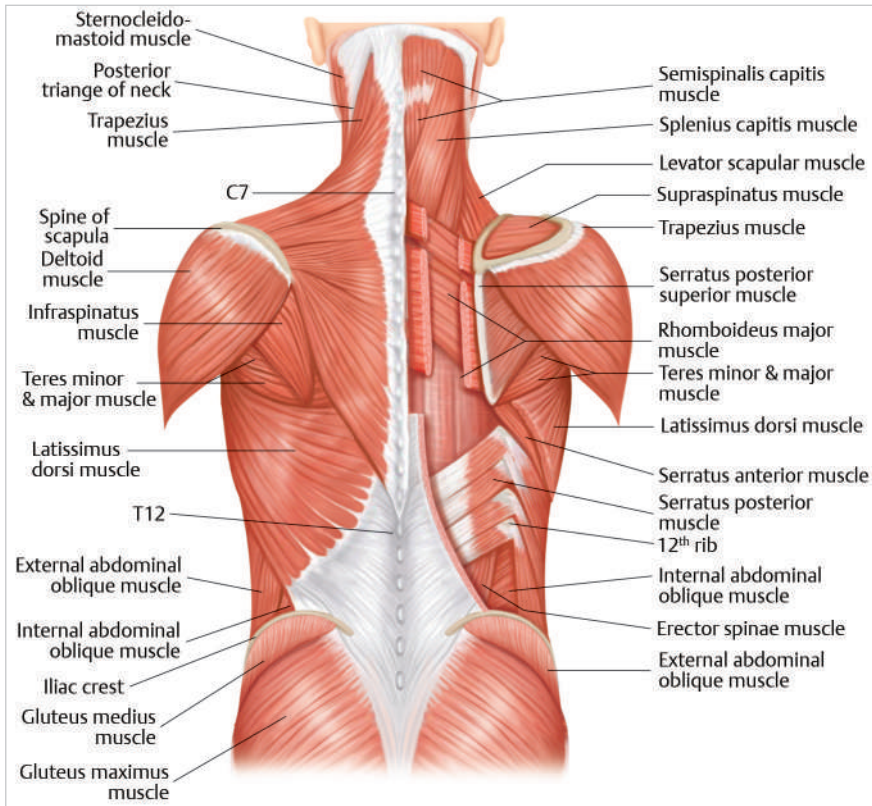
Fig. 4.4 Muscular anatomy of superficial and deep posterior neck. (Reproduced with permission from An HS, Singh K, eds. Synopsis of Spine Surgery. 3rd ed. New York, NY: Thieme; 2016.)

- Ascending cervical:
  - Travels with phrenic nerve.
  - Runs along anterior scalene muscle.
- Superficial cervical:
  - Travels into posterior neck.
- Deep cervical:
  - Anastomoses with occipital artery.
- Vertebral artery (**Fig. 4.8**):
  - Originates from subclavian artery:
    - Ascends between anterior scalene and longus colli muscles.
    - Reaches C6 vertebrae and enters transverse foramen.
  - Four segments: progresses superiorly:
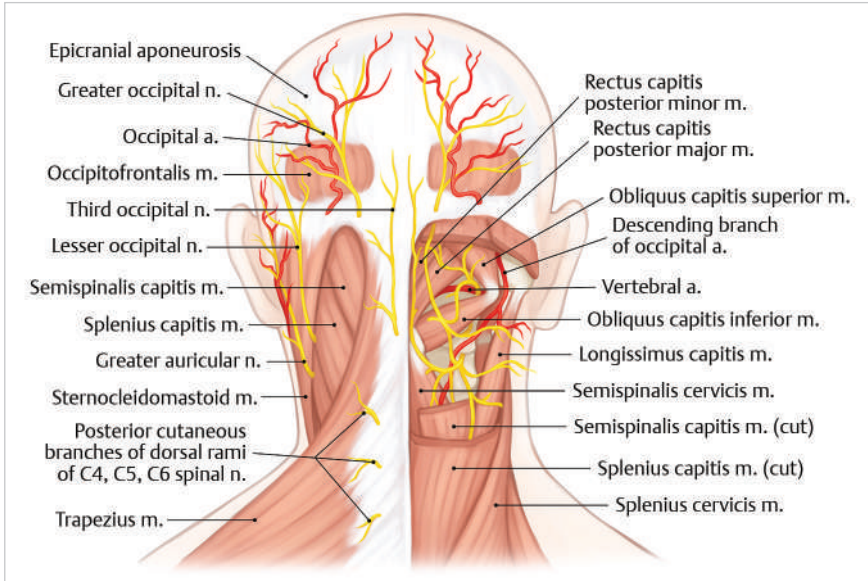
Fig. 4.5 Muscular anatomy of superficial and deep posterior neck and suboccipital triangle with associated nerves.

Table 4.4 Occipital triangle

Muscle	Origin	Insertion	Action	Innervation
Anterior scalene	Transverse process of C3–C6	First rib	Laterally flexes neck and raises first rib	C5–C8 nerve roots
Middle scalene	Transverse process of C2–C7	First rib	Laterally flexes neck and raises First rib	C5–C8 nerve roots
Posterior scalene	Transverse process of C4–C6	Second rib	Laterally flexes neck and raises second rib	C5–C8 nerve roots

- V1: preforaminal:
  - Subclavian artery to transverse foramen (C6).
  - Despite a vertebral foramen in C7, the vertebral artery does not travel through it in a majority of individuals.
- V2: foraminal:
  - Transverse foramen (C6) to C2 vertebrae.
- V3: above C2:
  - C2 to dura mater.
- V4: intradural:
  - Intradural to basilar artery (brainstem).
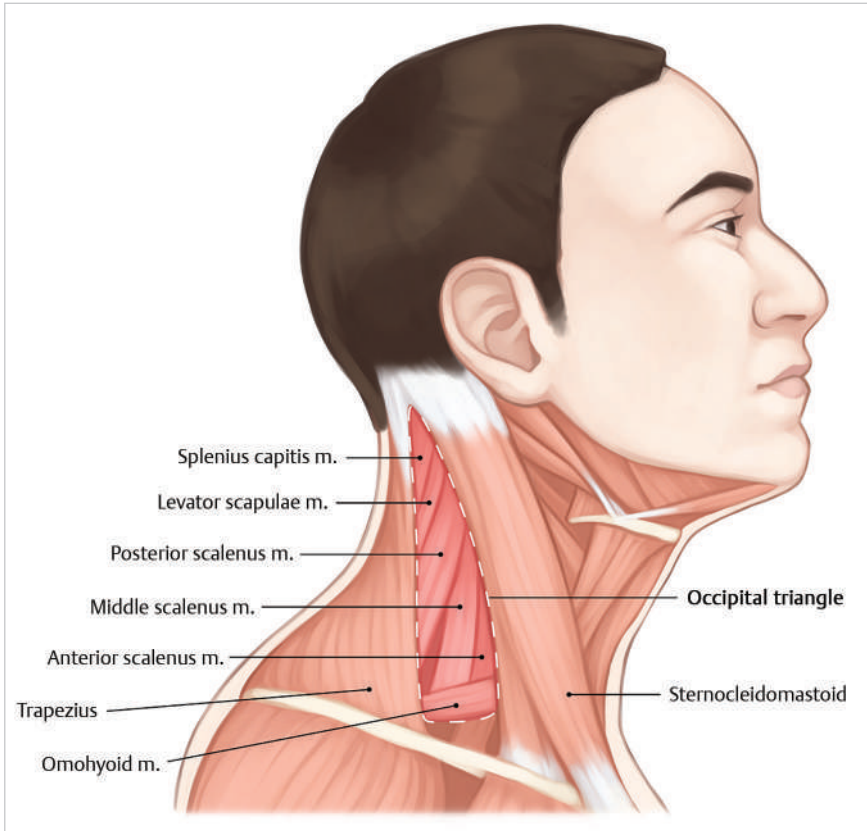
Fig. 4.6 Occipital triangle anatomy and associated borders.

- Branches:
  - Anterior spinal artery.
  - Posterior spinal artery.
  - Anterior ascending artery:
    - Primary supply to odontoid.
  - Posterior ascending artery:
    - Primary supply to odontoid.
  - Anterior segmental medullary artery.
  - Posterior segmental medullary artery.
- Anterior spinal artery:
  - Originates from vertebral artery:
    - Branches at pontomedullary junction of brainstem.
    - Travels within ventral median fissure.
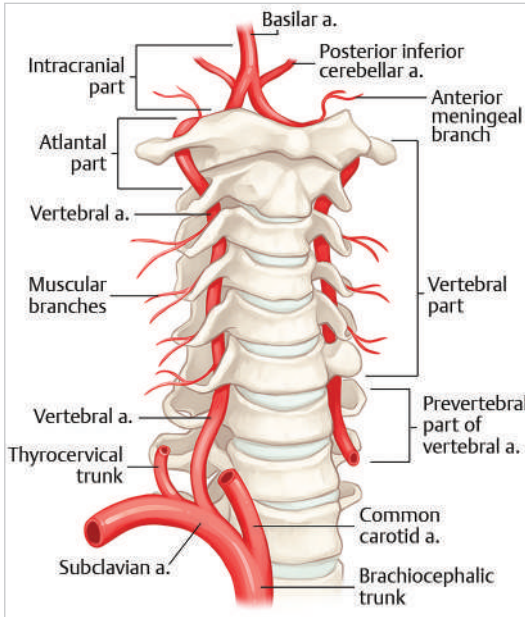
Fig. 4.7 Anatomy of the vertebral artery and associated branches.

- – Single midline artery:
    - ○ Feeds anterior two-thirds of spinal cord.
    - ○ Communicates with branches of other arteries:
        - ▪ Anterior segmental medullary artery (from vertebral artery) at C3.
        - ▪ Anterior cervical artery (from inferior thyroid artery) at C6.
- • Posterior spinal artery:
    - – Originates from vertebral artery:
        - ○ Branches at medulla.
    - – Bilateral artery:
        - ○ Feeds posterior one-third of spinal cord.
        - ○ Travels within posterolateral sulci of spinal cord.

4.6 Neural Anatomy

- • Cervical spinal cord decreases in diameter cranially.
- • Nerve roots:
    - – Exit anterolateral to superior facet.
    - – C3–C7 nerve roots exit **above** the pedicle of their respective vertebrae.
    - – C8 exits **below** C7 vertebra (above T1 pedicle).
    - – Dorsal (posterior) rami provide sensation for majority of posterior neck and head.
    - – Ventral (anterior) rami form two nerve plexuses:
        - ○ Cervical plexus.
        - ○ Brachial plexus.
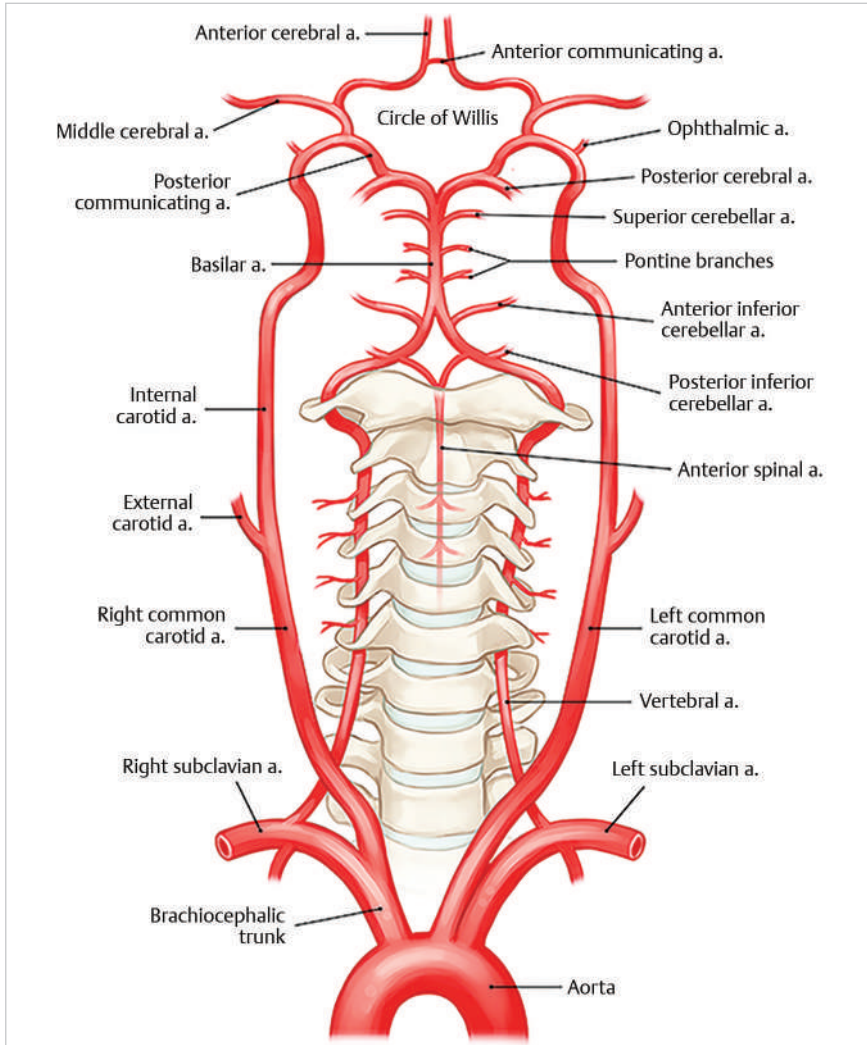
Fig. 4.8 Vascular anatomy of the cervical spine.

- Cervical plexus (**Fig. 4.9**):
  - Anterior rami of C1–C4.
  - Gives rise to:
    - Ansa cervicalis:
      - Described in Chapter 3.
    - Phrenic nerve (C3–C5):
      - Innervates diaphragm.
    - Cutaneous nerves of posterior head and neck.
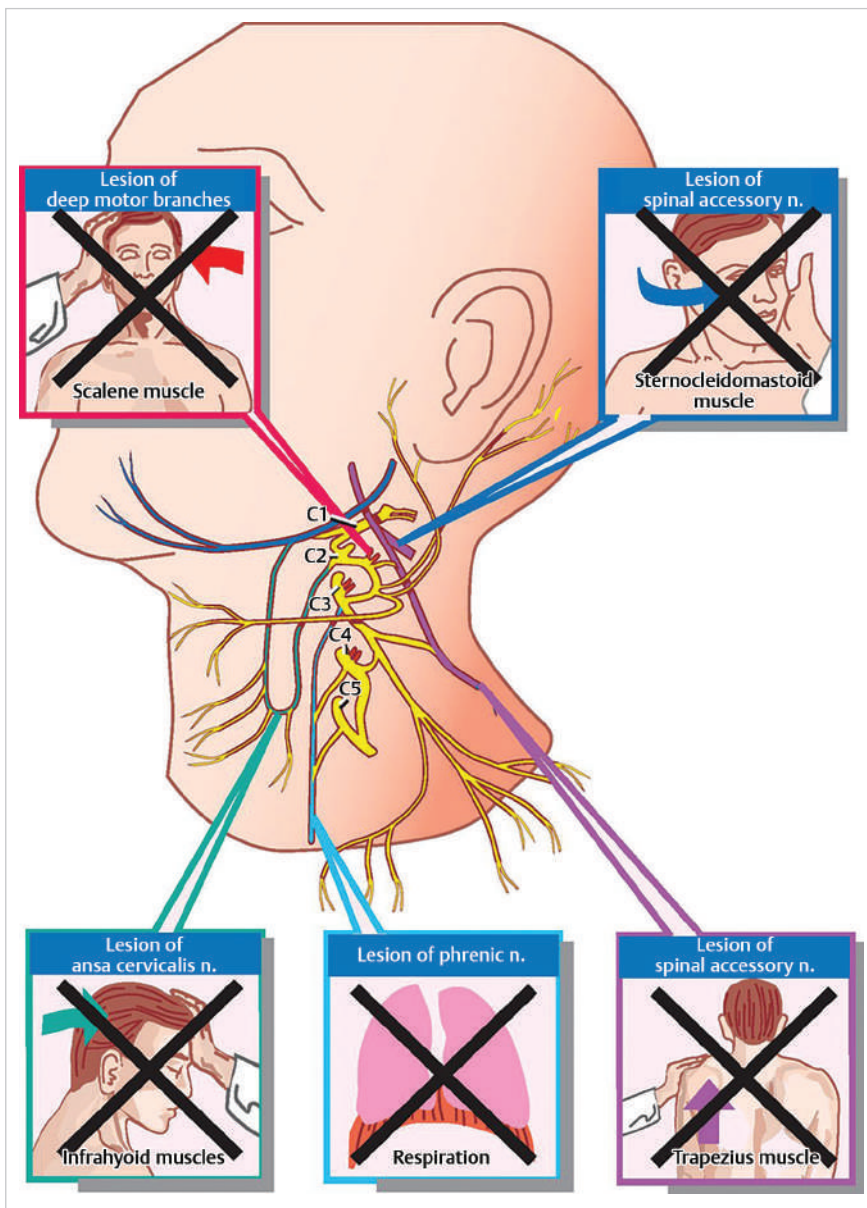
Fig. 4.9 Cervical plexus with corresponding nerve roots and terminal innervations. (Reproduced with permission from Albertstone CD, Benzel EC, Najm IM, Steinmetz M, eds. Anatomic Basis of Neurologic Diagnosis. New York, NY: Thieme; 2009.)

- Brachial plexus (**Fig. 4.10**):
  - Anterior rami of C5–T1 (**Tables 4.5, 4.6**).
  - Divided into five segments:
    - Roots.
    - Trunks.
    - Divisions.
    - Cords.
    - Terminal nerves.
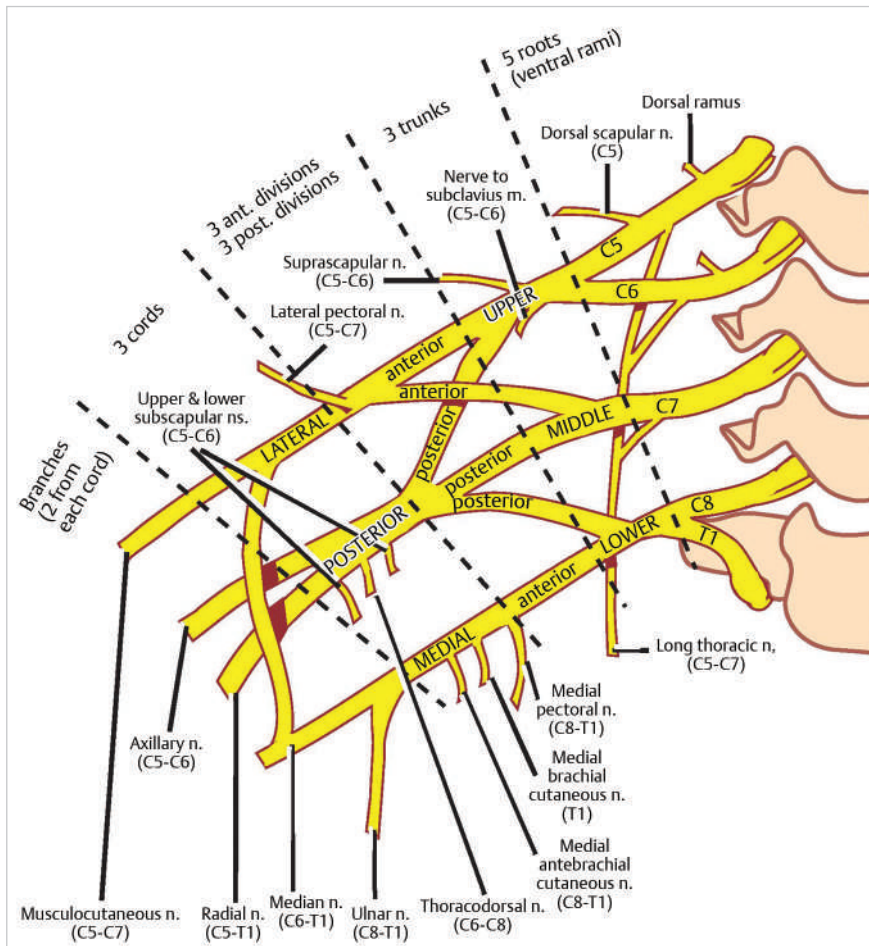
Fig. 4.10 Brachial plexus divided by segments and branching nerves. (Reproduced with permission from Albertstone CD, Benzel EC, Najm IM, Steinmetz M, eds. Anatomic Basis of Neurologic Diagnosis. New York, NY: Thieme; 2009.)

• Cervical dermatomes:
  – Each nerve root provides the predominant sensory innervation for a specific area
    of skin.
  – Important dermatomes:
    ◦ C5: lateral shoulder and arm.
    ◦ C6: lateral forearm and thumb.
    ◦ C7: index and middle fingers.
    ◦ C8: ring and little fingers.
    ◦ T1: medial forearm.

Table 4.5 Brachial plexus

Level	Nerve	Origin	Motor	Sensory
Roots	Long thoracic nerve	C5, C6, C7	Serratus anterior	None
	Dorsal scapular nerve	C4, C5	Levator scapulae, rhomboids	None
	Phrenic nerve (contribution)	C5	Diaphragm	Diaphragm
Trunks	Suprascapular nerve	C5, C6	Supraspinatus and infraspinatus	None
	Nerve to subclavius	C5, C6	Subclavius	
Cords	Lateral pectoral nerve	C5, C6, C7	Pectoralis major and minor	None
	Thoracodorsal nerve	C6, C7, C8	Latissimus dorsi	None
	Inferior subscapular nerve	C5, C6	Subscapularis and teres major	None
	Superior subscapular nerve	C5, C6	Subscapularis	None
	Medial pectoral nerve	C8, T1	Pectoralis major and minor	None
	Medial cutaneous nerve of arm	C8, T1	None	Medial aspect of upper arm overlying biceps brachii
	Medial cutaneous nerve of forearm	C8, T1		Ulnar aspect of volar forearm

(Continued)

Table 4.5 (*Continued*)

Level	Nerve	Origin	Motor	Sensory
Terminal branches	Axillary nerve	C5, C6	Deltoid and teres minor	Deltoid and superior posterior arm
	Musculocutaneous nerve	C5, C6, C7	Anterior compartment of upper arm (biceps brachii, brachialis)	Lateral forearm (lateral antebrachial cutaneous nerve branch)
	Median nerve	C5–T1	Anterior compartment of forearm, except flexor carpi ulnaris and ulnar side of flexor digitorum profundus	Volar aspect of first three digits, lateral two-thirds of palm
	Radial nerve	C5–T1	Posterior compartment of arm and forearm	Posterior arm and forearm, dorsal aspect of first three digits, lateral two-thirds of dorsum of hand
	Ulnar nerve	C8, T1	Most intrinsic muscles of the hand, flexor carpi ulnaris, ulnar side of flexor digitorum profundus	Medial side of hand and fourth and fifth digits

4.7 Clinical and Surgical Pearls

• Cervical disk herniation most commonly occurs at C5–C6 and C6–C7.
• Due to smaller pedicles in the cervical spine, screw placement here is not feasible:
  – Magerl's technique used for screw placement in cervical lateral masses:
    ◦ Vertebral artery at risk; to avoid risk, drill is positioned slightly medial to midpoint of lateral mass, and angled superiorly and laterally.

Table 4.6 Common brachial plexus injuries

Disorder	Etiology	Nerves	Physical examination
Winged scapula	Avulsion of proximal C5, C6 nerve roots	• Long thoracic nerve loss • Dorsal scapular nerve loss • Phrenic nerve deficiency (loss of serratus anterior and rhomboids)	Medial displacement of scapula, flail arm, elevated hemidiaphragm
Erb's palsy	Traction or avulsion of upper trunk (C5, C6)	• Axillary nerve deficiency (weak deltoid/teres minor) • Suprascapular nerve deficiency (weak infra/supraspinatus) • Musculocutaneous nerve deficiency (weak biceps) • Radial nerve deficiency (weak brachioradialis, supinator)	Arm internally rotated, adducted, pronated, and extended at elbow
Klumpke's palsy	Traction or avulsion of lower trunk (C8, T1)	• Ulnar nerve deficiency (loss of hand intrinsics) • Median nerve deficiency (loss of wrist flexors)	Wrist extended, metacarpophalangeal (MCP) joints extended, flexion of proximal interphalangeal (PIP) joints
Claw hand	Damage to peripheral ulnar nerve	• Ulnar nerve deficiency (loss of hand intrinsics)	Fourth and fifth digits extended at MCP and flexed at PIP

5 **Thoracic Spine**

Catherine Maloney, Fady Y. Hijji, Ankur S. Narain, Philip K. Louie, Daniel D. Bohl, and Kern Singh

5.1 General Information

- T1–T12 are defined as the thoracic vertebrae (**Table 5.1**):
- Kyphotic curvature: 20–40 degrees:
  - Apex of kyphosis at T7–T8:
    - ◦ Pathologic kyphosis can have an apex at any level.
- Articulate with their corresponding ribs at facet joints, limited range of motion:
  - Flexion–extension minimal at T1–T2; maximum T12–L1.
  - Axial rotation minimal at thoracolumbar junction; maximum at T12.
- Wedge shaped with anterior height shorter than posterior height.
- Width of vertebral canal is smallest in the thoracic vertebrae.

5.2 Bony Anatomy (Fig. 5.1)

- Vertebral body:
  - Anterior border of intervertebral foramen.
  - Forms articulation with ribs:
    - ◦ Each rib articulates with two vertebral bodies:
      - ▪ Inferior costal demifacet of superior vertebral body and superior costal facet of inferior vertebral body.

Table 5.1 Thoracic landmarks

Vertebrae	Associated structure
T1	Sternoclavicular joint
T1–T2	Superior angle of the scapula
T2	Jugular notch
T3	Base of the spine of the scapula
T4	Sternal angle of Louis
T5–T9	Body of the sternum
T7	Inferior angle of the scapula
T8	Level at which the inferior vena cava passes through the diaphragm
T9	Xiphisternal junction
T9–L3	Costal margin
T10	Esophagus passes through diaphragm
T12	Aorta, thoracic duct, and azygos vein pass through diaphragm
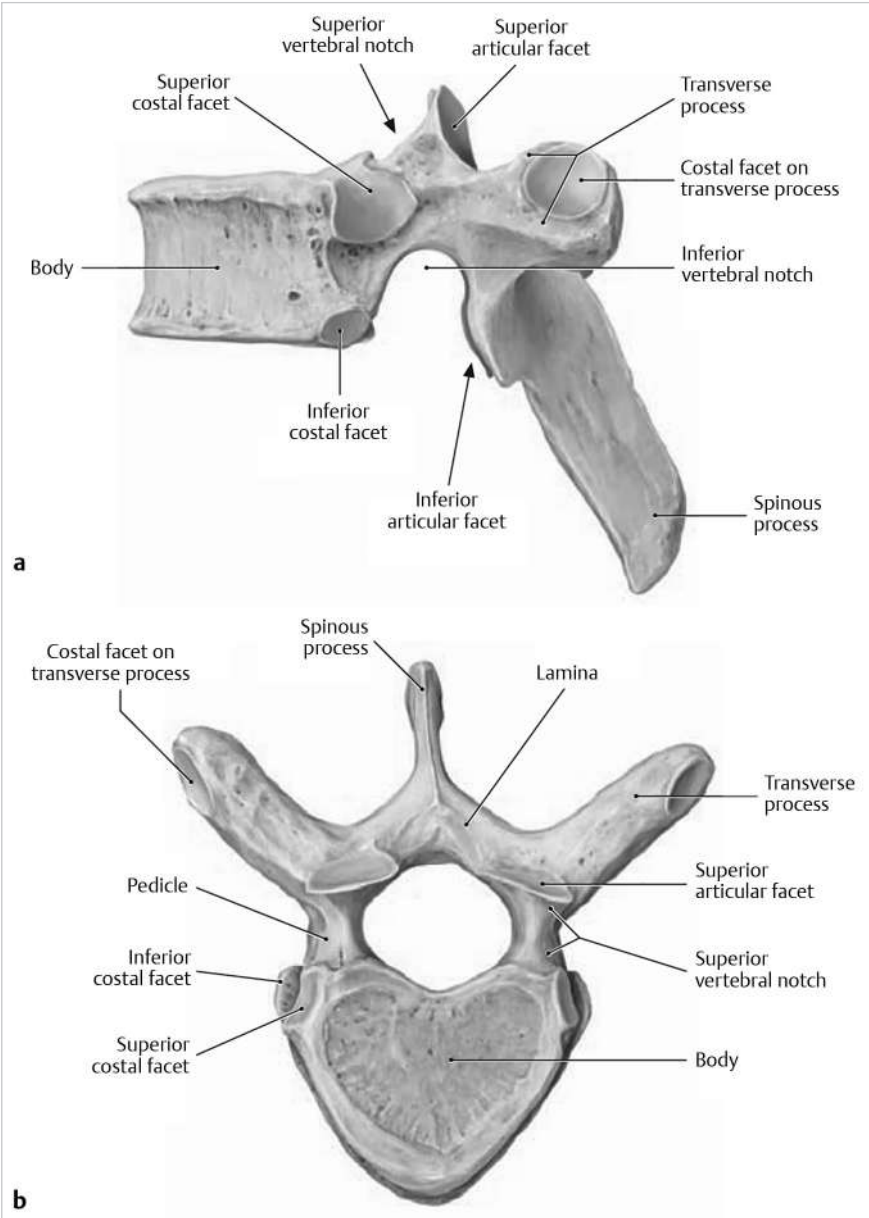
Fig. 5.1 Lateral **(a)** and superior **(b)** views of the thoracic vertebrae. (Reproduced with permission from Baaj AA, Mummaneni PV, Uribe JS, Vaccaro AR, Greenberg MS, eds. Handbook of Spine Surgery. 2nd ed. New York, NY: Thieme; 2016.)

- – Superior costal demifacet:
  - ◦ Superoposterior edge of vertebral body.
  - ◦ Articulates with corresponding rib of same number.
  - ◦ Exceptions:
    - ▪ Superior costal facet of T1 is not a demifacet:
      - ❖ First rib only articulates with T1.
    - ▪ T10 has one pair of complete costal facets located between the vertebral body and pedicle.
    - ▪ T11 and T12 have one pair of complete costal facets located on the pedicles.
- – Inferior costal demifacet:
  - ◦ Inferoposterior edge of vertebral body.
  - ◦ Articulates with head of rib below.
- • Pedicle:
  - – Height of pedicle is double that of the width.
  - – Inferior notch is superior border of intervertebral foramen.
  - – Superior notch is inferior border of intervertebral foramen.
  - – Pedicle diameter is maximal at T1 and minimal at T6:
    - ◦ Diameter gradually increases again from T6.
- • Superior articular process:
  - – Faces posterolaterally.
  - – Articulates with inferior articular process of adjacent superior vertebrae.
- • Inferior articular process:
  - – Faces anteromedially.
  - – Articulates with superior articular process of adjacent inferior vertebrae.
- • Lamina.
- • Posterior border of vertebral foramen.
- • Transverse process:
  - – Forms the costotransverse joint.
  - – T1–T10 have a costal facet on transverse process that articulates with tubercle of rib.
- • Spinous process:
  - – Long, points downward.
  - – Becomes level with body of vertebrae below.

5.3 Ligamentous Anatomy

- • Radiate ligament of head of rib:
  - – Attaches head of rib to bodies and disk.
  - – Reinforces costovertebral joint anteriorly.

- Costotransverse ligament:
  - Attaches neck of rib to transverse process.
- Superior costotransverse ligament:
  - Attaches rib to transverse process of superior vertebrae.
- Intratransverse ligament:
  - Fibrous cords that join adjacent thoracic vertebrae and blend with adjacent back muscles.
- Lateral costotransverse ligament:
  - Attaches transverse process to tubercle of rib.

5.4 Muscular Anatomy (Tables 5.2–5.4) Vascular Anatomy (Fig. 5.2)

- Less blood supply to thoracic spinal cord than cervical and lumbar regions:
  - Watershed region in midthoracic spinal cord:
    ∘ Poorly vascularized area.
    ∘ Between T4 and T9, least profuse blood supply; narrowest region of spinal canal.

**Table 5.2** Superficial layers of the back

Muscle	Origin	Insertion	Action	Innervation
Trapezius (upper, middle, and lower divisions)	Upper division: medial one-third of superior nuchal line, external occipital protuberance, ligamentum nuchae, spinous processes of C7 Middle division: spinous process of T1–T5 Lower division: spinous process of T6–T12	Upper division: lateral one-third of clavicle and acromion process of scapula Middle division: superior border of spine of scapula Lower division: medial one-third of spine of scapula	Upper division: upward rotation of scapula and elevation of scapula Middle division: retraction of scapula Lower division: upward rotation of scapula and depression of scapula	Cranial nerve XI C3–C4 dorsal rami (for proprioception)
Latissimus dorsi	Spinous processes of T7–L5, lower three or four ribs, posterior one-third of iliac crest	Floor of intertubercular groove	Extension and internal (medial) rotation of arm	Thoracodorsal nerve (C7–C8)
Rhomboid major	Spinous processes of T2–T5	Medial border of scapula (inferior to spine of scapula)	Retraction, elevation, and rotation of scapula	Dorsal scapular nerve (C5)
Rhomboid minor	Inferior end of ligamentum nuchae, spinous processes of C7–T1	Medial border of scapula	Retraction, elevation, and rotation of scapula	Dorsal scapular nerve (C5)

Table 5.3 Intermediate layers of the back

Muscle	Origin	Insertion	Action	Innervation
Serratus posterior superior	Ligamentum nuchae, spinous processes of C7–T3	Ribs 2–5 (lateral to angle of rib)	Elevation of upper ribs	T1–T4 ventral rami
Serratus posteroinferior	Thoracolumbar fascia, spinous processes of T11–L2	Ribs 9–12 (lateral to the angle of rib)	Depression of lower ribs	T9–T12 ventral rami
Iliocostalis thoracis (erector spinae)	Superior borders of the angles of the lower six ribs	Angles of upper six or seven ribs and transverse process of C7	Extension and lateral flexion of trunk and neck	C4–S5 dorsal rami
Longissimus thoracis (erector spinae)	Transverse process and spinous process of lumbar vertebrae, sacrum, and iliac crest	Transverse process of T1–T12	Extension and lateral flexion of trunk and neck	C1–S1 dorsal rami
Spinalis thoracis (erector spinae)	Spinous process of T11–L3	Spinous processes of T3–T8	Extension and lateral flexion of trunk and neck	C2–L3 dorsal rami

Table 5.4 Deep layers of the back

| Muscle	Origin	Insertion	Action	Innervation
Semispinalis thoracis	Transverse processes of C7–T12	Semispinalis capitis: back of skull between nuchal lines; semispinalis cervicis and thoracis: spinous processes of four to six vertebrae above origin	Extension lateral flexion, and contralateral rotation of trunk	C1–T12 dorsal rami
Thoracic interspinales	Spinous processes of thoracic vertebrae	Adjacent spinous process	Extension of spine	Dorsal rami of spinal nerves of region
Thoracic intertransversarii	Transverse process of vertebrae	Adjacent transverse process	Assist with lateral flexion of spine	Dorsal rami of spinal nerves of region
Multifidus	Sacrum, ilium, transverse processes of T1–T12, and articular processes of C4–C7	Spinous processes of superior vertebrae, spanning two to four segments	Stabilize vertebral column	Dorsal rami of spinal nerves of region
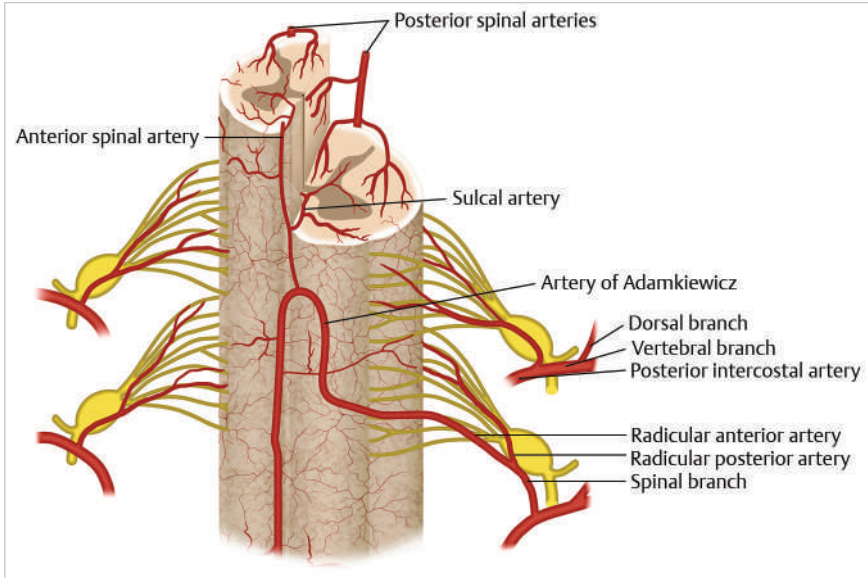
Fig. 5.2 Vascularization of the spinal cord. Note the origin of the artery of Adamkiewicz from the left posterior intercostal artery.

- Anterior spinal artery:
  - Supplies ventral two-thirds of thoracic cord.
  - Originates from vertebral artery in region of medulla oblongata.
- Anterior medial spinal artery:
  - Continuation of the anterior spinal artery below T4.
- Posterolateral spinal arteries:
  - Originate from vertebral arteries.
  - Descend toward lower cervical and upper thoracic region.
- Posterior spinal arteries:
  - Paired arteries originating from vertebral arteries that branch at various levels to form the posterolateral arterial plexus.
  - Supply posterior one-third of cord (dorsal white columns and posterior portion of dorsal gray columns).
- Radicular arteries:
  - Originate from intercostal arteries at level of costotransverse joint:
    - Intercostal arteries arise from the subclavian artery and thoracic aorta.
  - Enter vertebral canal through intervertebral foramina:
    - Form anterior and posterior radicular arteries:
      - Supply anterior and posterior spinal arteries.
- Radicular artery of Adamkiewicz:

- Largest segmental artery:
  - Typically arises from a left posterior intercostal artery.
  - Enters the spinal canal between T9 and T12.
- Major blood supply to inferior two-thirds of spinal cord.
- Usually travels with ventral roots of T9, T10, or T11.

5.5 Neural Anatomy

- Spinal cord enlarges between T9 and T12 (lumbar enlargement).
- Thoracic spinal nerves:
  - Exit **below** the pedicle of the corresponding numbered vertebrae.
  - Form from dorsal and ventral roots in the intervertebral foramen region.
  - Spinal nerve divides in the foramen into dorsal and ventral rami:
    - Ventral rami continue as intercostal nerves:
      - Innervate intermediate back muscle layers.
    - Dorsal rami provide cutaneous sensation and innervation of deep back muscles and thoracic facet joints.
- Thoracic neurovascular bundle:
  - Contains a posterior intercostal vein, posterior intercostal artery, and ventral rami of a spinal nerve.
  - Lies inferior to each rib.
  - Vein, artery, nerve (V-A-N) relationship from superior to inferior.
- Thoracic sinuvertebral nerves:
  - Three branches.
    - Ascending.
    - Descending.
    - Transverse.
  - Recurrent branches of ventral rami.
  - Mixed nerves; provide pain sensation to ventral surface of dura mater, intervertebral disk, posterior longitudinal ligaments, and intervertebral disk.
- Sympathetic trunk (**Fig. 5.3**):
  - Thoracic sympathetic trunk is located along anterior surface of rib head.
  - Each ganglia (T1–L2) in chain gives off a ramus communicans:
    - Ramus communicans merges with spinal nerve distal to where the anterior and posterior roots join.
- Thoracic dermatomes:
  - Lateral and anterior cutaneous branches of the intercostal nerves innervate skin of thorax.
  - Important dermatomes:
    - T4 dermatome: nipple (*note*: nipple may sit lower in females).
    - T6 dermatome: xiphoid process.
    - T10 dermatome: umbilicus.
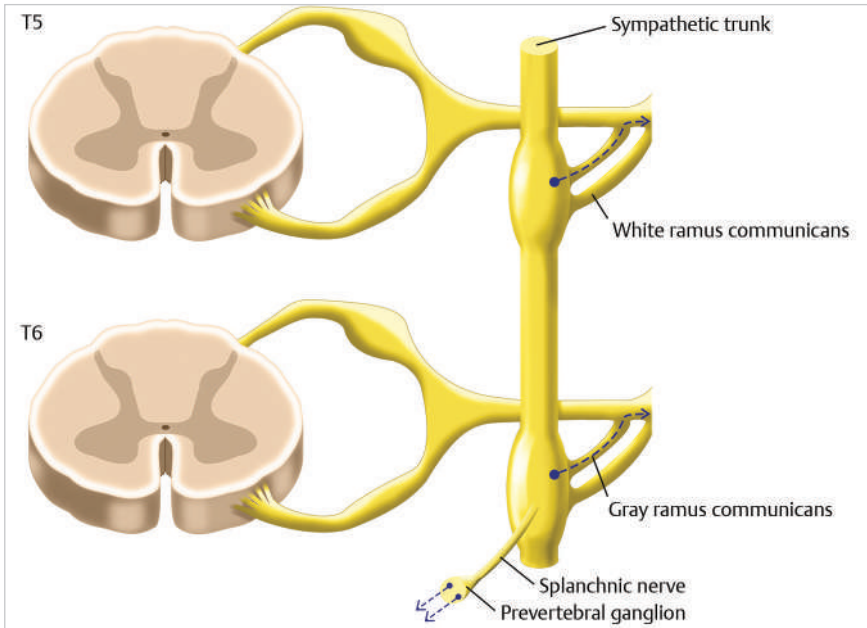
Fig. 5.3 Thoracic vertebrae and the sympathetic trunk. Note the merging of the sympathetic root distal to the merging of the anterior and posterior roots.

5.6 Clinical and Surgical Pearls

- Ending spinal instrumentation at the thoracic kyphotic apex can lead to early instrumentation failure.
- Fractures above midthoracic region are not common: suspect osteolytic tumor rather than benign fracture.
- Collateral blood flow to the thoracic cord comes from the internal and lateral thoracic arteries:
  - Prevents infarction if blood supply from the aorta is interrupted.

Suggested Readings

1.   Yoganandan N, Halliday AL, Dickman CA, Benzel E. Practical anatomy and fundamental biomechanics. In: Benzel EC, ed. Spine Surgery Techniques, Complication Avoidance, and Management. 2nd ed. Philadelphia, PA: Elsevier; 2005:109–135
2.   Netter FH. Atlas of Human Anatomy. 6th ed. Philadelphia, PA: Saunders; 2014
3.   An HS, Singh K. Synopsis of Spine Surgery. 3rd ed. New York, NY: Thieme; 2016

6 Lumbar Spine Anatomy

Melissa G. Goczalk, Ankur S. Narain, Fady Y. Hijji, Philip K. Louie, Daniel D. Bohl, and Kern Singh

6.1 General Information

• Anatomy and function:

  – Lordotic curvature.
  – Long transverse processes for muscle attachment.
  – Lacks facets for rib articulation.
  – Supports weight of trunk.
  – Allow flexion, extension, lateral flexion, and rotation of spine.

• Landmarks:

  – L1: conus medullaris.
  – L3: umbilicus.
  – L4: iliac crests, aortic bifurcation.

6.2 Bony Anatomy (Fig. 6.1)

• Vertebral body:

  – Cylindrically shaped and widest transversely.

• Vertebral foramen:

  – Triangular spinal canal.

• Pedicles:

  – Connect vertebral body to lamina.
  – Directed posteriorly and located in the middle one-third of the transverse process.

• Transverse processes:

  – Thin and long from L1 to L4.
  – Large and cone-shaped at L5 due to iliolumbar ligament attachment to pelvic bones.

• Facet joints:

  – L1–L4 facets are sagittally oriented to limit axial rotation.
  – L5 facet is more coronal and resists anteroposterior movement.
  – Prominent pars interarticularis.

• Lamina:

  – Connect spinous process to pedicles.

• Spinous process:

  – Broad and thick orientation.
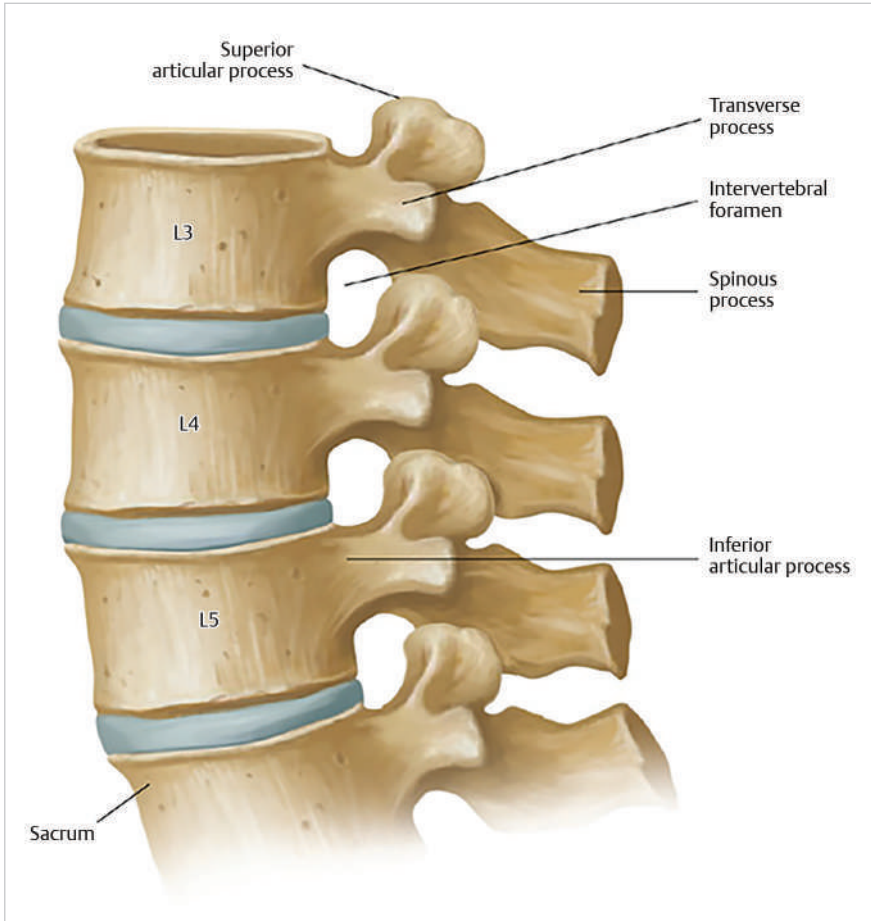
Fig. 6.1 Bony anatomy of the lumbar vertebrae.

6.3 Ligamentous Anatomy (Fig. 6.2)

• Anterior longitudinal ligament:
  – Located on the anterior surface of vertebral bodies.
  – Functions include limiting spine extension and securing intervertebral disks.
• Posterior longitudinal ligament:
  – Located on the posterior surface of vertebral bodies.
  – Limits spine flexion and secures intervertebral disks.
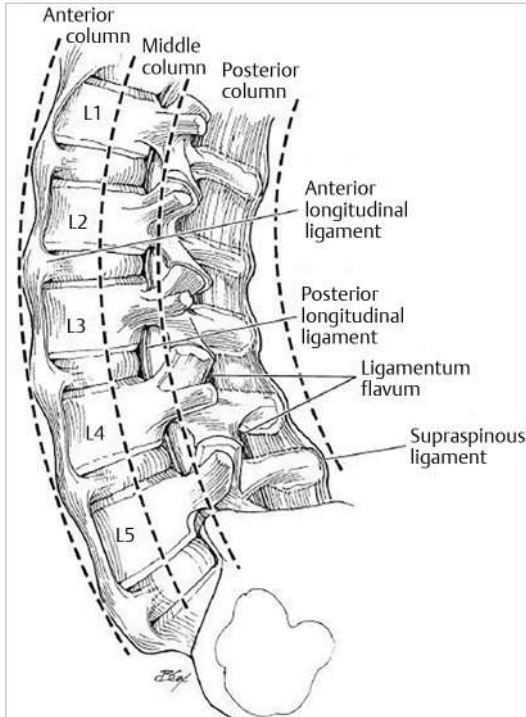
Fig. 6.2 Ligamentous anatomy of the lumbar spine. (Reproduced with permission from Baaj AA, Mummaneni PV, Uribe JS, Vaccaro AR, Greenberg MS, eds. Handbook of Spine Surgery. 2nd ed. New York, NY: Thieme; 2016.)

• Ligamentum flavum:
  – Spans posterior aspect of the inferior lamina to the anterior aspect of the superior lamina.
  – Limits laminar flexion and separation.
• Supraspinous ligament:
  – Spans the tips of spinous processes; terminates at L3.
• Interspinous ligament:
  – Connect adjacent spinous processes; oriented obliquely.

6.4 Muscular Anatomy (Tables 6.1–6.6, Figs. 6.3–6.5)

6.5 Vascular Anatomy (Table 6.7)

6.6 Neural Anatomy (Tables 6.8 and 6.9, Figs. 6.6, 6.7)

• Five pairs of lumbar spinal nerves:
  – Exit below corresponding vertebral level.

Table 6.1 Superficial extrinsic back muscles

Muscle	Origin	Insertion	Action	Innervation
Trapezius	Spinous processes of C7–T12	Clavicle, scapula	Rotate scapula	Cranial nerve XI
Latissimus dorsi	Spinous processes of T6–T12, lumbar spine, sacrum, iliac crests, ribs 9–12	Intertubercular sulcus of humerus	Extend, adduct, and medically rotate humerus	Thoracodorsal nerve
Levator scapulae	Transverse processes of C1–C4	Medial scapulae	Elevate scapula	Dorsal scapular nerve
Rhomboid minor	Spinous processes of C7–T1	Scapular spine	Adduct scapula	Dorsal scapular nerve
Rhomboid major	Spinous processes of T2–T5	Medial border of scapula	Adduct scapula	Dorsal scapular nerve
Serratus posterosuperior	Spinous processes of C7–T5	Upper border of ribs 2–5	Elevate ribs	Intercostal nerves T1–T4
Serratus posterior inferior	Spinous processes of T11–L3	Lower border of ribs 9–12	Depress ribs	Intercostal nerves T9–T12

Table 6.2 Deep intrinsic back muscles: spinotransverse group

Muscle	Origin	Insertion	Action	Innervation
Splenius capitis	Ligamentum nuchae	Mastoid and nuchal line	Laterally flex and rotate ipsilateral neck	Dorsal rami of inferior cervical nerves
Splenius cervicis	Spinous processes of T1–T6	Transverse processes of C1–C4	Laterally flex and rotate ipsilateral neck	Dorsal rami of inferior cervical nerves

Table 6.3 Deep intrinsic back muscles: sacrospinalis group

Muscle	Origin	Insertion	Action	Innervation
Iliocostalis lumborum	Sacrum, spinous processes of lumbar and lower thoracic vertebrae, supraspinous ligaments, and iliac crests	Lower six to seven ribs	Bilateral: vertebral column and head extension Unilateral: vertebral column lateral flexion	Dorsal primary rami
Longissimus thoracis	Transverse processes of lumbar vertebrae	Transverse processes of thoracic vertebrae	Bilateral: vertebral column and head extension Unilateral: vertebral column lateral flexion	Dorsal primary rami
Spinalis thoracis	Spinous processes of T10–L2	Spinous processes of T1–T8	Bilateral: vertebral column and head extension Unilateral: vertebral column lateral flexion	Dorsal primary rami

**Table 6.4** Deep intrinsic back muscles: transversospinales group

Muscle	Origin	Insertion	Action	Innervation
Semispinalis cervicis	Transverse processes	Spinous processes	Extend, rotate contralateral side	Dorsal primary rami
Semispinalis thoracic	Transverse processes	Spinous processes	Extend, rotate contralateral side	Dorsal primary rami
Semispinalis capitis	Transverse processes of T1–T6	Nuchal ridge	Extend, rotate contralateral side	Dorsal primary rami
Multifidus	Transverse processes of C2–S4	Spinous processes	Contralateral lateral flexion and rotation	Dorsal primary rami
Rotatores	Transverse processes	Spinous processes of superior vertebral level	Rotate contralateral superior vertebrae	Dorsal primary rami
Interspinales	Spinous processes	Spinous processes of superior vertebral level	Extend vertebral column	Dorsal primary rami
Intertransversarii	Transverse processes	Transverse processes of superior vertebral level	Lateral flex vertebral column	Dorsal primary rami

Table 6.5 Anterolateral abdominal wall

| Muscle	Origin	Insertion	Action	Innervation
Rectus abdominis	Pubic crest, pubic tubercle, pubic symphysis	Costal cartilages of ribs 5–7 and xiphoid process	Compress abdominal contents, flex vertebral column, tense abdominal wall	Anterior rami of T7–T12
External oblique	Anterior angles of ribs 5–12	Iliac crest and aponeurosis to linea alba	Compress abdominal contents, flex trunk	Anterior rami of T7–T12
Internal oblique	Thoracolumbar fascia, iliac crests, inguinal ligament	Inferior border of lower ribs, aponeurosis to linea alba, pubic crest, pectineal line	Compress abdominal contents, flex trunk	Anterior rami of T7–T12 and L1
Transversus abdominis	Thoracolumbar fascia, iliac crests, inguinal ligament, costal cartilages of ribs 7–12	Aponeurosis to linea alba, pubic crest, pectineal line	Compress abdominal contents	Anterior rami of T7–T12 and L1

Table 6.6 Posterior abdominal wall muscles

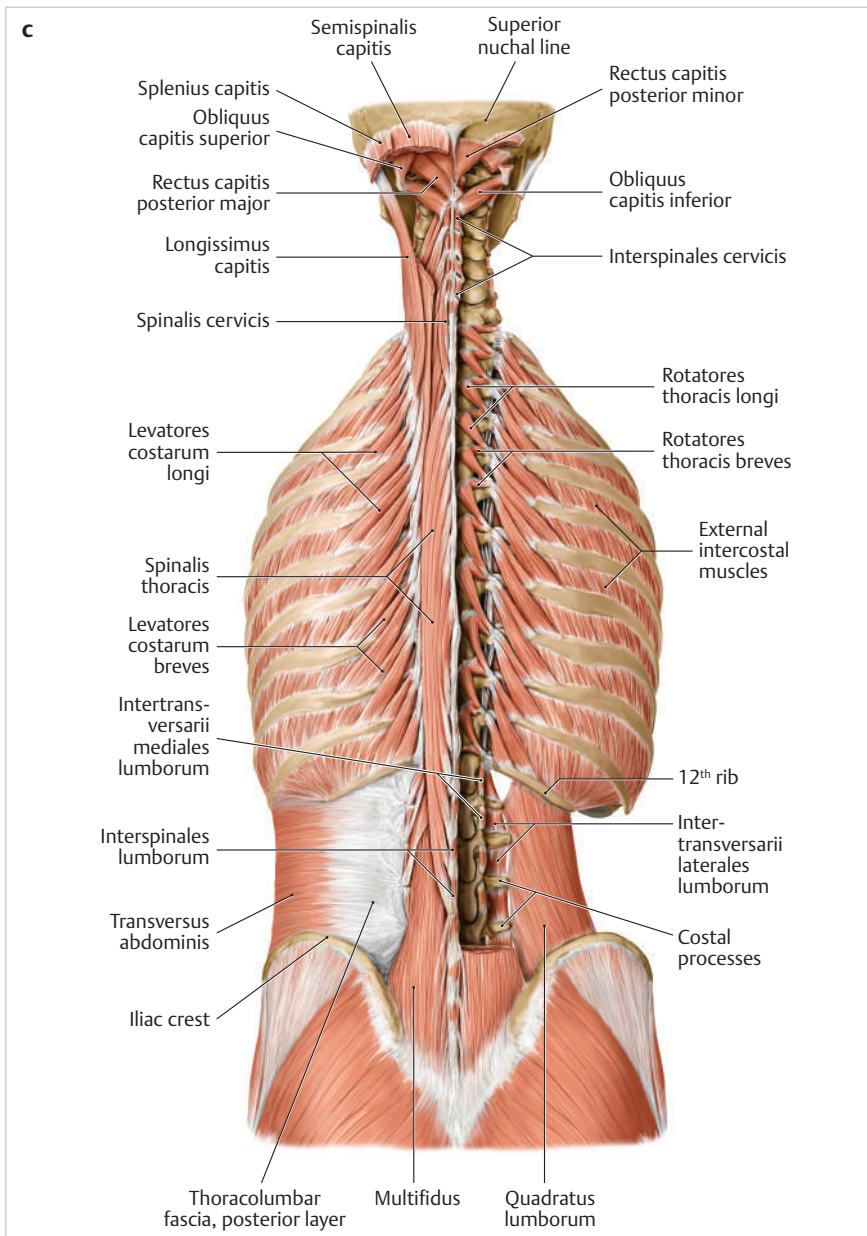| Muscle	Origin	Insertion	Action	Innervation
Iliacus	Iliac fossa, anterior sacroiliac and iliolumbar ligaments, and sacrum	Lesser trochanter of femur	Flexion of thigh at hip	Femoral nerve
Psoas major	Vertebral bodies of T12 and L1–L5, transverse processes of lumbar vertebrae, and intervertebral disks of T12 and L1–L5	Lesser trochanter of femur	Flexion of thigh at hip	Anterior rami of L1–L3
Psoas minor	Vertebral bodies and intervertebral disks of T12 and L1	Pectineal line of pelvic brim and iliopubic eminence	Flexion of lumbar vertebral column	Anterior rami of L1
Quadratus lumborum	Transverse process of L5, iliolumbar ligament, iliac crest	Transverse process of L1–L4 and inferior border of rib 12	Depress and stabilize rib 12 and lateral bending of trunk	Anterior rami of T12 and L1–L4
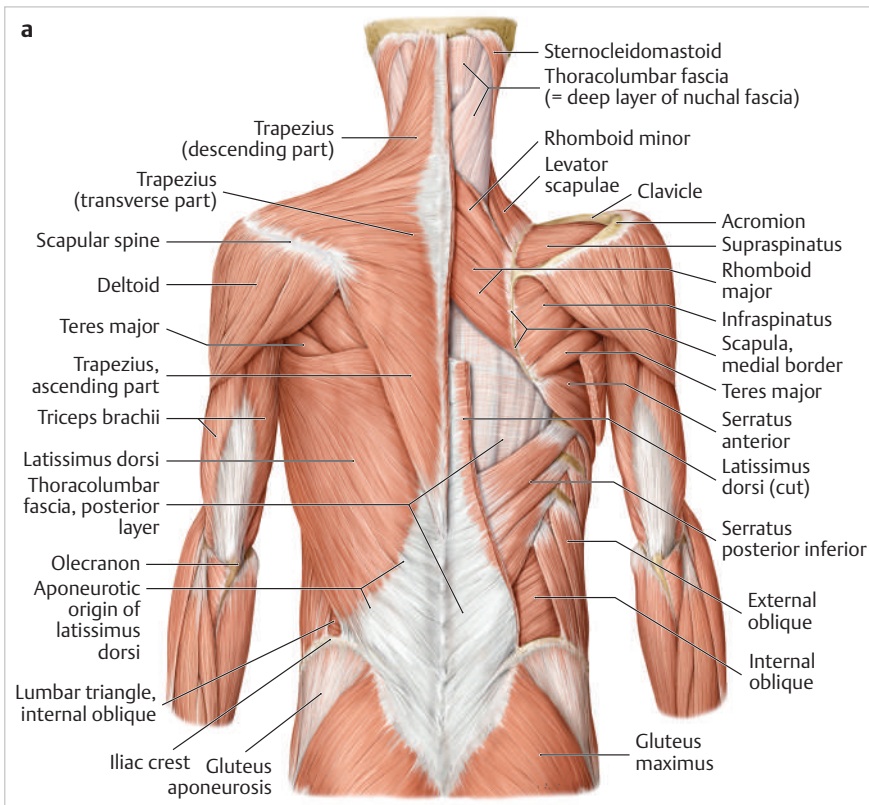
Fig. 6.3 (a) Superficial and intermediate back muscles. (Reproduced with permission from Gilroy A, MacPherson B, Schünke M et al., eds. Atlas of Anatomy. 3rd Edition. New York, NY: Thieme; 2017.)
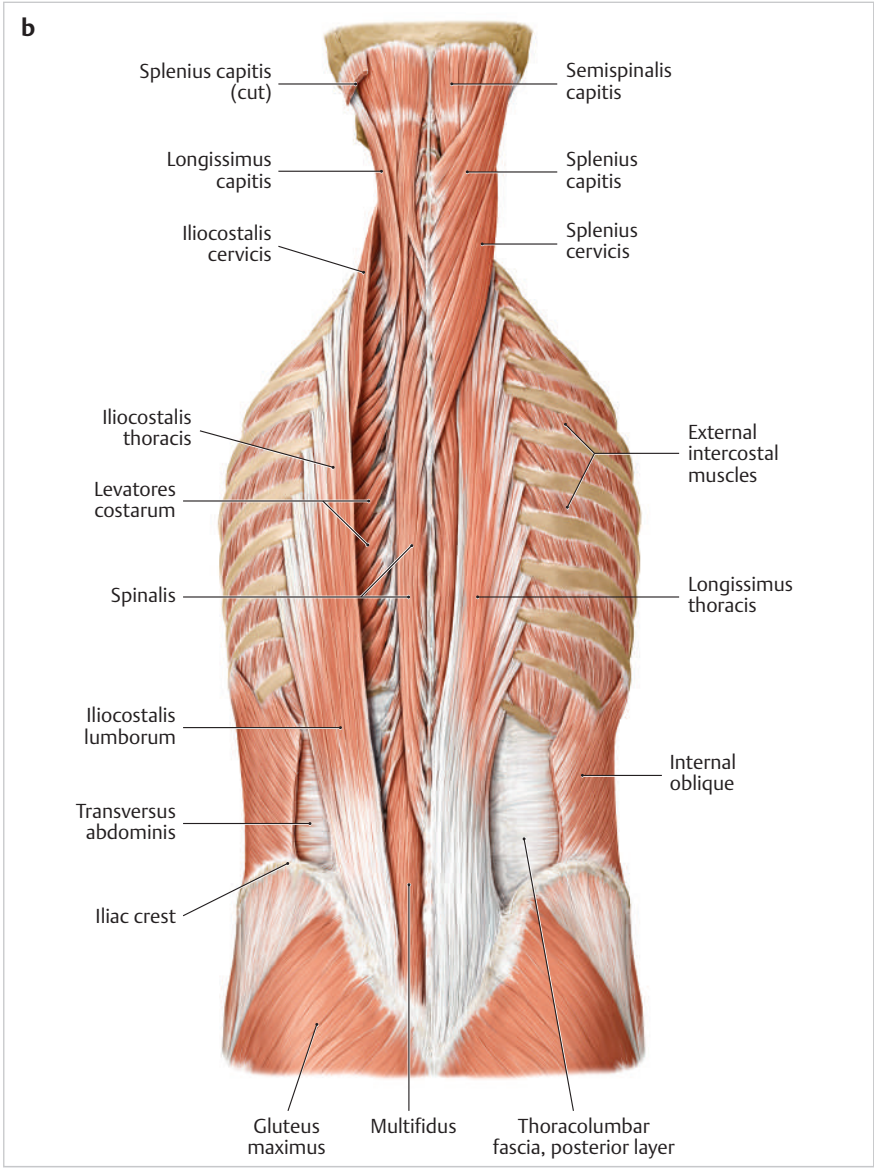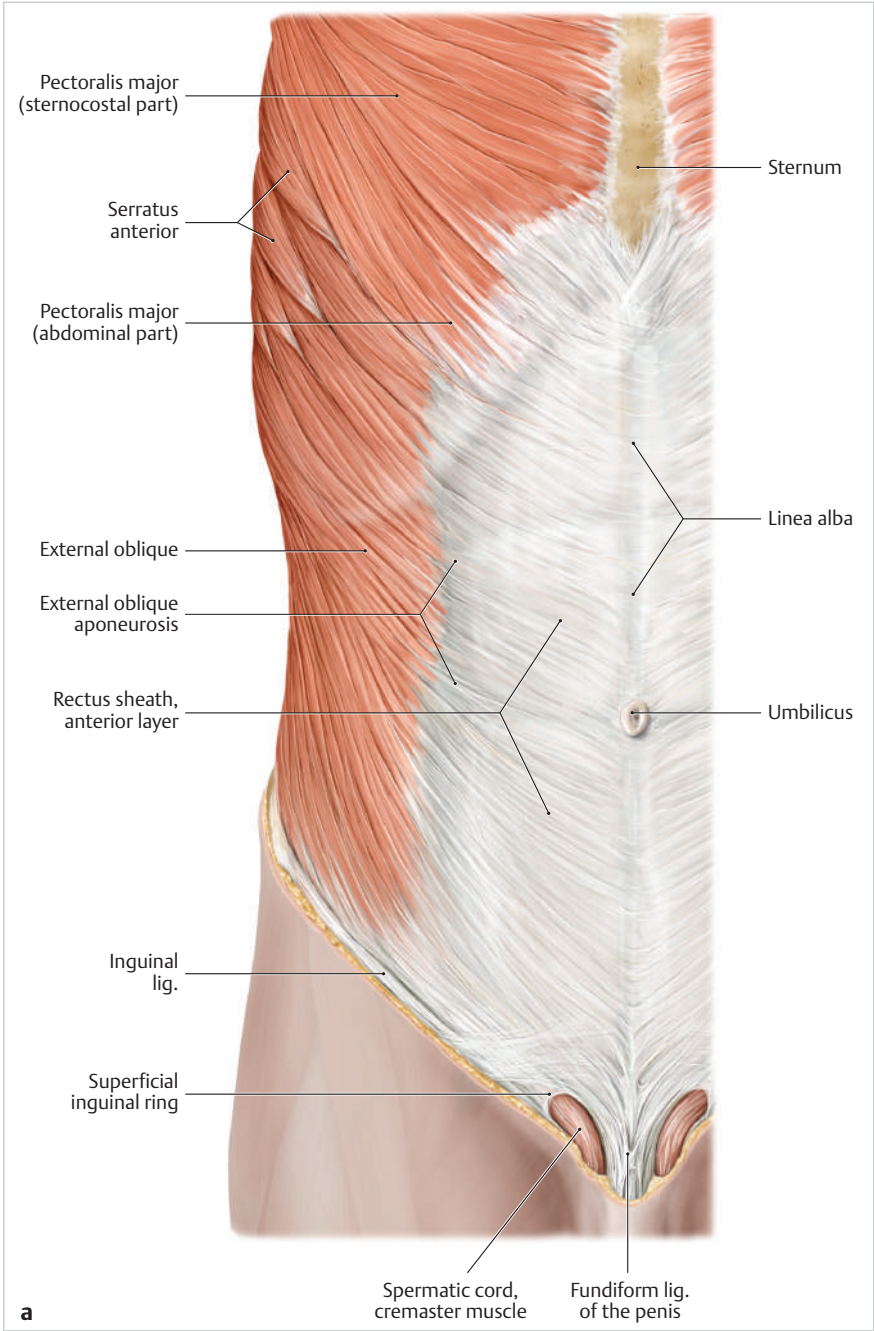
(*Continued*)

Fig. 6.3 (*Continued*) **(b)** Intermediate and deep back muscles. (Reproduced with permission from Gilroy A, MacPherson B, Schünke M et al., eds. Atlas of Anatomy. 3rd Edition. New York, NY: Thieme; 2017.)
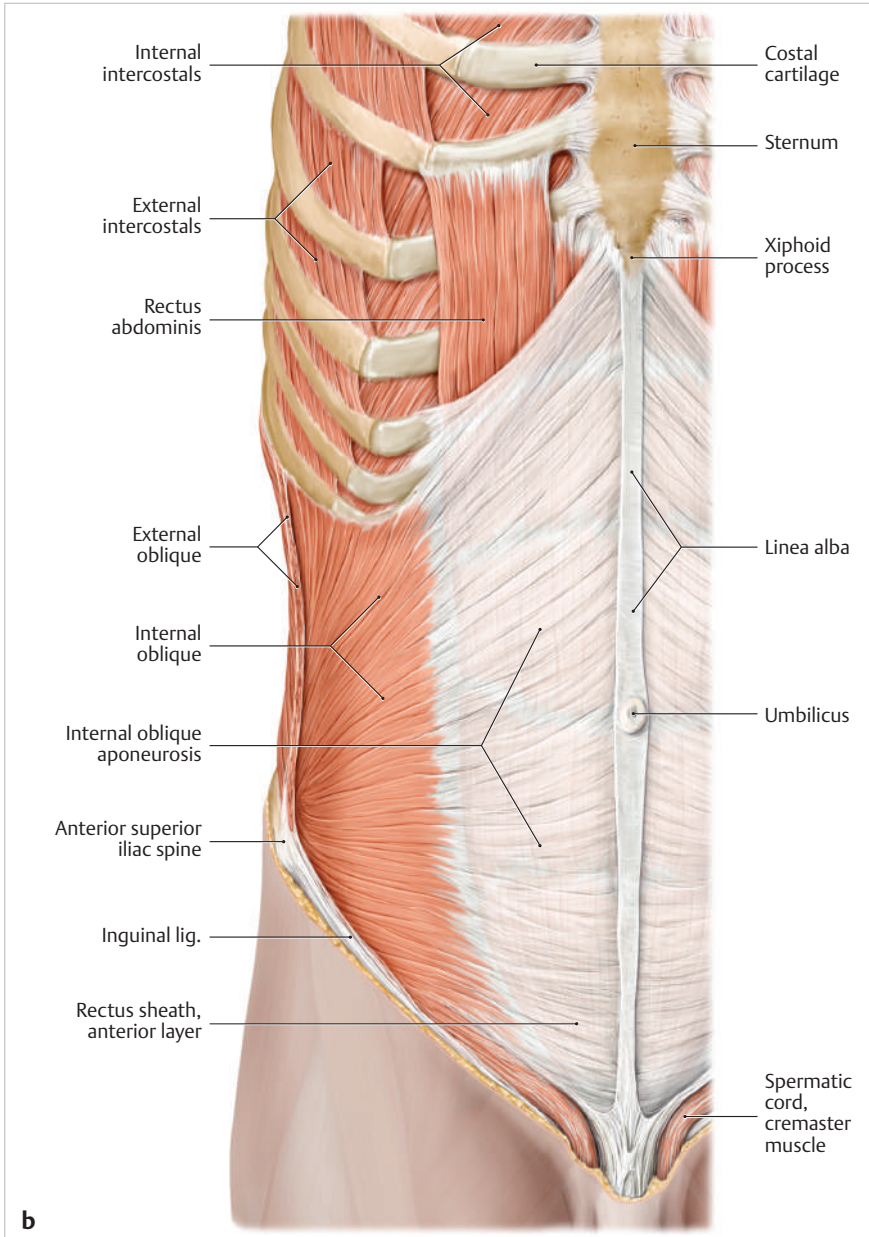
(*Continued*)

c

Semispinalis capitis

Superior nuchal line

Splenius capitis

Obliquus capitis superior

Rectus capitis posterior minor

Rectus capitis posterior major

Obliquus capitis inferior

Longissimus capitis

Interspinales cervicis

Spinalis cervicis

Rotatores thoracis longi

Levatores costarum longi

Rotatores thoracis breves

Spinalis thoracis

External intercostal muscles

Levatores costarum breves

Intertrans-versarii mediales lumborum

12th rib

Interspinales lumborum

Inter-transversarii laterales lumborum

Transversus abdominis

Costal processes

Iliac crest

Thoracolumbar fascia, posterior layer

Multifidus

Quadratus lumborum

Fig. 6.3 (*Continued*) **(c)** Deep back muscles. (Reproduced with permission from Gilroy A, MacPherson B, Schünke M et al., eds. Atlas of Anatomy. 3rd Edition. New York, NY: Thieme; 2017.)
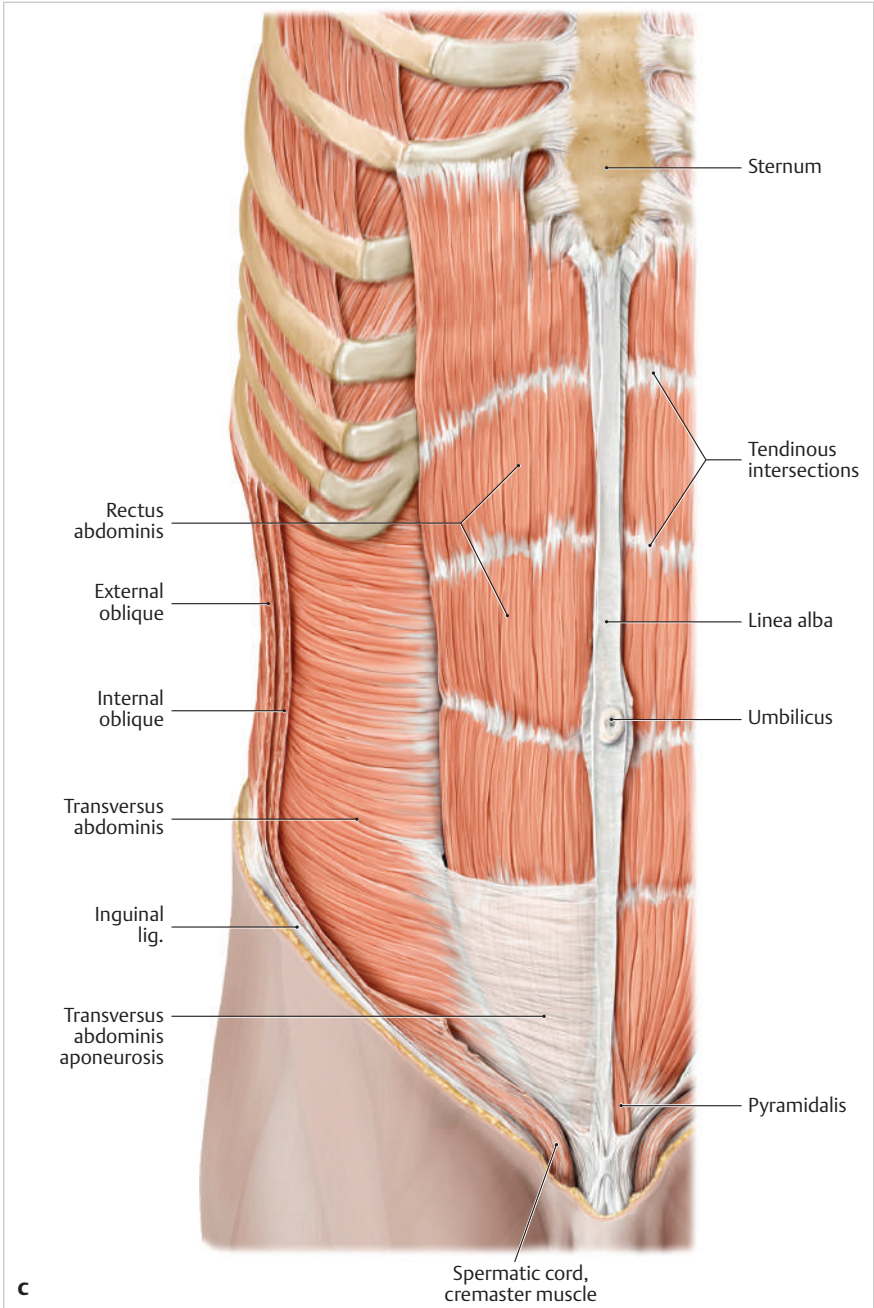
Fig. 6.4 (a) Superficial anterolateral abdominal wall muscles. (Reproduced with permission from Gilroy A, MacPherson B, Schünke M et al., ed. Atlas of Anatomy. 3rd Edition. New York, NY: Thieme; 2017.)

(*Continued*)

Fig. 6.4 (*Continued*) **(b)** Intermediate anterolateral abdominal wall muscles. (Reproduced with permission from Gilroy A, MacPherson B, Schünke M et al., ed. Atlas of Anatomy. 3rd Edition. New York, NY: Thieme; 2017.)

(*Continued*)

Sternum

Tendinous intersections

Rectus abdominis

External oblique

Internal oblique

Transversus abdominis

Inguinal lig.

Transversus abdominis aponeurosis

Linea alba

Umbilicus

Pyramidalis

Spermatic cord, cremaster muscle

c

Fig. 6.4 (*Continued*) **(c)** Deep anterolateral abdominal wall muscles. (Reproduced with permission from Gilroy A, MacPherson B, Schünke M et al., ed. Atlas of Anatomy. 3rd Edition. New York, NY: Thieme; 2017.)
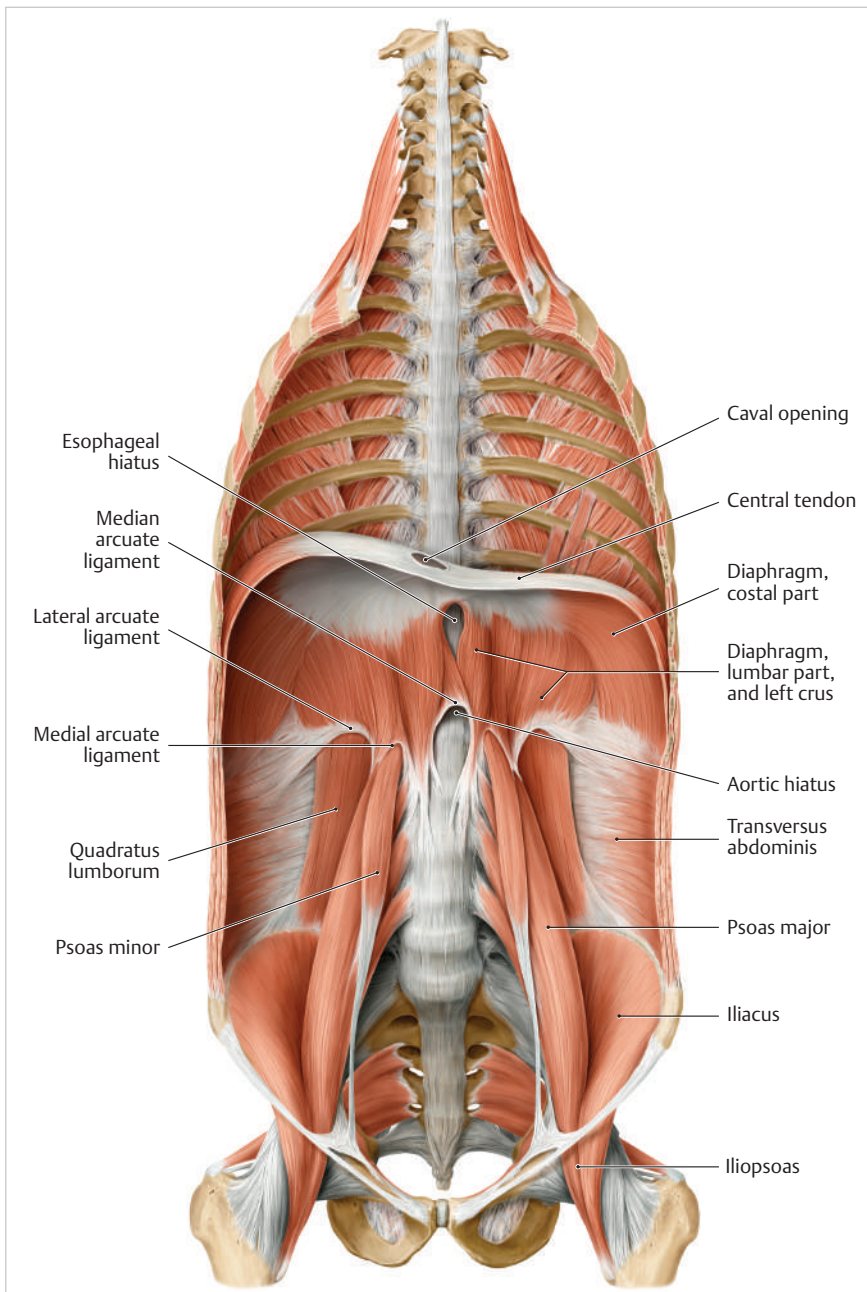
Fig. 6.5 Posterior abdominal wall musculature. (Reproduced with permission from Baker E, Schünke M, Schulte E et al., ed. Anatomy for Dental Medicine. 2nd ed. New York, NY: Thieme; 2015.)

- Conus medullaris is located at inferior aspect of L1 vertebrae:
  - Spinal cord termination.
- Sympathetic trunk:
  - Bilateral to vertebral column.
  - Connects to anterior rami via rami communicantes.

Table 6.7 Lumbar vasculature

Artery	Location	Branches	Supplies
Abdominal aorta	Runs caudally along vertebral canal until bifurcating at L4	Segmental intercostal arteries Lumbar arteries	Organs and tissues of abdomen, pelvis, and legs
Segmental intercostal	Anterior to vertebral bodies and transverse processes Inferior borders of ribs	Dorsal branch Spinal branch Ventral branch Anterior segmental medullary	Dura Spinal cord Vertebral bodies Anterior spinal artery
Lumbar	Bilateral arteries Posterolateral along vertebral bodies	Posterior segmental medullary Anterior radicular arteries Posterior radicular arteries	Dorsal back muscles Posterior spinal arteries
Anterior segmental medullary	Midline along nerve roots	Anterior spinal artery Anterior radicular arteries	Lumbar and sacral spinal cord
Posterior segmental medullary	Paired arteries along nerve roots	Posterior spinal artery Posterior radicular arteries	Lumbar and sacral spinal cord
Anterior spinal	Ventral median fissure of spinal cord	Sulcal branches Pial arterial plexus	Anterior two-thirds of spinal cord
Posterior spinal	Paired arteries along posterolateral sulci of spinal cord		Posterior one-third of spinal cord

**Table 6.8** Lumbar plexus: anterior division

Nerve	Origin	Motor	Sensory
Subcostal	T12		Subxiphoid region
Iliohypogastric	T12–L1	Transversus abdominis Abdominal internal oblique	Above pubis Posterolateral buttocks
Ilioinguinal	L1		Inguinal region
Genitofemoral	L1–L2	Cremaster	Scrotum (M) Mons (F)
Obturator	L2–L4	External oblique Adductor longus Adductor brevis Adductor magnus Gracilis Obturator externus	Inferomedial thigh
Accessory obturator	L2–L4	Psoas	

Table 6.9 Lumbar plexus: posterior division

Nerve	Origin	Motor	Sensory
Lateral femoral cutaneous	L2–L3		Lateral thigh
Femoral	L2–L4	Psoas Iliacus Pectineus Rectus femoris Vastus lateralis Vastus intermedius Vastus medialis Sartorius Articularis genu	Anteromedial thigh Medial leg and foot
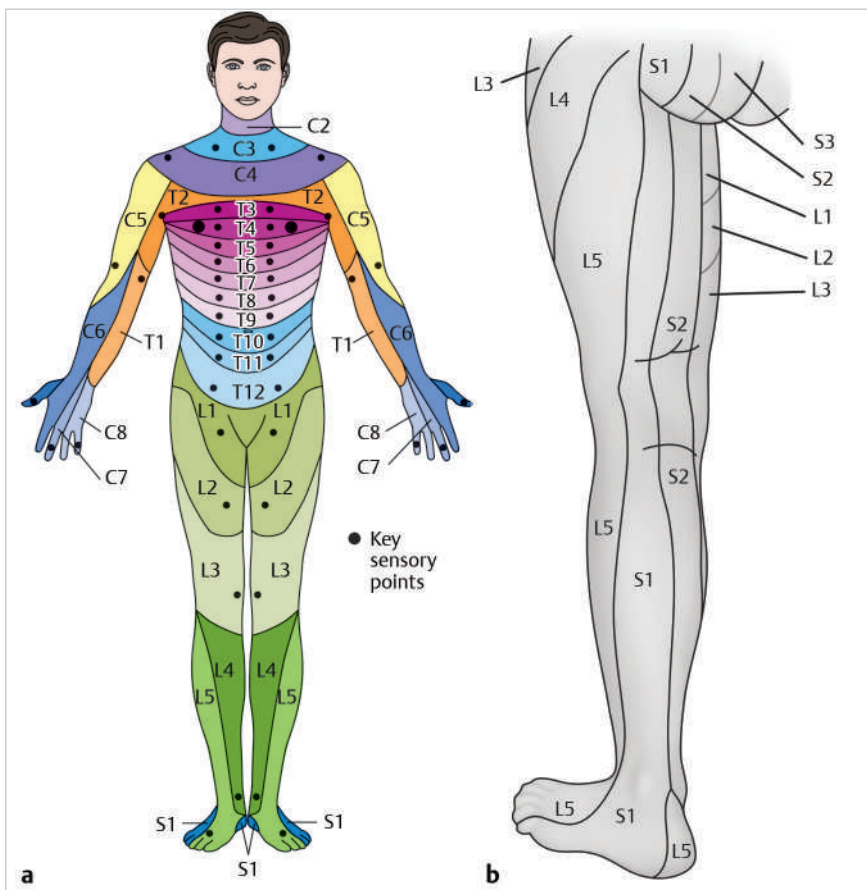
Fig. 6.6 (a) Anterior dermatomes. (Reproduced with permission from An HS, Singh K, eds. Synopsis of Spine Surgery. 3rd ed. New York, NY: Thieme; 2016.) **(b)** Dermatomal map of sacral nerve roots. (Reproduced with permission from Baaj AA, Mummaneni PV, Uribe JS, Vaccaro AR, Greenberg MS, eds. Handbook of Spine Surgery. 2nd ed. New York, NY: Thieme; 2016.)
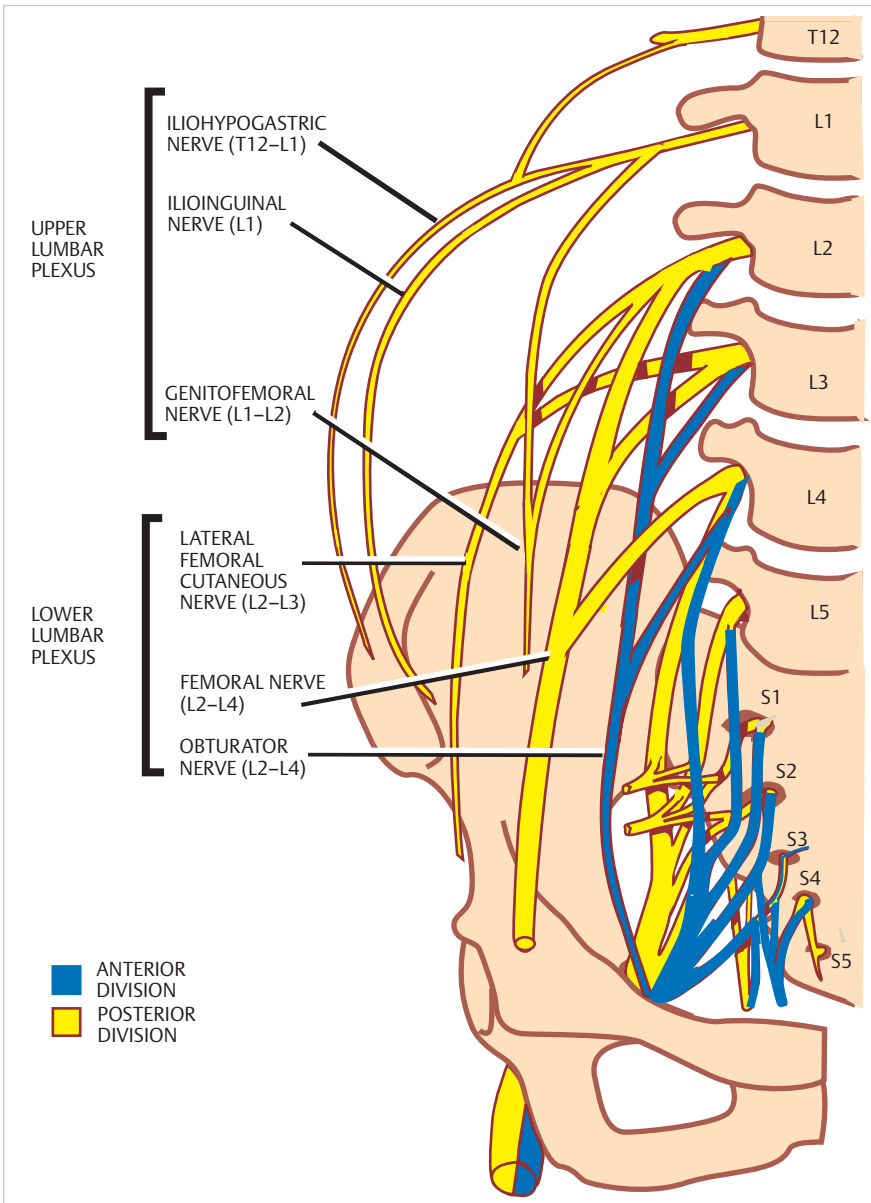
Fig. 6.7 Lumbar plexus. (Reproduced with permission from Albertstone CD, Benzel EC, Najm IM, Steinmetz M, eds. Anatomic Basis of Neurologic Diagnosis. New York, NY: Thieme; 2009.)

- Lumbar plexus:
  - Anterior rami of T12–L4.
  - Deep to psoas muscle.
- Lumbar dermatomes:
  - Lower back and hips.
  - Anterior, medial, and lateral thighs.
  - Anterior and medial lower leg.
  - Dorsum, medial, and plantar foot.

Suggested Readings

1. Gilroy AM, MacPherson BR, Ross LM, Schuenke M, Schulte E, Schumacher U. Atlas of Anatomy. 2nd ed. New York, NY: Thieme; 2012
2. Drake RL, Vogl W, Mitchell AWM. Gray's Anatomy for Students. Philadelphia, PA: Elsevier; 2005
3. Thompson JC. Netter's Concise Atlas of Orthopaedic Anatomy. 1st ed. Philadelphia, PA: Elsevier; 2001

7 Sacral Spine

Antonios Varelas, Fady Y. Hijji, Ankur S. Narain, Philip K. Louie, Daniel D. Bohl, and Kern Singh

7.1 General Information

• Begins as five initially unfused vertebrae:
  – Fusion begins around age 18 years and is completed by age 30 years.
• Concave, inverted triangular shape.
• Structural orientation:
  – Base: broad, superior end.
  – Apex: narrow, inferior end.
• Articulations:
  – Ilium: with the superolateral articular surface.
  – L5 (final lumbar vertebrae): with the superior articular process.
  – Coccyx: with the apex of the sacrum.

7.2 Bony Anatomy (Fig. 7.1)

• Dorsal (posterior) surface:
  – Contains four pairs of foramina:
    ◦ Allow passage of ventral rami for first four sacral spinal nerves and sacral arteries.
  – Median sacral crest:
    ◦ Fusion of first three or four sacral spinous processes.
    ◦ Bony projection at midline of pelvic surface.
  – Intermediate sacral crest:
    ◦ Fusion of the sacral articular processes of S2, S3, S4.
  – Lateral sacral crest:
    ◦ Fusion of all five sacral vertebral articular processes:
      ▪ Incomplete fusion leads to the formation of the posterior sacral foramina.
• Pelvic (anterior) surface:
  – Four transverse ridges, marking the traces of the four fused intervertebral disks.
  – Sacral promontory:
    ◦ Anterior projection of the pelvic surface.
    ◦ Forms the posterior margin of the pelvic inlet.
    ◦ Less prominent in females than in males:
      ▪ Leads to an oval pelvic inlet in females and a heart-shaped inlet in males.
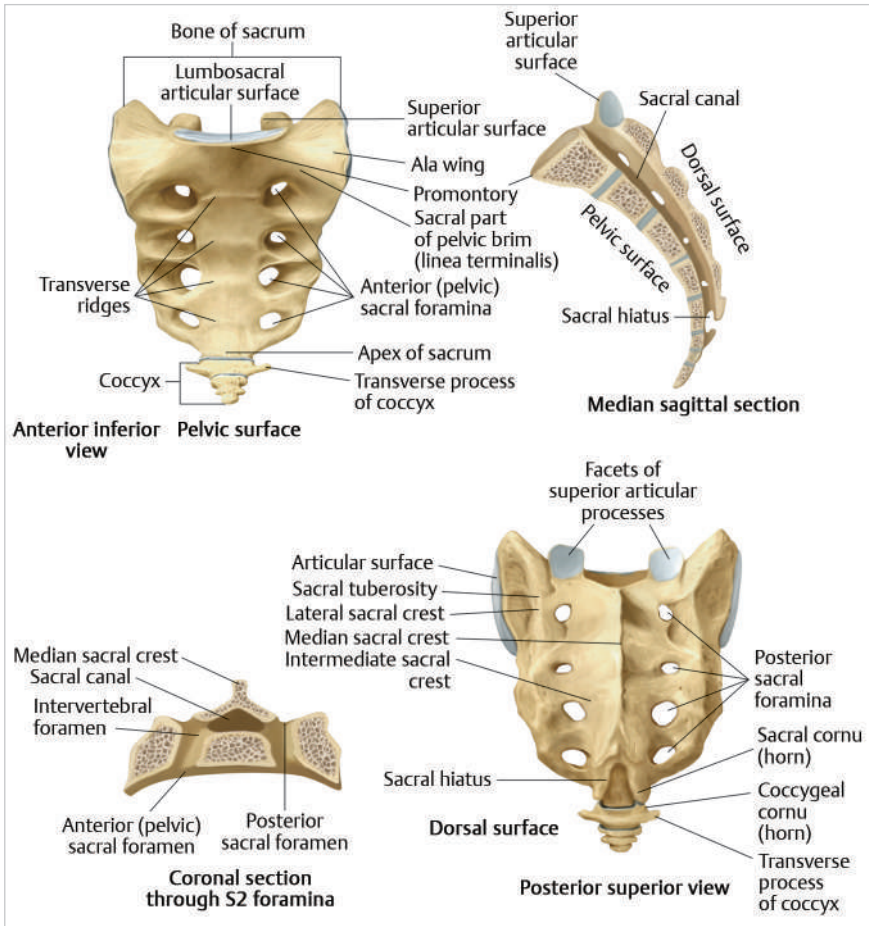
Fig. 7.1 Bony anatomy of the pelvic, lateral, superior, and dorsal sacral surfaces. (Reproduced with permission from An HS, Singh K, eds. Synopsis of Spine Surgery. 3rd ed. New York, NY: Thieme; 2016.)
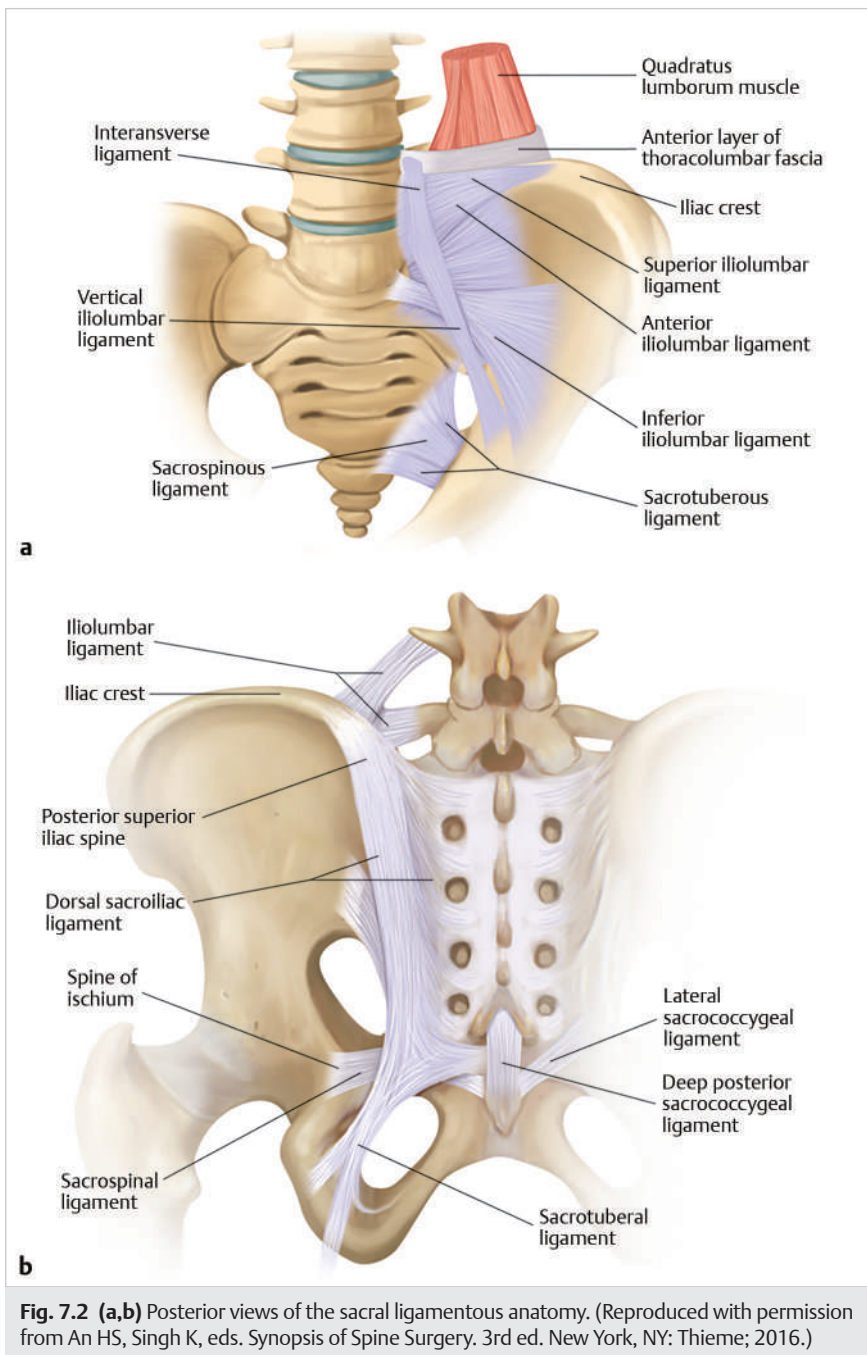
- Ala of sacrum:
  - Large superolateral projections of S1 due to fusion of the transverse vertebral processes.
  - L5 nerve root runs over the top of the sacral ala.
- Sacral canal:
  - Inferior extension of the vertebral foramen.
  - Contains the filum terminale and cauda equina:
    - Filum terminale is a nonneural, connective tissue filament that provides longitudinal support for the spinal cord:
      - Fibrous extension of the conus medullaris.

- Filum terminale internum is enclosed within dural sac, while the externum (coccygeal ligament) is extradural and attaches to the first segment of the coccyx.
  - Cauda equina is a collection of spinal nerves and nerve roots of the L1–S5 nerve pairs and coccygeal nerve:
    - Emerges from the conus medullaris.
- Sacral hiatus:
  - An opening at the inferior border of the sacral canal:
    - Occurs when the lamina of the fifth sacral vertebrae fail to fuse.

7.3 Ligamentous Anatomy

- Sacroiliac ligaments:
  - Stabilize the sacroiliac joint.
  - Comprises three divisions:
    - Anterior (symphyseal ligaments):
      - Weak stabilization of the sacroiliac joint.
      - Resists external rotation.
    - Posterior (**Fig. 7.2**):
      - Forms the primary bond between sacrum and ilium.
      - Considered by many as the strongest ligaments in the body.
      - Important for pelvic ring stability.
    - Interosseous:
      - Resists abduction of the sacroiliac joint.
- Sacrotuberous ligament (pelvic floor):
  - Spans the sacrum and tuberosity of the ischium:
    - Helps create a boundary for the greater and lesser sciatic foramina.
  - Stabilizes the pelvic girdle.
  - Resists shear and flexion.
  - Passes posterior to the sacrospinous ligament.
- Sacrospinous ligament (pelvic floor):
  - Located within the greater sciatic notch:
    - Spans the sacrum and spine of the ischium.
    - Forms the greater and lesser sciatic foramina.
  - Resists external rotation of the ilium beyond the sacrum.
- Sacrococcygeal ligaments:
  - Spans the sacrum and coccyx.
  - Closes the sacral hiatus.
  - Comprises three divisions:
    - Anterior:
   - A continuation of the anterior longitudinal ligament.

Fig. 7.2 (a,b) Posterior views of the sacral ligamentous anatomy. (Reproduced with permission from An HS, Singh K, eds. Synopsis of Spine Surgery. 3rd ed. New York, NY: Thieme; 2016.)

- ◦ Posterior:
  - ▪ Consists of two components: deep and superficial:
    - ❖ Deep ligament is a continuation of the posterior longitudinal ligament.
    - ❖ Superficial ligament completes the inferior portion of the sacral canal.
  - ◦ Lateral:
    - ▪ Completes the final foramen for the fifth sacral nerve.
- • Coccygeal ligament:
  - – Anchors the termination of the dural sac at S2 to the first segment of the coccyx.

7.4 Muscular Anatomy

- • Anterior sacral muscles (**Table 7.1, Figs. 7.3, 7.4**):
  - – Muscular attachments occur along the pelvic (anterior) surface of sacrum:
    - ◦ Piriformis.
    - ◦ Coccygeus.
    - ◦ Iliacus.

Table 7.1 Anterior surface

Muscle	Origin	Insertion	Action	Innervation
Piriformis	Sacrum (S2, S3, S4)	Greater trochanter of femur	External rotation, abduction, extension of hip joint	Nerve to the piriformis (L5, S1, S2)
Coccygeus	Ischial spine, sacrospinous ligament	Inferior sacrum, coccyx	Elevation/support of pelvic floor, flexion of coccyx	Anterior primary rami of S4, S5
Iliacus	Ala of sacrum, iliac fossa	Lesser trochanter of femur	Flexion, external rotation of hip joint	Femoral nerve (L2, L3, L4)
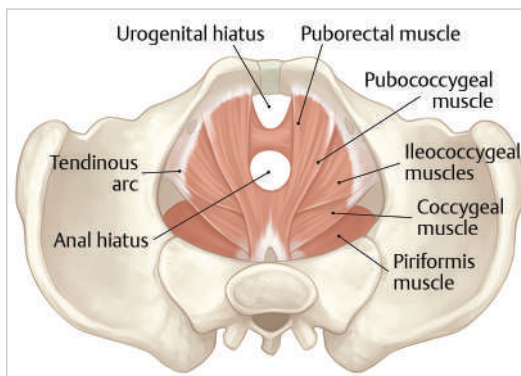
Fig. 7.3 View of the pelvic floor and the muscular attachments of the piriform and coccygeus to the sacrum.
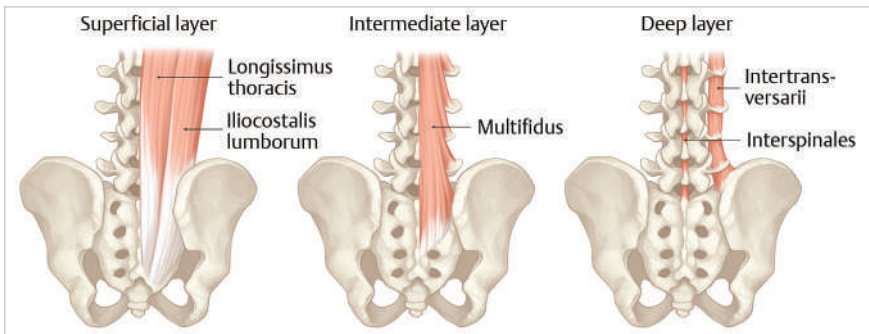
• Posterior sacral muscles (**Table 7.2, Figs. 7.5, 7.6**):

 – Muscular attachments occur along the dorsal (posterior) surface of sacrum:

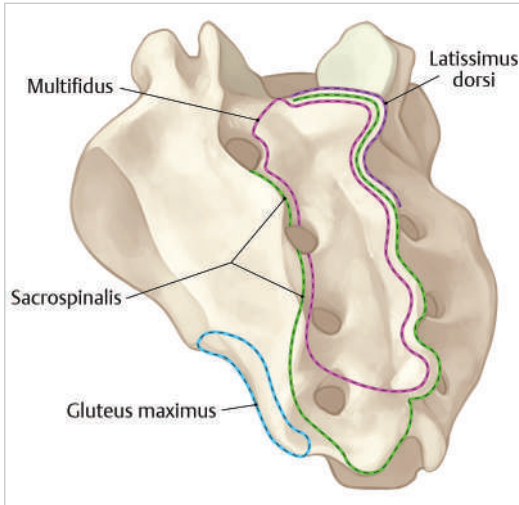   ◦ Multifidus lumborum.
   ◦ Erector spinae.
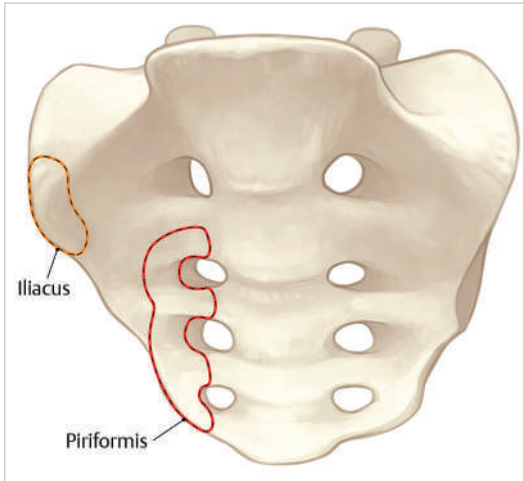
Fig. 7.4 Anatomical view of the attachment sites for the anterior sacral muscles.

Table 7.2 Posterior surface

Muscle	Origin	Insertion	Action	Innervation
Erector spinae	Sacrum, iliac crest	Varies for each erector spinae muscle	Extension, lateral flexion of vertebral column and neck	Dorsal primary rami of spinal and thoracic nerves
Multifidus lumborum	Sacrum, transverse process of C2–L5	Spinous processes of vertebrae	Extension, ipsilateral lateral flexion, contralateral rotation of spine	Dorsal primary rami of C1–L5

Fig. 7.5 Posterior view of the muscular attachment of the erector spinae and multifidus lumborum to the sacrum.

Fig. 7.6 Anatomical view of the attachment sites for the posterior and lateral sacral muscles.

Table 7.3 Lateral border

Muscle	Origin	Insertion	Action	Innervation
Gluteus maximus	Sacrum, ilium, coccyx	Upper fibers: iliotibial tract Lower fibers: gluteal tuberosity of femur	Extension of hip, external rotation of femur	Inferior gluteal nerve (L5, S1, S2)

• Lateral sacral muscles (**Table 7.3, Fig. 7.6**):
  – Muscular attachments occur along the lateral edge of sacrum:
    ◦ Gluteus maximus.

7.5 Vascular Anatomy

• Median (middle) sacral artery:
  – Vestigial structure.
  – Supplies the coccyx, sacrum, and lumbar vertebrae.
  – Originates from the posterior surface of the abdominal aorta near the aortic bifurcation (**Fig. 7.7**):
    ◦ Descends vertically following the pelvic surface of the sacrum.
    ◦ Terminates in the coccygeal body.
  – Anastomoses:
    ◦ Iliolumbar artery:
      ▪ At the level of the lumbar vertebrae.
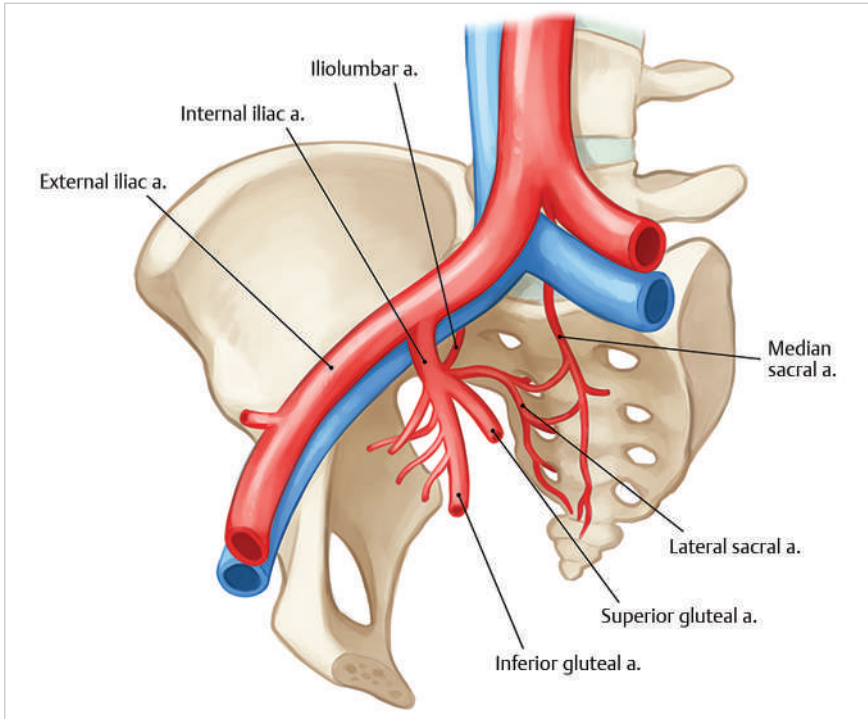
Fig. 7.7 Anatomy of the abdominal aorta, common iliacs, and sacral arteries.

- Lateral sacral arteries:
  - Anterior to the sacrum.
  - Resulting branches travel through the anterior sacral foramina.
- Lateral sacral arteries:
  - Often observed as bilateral vessels:
    - Superior and inferior.
  - Supply the sacral canal, erector spinae, and piriformis.
  - Originate from the posterior division of the internal iliac artery:
    - Typically manifests as the second branch; however, it can also arise from the superior gluteal artery.
  - Anastomoses:
    - Gluteal arteries:
      - Over the dorsal surface of the sacrum.
    - Median artery:
      - Anterior to the sacrum and coccyx.
    - Contralateral lateral sacral artery:
      - Anterior to the coccyx.

7.6 Neural Anatomy

- Nerve roots:
  - Cauda equina contains the sacral fibers (**Fig. 7.8**):
    - Travels within the lumbosacral canal.
    - Collection of L1–S5 peripheral nerves.
    - Dural sac ends at S2:
      - Extradural portion of the filum terminale emerges from dural sac.
  - Upper four sacral roots exit the sacrum by way of the sacral foramina.
  - Fifth sacral root, filum terminale, and coccygeal roots exit through the sacral hiatus.
  - Ventral (anterior) rami of L4–S4 form the sacral plexus.
- Sacral plexus (**Fig. 7.9**):
  - Anterior rami of L4–S3 and the upper portion of S4.
  - Located deep to the pelvic (Waldeyer's) fascia and superior to the surface of the piriformis muscle.
  - Nearly all branches leave through the greater sciatic foramen:
    - Those that remain in the pelvis innervate the perineum, pelvic muscles, and pelvic organs.
  - Gives rise to (**Table7.4**):
    - Sciatic nerve (L4–S3):
      - Common fibular and tibial nerve components.

L3
L4
L5
S1
S2
S3
S4
S5
Coccygeal nerve
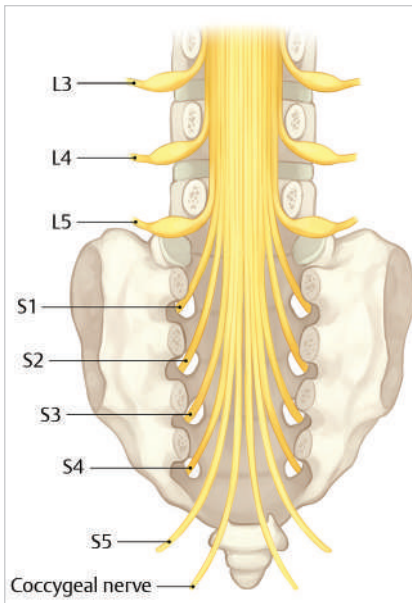
Fig. 7.8 Sacral nerve roots passing through the sacral foramina.
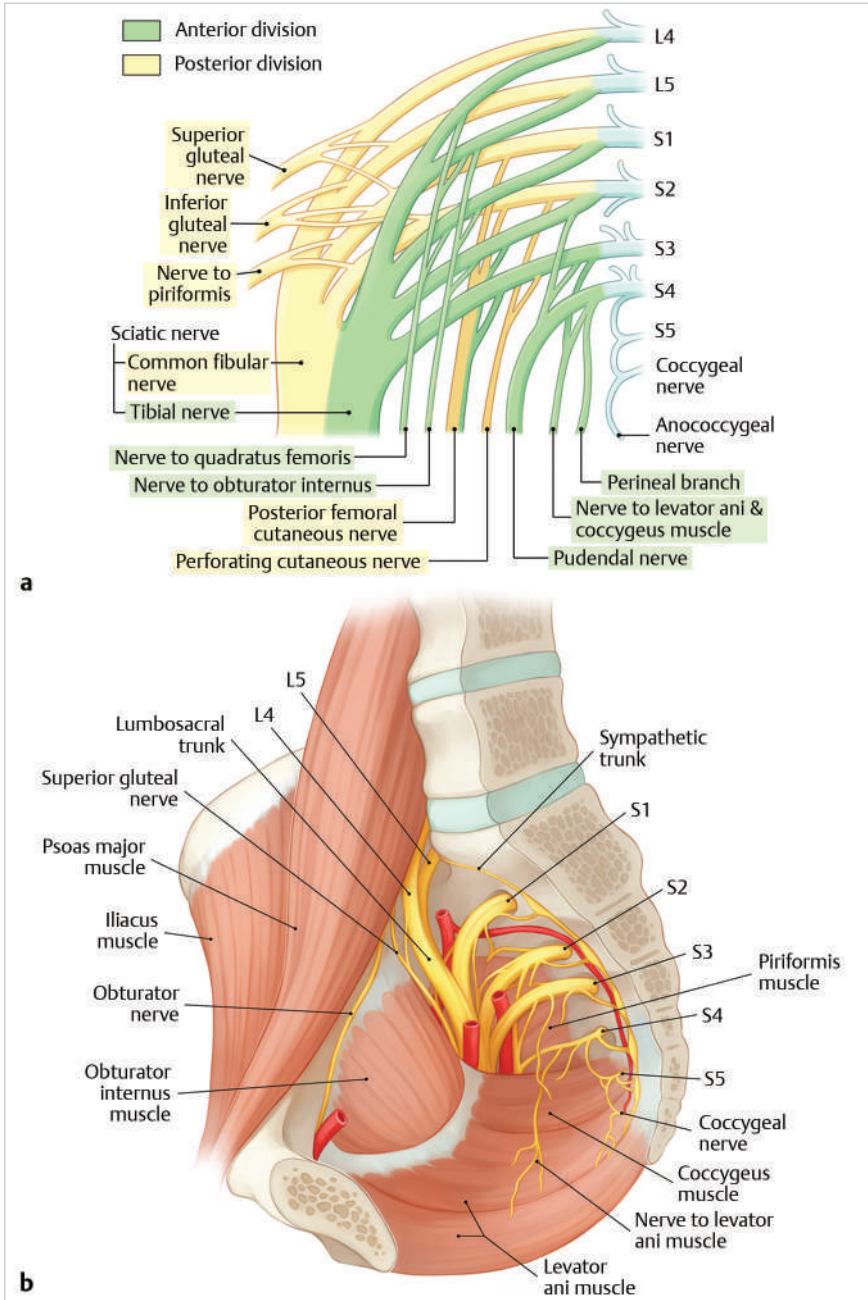
Fig. 7.9 (a,b) Sacral plexus with corresponding nerve roots and terminal innervations.

Table 7.4 Sacral plexus

Nerve	Origin	Motor	Sensory
Superior gluteal	L4, L5, S1	Gluteus medius, gluteus minimus, tensor fasciae latae	None
Inferior gluteal	L5, S1, S2	Gluteus maximus	None
Nerve to the piriformis	L5, S1, S2	Piriformis	None
Nerve to the obturator internus	L5, S1, S2	Obturator internus, superior gemellus	None
Nerve to the quadratus femoris	L4, L5, S1	Quadratus femoris, inferior gemellus	None
Posterior cutaneous femoral nerve	S1, S2, S3	None	Perineum, posterior surface of thigh and leg
Sciatic	L4, S1, S2, S3	Tibial portion: semitendinosus, semimembranosus, long head of biceps femoris, adductor magnus (hamstring portion) Common fibular portion: short head of biceps femoris	Tibial portion: posterolateral and medial surface of foot, sole of foot Common fibular portion: anterolateral surface of leg, dorsal portion of foot
Pudendal	S2, S3, S4	External urethral sphincter, external anal sphincter, levator ani, skeletal muscles of perineum	External genitalia, skin of perineum

- ○ Superior (L4–S1) and inferior (L5–S2) gluteal.
- ○ Pudendal nerve (S2–S4).
- ○ Posterior cutaneous femoral (S1–S3).
- ○ Nerves to piriformis, obturator internus, and quadratus femoris.
- Sacral dermatomes:
  - – Sacral nerve roots providing sensation for various areas around the perineum, thighs, and legs.
  - – Important dermatomes:
    - ○ S1: posterior thigh and leg (lateral).
    - ○ S2: posterior thigh and leg (medial).
    - ○ S2–S4: perineum and genitals.

7.7 Clinical and Surgical Pearls

- Cauda equina syndrome is considered a true medical emergency. Key features include the following: lower extremity sensorimotor changes, bilateral lower extremity pain/weakness, bladder/bowel changes, and/or saddle anesthesia.
- The sacrotuberous ligament is surgically severed to relieve perineal pain resulting from the entrapment of the pudendal nerve between the sacrotuberous and sacrospinous ligament.

- The posterior sacroiliac ligamentous complex are considered the strongest ligaments in the body; they are more important than the anterior ligaments for pelvic ring stability.
- The sacral hiatus offers access to the sacral epidural space for the administration of anesthetics.

Suggested Readings

1.   An HS, Singh K. Synopsis of Spine Surgery. 3rd ed. New York, NY: Thieme; 2016
2.   Netter FH. Atlas of Human Anatomy. 6th ed. Philadelphia, PA: Saunders; 2014
3.   Herkowitz HN, Garfin SR, Eismont FJ, et al. The Spine. 5th ed. Philadelphia, PA: Saunders Elsevier; 2006:22

8 Spinal History and Physical Examination

Fady Y. Hijji, Ankur S. Narain, Junyoung Ahn, Philip K. Louie, Daniel D. Bohl, and Kern Singh

8.1 Spinal History

8.1.1 Background

• Obtaining an accurate clinical history is the most important aspect of evaluation:
  – Physical examination.
  – Diagnostic imaging.
  – Urgency of spinal pathology.
  – Therapeutic modalities.

8.1.2 History

• Age:
  – Younger than 40 years: isthmic spondylolisthesis, disk herniation, congenital deformities.
  – Older than 40 years: degenerative disk disease, spinal stenosis, disk herniation.
• Pain:
  – Character:
    ◦ Axial versus radicular:
      ▪ Axial: more diffuse/generalized.
      ▪ Radicular (extremities): pain associated with paresthesias, numbness, weakness in a dermatomal distribution.
    ◦ Mechanical versus nonmechanical:
      ▪ Mechanical: worse with activity, progresses over the day, relief with rest.
      ▪ Nonmechanical: independent of activity or rest, worse at night.
  – Location:
    ◦ Determine anatomic location (neck, back, upper or lower extremity) and presence of radiation:
      ▪ Must distinguish pain due to radiation versus referred pain:
        ❖ Radiating: pain pattern not localizable to a specific dermatome.
        ❖ Referred pain:
          ◊ Shoulder pain referred form cervical spine.
          ◊ Buttocks/posterior thigh pain referred from lumbar spine.
    ◦ Determine unilateral versus bilateral nature.

- Timing:
  - Acute: associated with lumbar muscle strain, disk herniation, spondylolisthesis.
  - Progressive: spondylosis, spondylolisthesis, tumor.
  - Night pain: associated with space-occupying lesions (tumors) and infections.
- Alleviating and exacerbating factors:
  - Can distinguish spinal stenosis (neurogenic claudication), disk herniation:
    - Spinal stenosis improves with sitting, leaning forward:
      - ❖ Vascular claudication differs in that pain is exacerbated by physical activity, pain relief occurs with rest, and weakness is not typically present.
    - Herniation pain improves with lumbar extension, worse with flexion.
- Mechanism of injury:
  - Trauma: assess airway, breathing, circulation.
  - Activity: often associated with sports.
  - Progressive/atraumatic: common with degenerative conditions.
- Neurologic symptoms:
  - Radiculopathy or neuropathy: paresthesias, numbness, weakness in a dermatomal pattern.
  - Myelopathy: broad-based gait, clumsiness, inability to perform fine motor activities, pain in a nondermatomal pattern.
- Constitutional symptoms:
  - Accompanying fevers, chills, night sweats, and significant weight loss may be consistent with infectious or oncologic etiologies.
- Patient factors that may be associated with spinal pathology:
  - Past medical history:
    - Previous infections, diagnosed tumors, childhood illnesses, neurological diseases.
    - Mental disorders (depression, anxiety) may be associated with low back pain.
    - Underlying systemic illnesses.
  - Family history:
    - Previous history of spinal pathology, spinal tumors, and other cancers.
  - Social history:
    - Inquire about occupation, job satisfaction, previous workers' compensation–related injuries.
    - Recreational activities.
    - Smoking, illicit drug use.

8.2 Physical Examination

8.2.1 Background

- Physical examination is crucial for narrowing differential diagnoses to identify spine pathology:
 - Must be individualized to patient's presentation:
    - History.

- ◦ Anatomic region of suspected pathology.
- ◦ Imaging findings.
- Physical examination includes five main components:
  - General:
    - ◦ Inspection.
    - ◦ Palpation.
    - ◦ Range of motion.
    - ◦ Walking gait.
  - Sensory.
  - Motor.
  - Reflexes.
  - Special maneuvers.

8.2.2 General Physical Examination

- Inspection:
  - Skin:
    - ◦ Must disrobe patient adequately for appropriate assessment.
    - ◦ Inspect for any unique growths or lesions:
      - ▪ Café au lait spots:
        - ❖ Neurofibromatosis.
      - ▪ Hair tufts in lumbar region:
        - ❖ Spina bifida.
  - Muscle tone/bulk:
    - ◦ Inspect for muscle size or abnormal contractions:
      - ▪ Atrophy:
        - ❖ Chronic neuropathy consequently decreasing muscle fiber innervation and usage.
      - ▪ Fasciculations:
        - ❖ Neuropathy causing limited innervation of muscle fibers:
          - ◊ Inability to stimulate full muscle contraction.
      - ▪ Contractures:
        - ❖ Chronic upper motor neuron pathology causing long-term immobilization and spasticity:
          - ◊ Reorganization of collagen fibers leads to muscles being held in shortened position for extended periods of time.
  - Posture and alignment:
    - ◦ Inspect spinal alignment, abnormal bony prominences, and upright position of patient:
      - ▪ Malalignment:
        - ❖ Forward-bending test:

- ◇ Asymmetric ribs or scapulae is often indicative of scoliosis (congenital or degenerative).
  - ❖ Can be associated with abnormal rib and iliac crest prominences.
  - ▪ Neck or pelvic tilting:
    - ❖ Paraspinal muscle spasms:
      - ◇ Consider torticollis in severe neck tilting with pediatric patients or patients taking dopamine antagonist medications.

- Palpation:
  - Soft tissue:
    - ◦ Firm palpation of paraspinal muscles to assess for tenderness:
      - ▪ Paraspinal muscle tenderness:
        - ❖ Can indicate paraspinal muscle spasm, trauma, or myofascial nodes.
  - Bony structures:
    - ◦ Firm palpation of spinous processes, sacrum, and coccyx:
      - ▪ Spinous process tenderness:
        - ❖ Can indicate spinous process fracture.
      - ▪ Coccygeal tenderness:
        - ❖ Possible fracture or contusion.

- Range of motion:
  - Cervical:
    - ◦ Flexion/extension:
      - ▪ Chin to chest and occiput to back.
      - ▪ Normal flexion: 45 degrees or within 3 to 4 cm of touching chest.
      - ▪ Normal extension: 70 degrees.
    - ◦ Lateral flexion:
      - ▪ Bending ear to shoulder.
      - ▪ Normal: 30 to 40 degrees in each direction.
    - ◦ Rotation:
      - ▪ Turning head in either direction with stationary shoulders.
      - ▪ Normal: 70 degrees in each direction.
  - Lumbar:
    - ◦ Flexion/extension:
      - ▪ Toe touch with straight legs and leaning backward.
      - ▪ Normal flexion: 45 to 60 degrees.
      - ▪ Normal extension: 20 to 30 degrees.
    - ◦ Lateral flexion:
      - ▪ Bend at waist to either side.
      - ▪ Normal: 10 to 20 degrees in each direction.
    - ◦ Rotation:
      - ▪ Rotating at the waist with hips stationary.
      - ▪ Normal: 5 to 15 degrees.

- Walking gait:
  - Patient walks across examination room.
  - Inspect for abnormal movements or postures:
    - Wide-based gait:
      - Late finding in myelopathy, usually involving the posterior columns of the spinal cord.
    - Leaning forward:
      - Often indicates spinal stenosis.
      - Spinal flexion increases space within spinal canal.
    - Trendelenburg gait (**Fig. 8.1**):
      - Pelvic tilt/drop of the side contralateral to the weight-bearing leg.
      - Indicates hip abductor weakness of weight-bearing side.
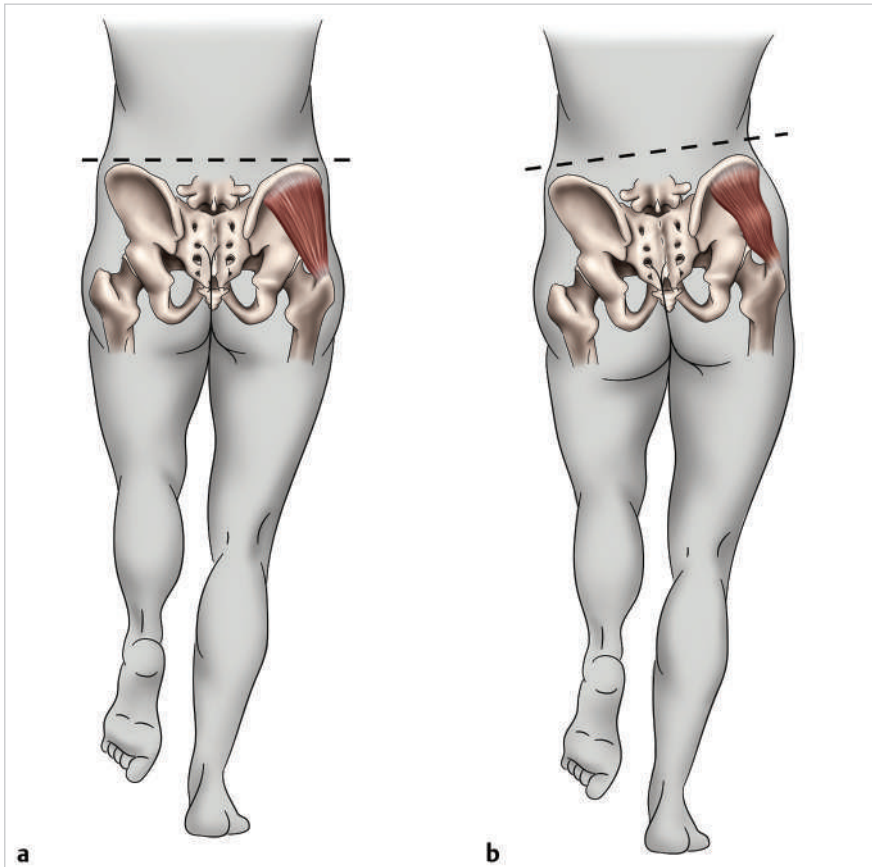
Fig. 8.1 (a,b) Trendelenburg gait. Note the weak gluteus medius, resulting in inability of hip abduction of the ipsilateral side.

- Antalgic gait:
  - Shortened stance phase of the walking gait for the side experiencing hip pain.
  - Indicates hip pain/pain with weight bearing.
- Circumduction gait:
  - Excessive leg abduction due to spasticity of leg extensors.
  - Indicates upper motor neuron pathology.
- High-steppage gait:
  - Excessive hip flexion to compensate for foot drop due to weak dorsiflexion.
  - Indicates neuropathy of L4 or L5 nerve root or deep peroneal nerve palsy.

8.3 Sensory Examination (Fig. 8.2)

• Four distinct sensory modalities:
  – Pain/pinprick:
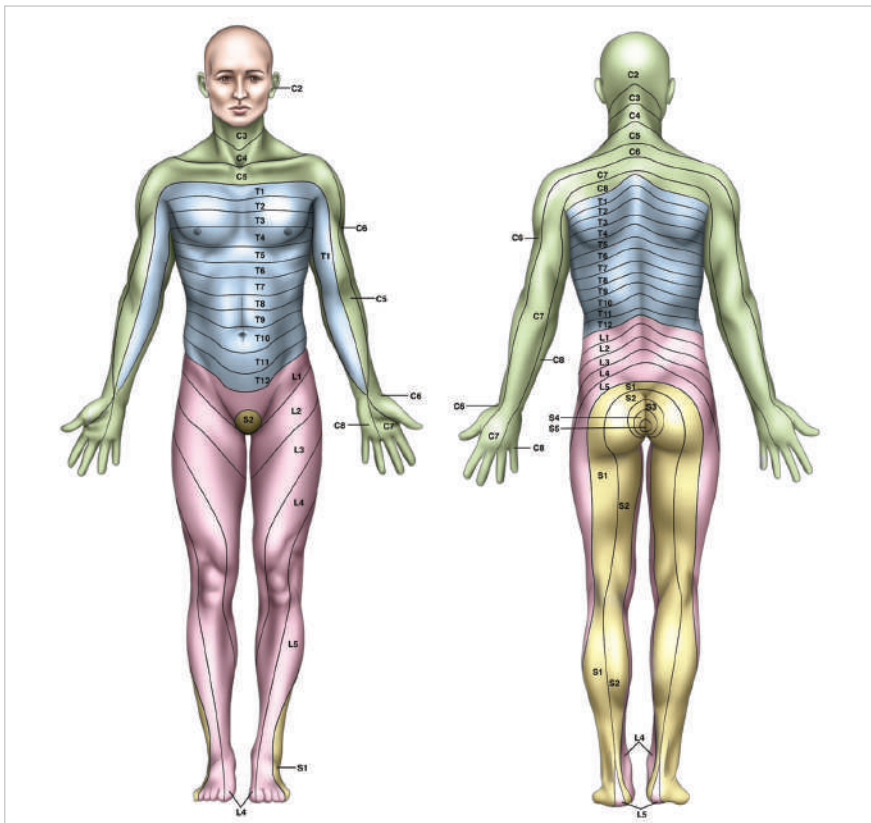
Fig. 8.2 Dermatomal distribution map. Note that many dermatomes can have overlap with one another.

- ◦ Prick patient with slightly sharp object such as a pin or broken wooden cotton swab.
- ◦ Assesses nerve root dermatomes and spinothalamic tract.
- – Light touch:
  - ◦ Gently stroke dermatome with cotton swab or monofilament.
  - ◦ Assesses nerve root dermatomes.
- – Temperature:
  - ◦ Crudely tested using a test tube with hot or cold solution.
  - ◦ Assesses spinothalamic tract and status of anterior white commissure.
- – Proprioception and vibration:
  - ◦ Proprioception: place the patient's big toe in the dorsiflexed or plantarflexed position, and ask the patient to identify its position while their eyes are closed:
    - ▪ If they are unable to correctly identify, progressively move to more proximal joints.
  - ◦ Vibration sense: place the base of a vibrating tuning fork on the metatarsal phalangeal joint of the big toe and ask the patient to identify the sensation while their eyes are closed:
    - ▪ If they are unable to sense the vibration, move to more proximal areas with skin overlying bone (lateral/medial malleolus).
  - ◦ Assesses dorsal column of spinal cord.
- • Decreased sensation may indicate pathology involving the anatomic pathway of that sensation.

8.4 Motor Examination

- • Assessment of muscle tone and strength.
- • Muscle tone:
  - – Resistance to passive range of motion:
    - ◦ Move patient arm without any resistance provided by the patient.
    - ◦ Assessment must be made at all major joints sequentially:
      - ▪ That is, wrist → elbow → shoulder.
  - – Hypertonia:
    - ◦ Excessive contraction and stiffness to passive movement.
    - ◦ Pathology involving upper motor neurons.
  - – Hypotonia:
    - ◦ No muscular contractions or resistance during passive movement.
    - ◦ Pathology involving lower motor neurons.
- • Muscle strength:
  - – Provide resistance to the muscle being assessed.
  - – Five-point grading scale:
    - ◦ Grade 5: full strength.
    - ◦ Grade 4: weakness against resistance.

- Grade 3: able to move against gravity but not resistance.
- Grade 2: able to move perpendicular to gravity, but not against gravity.
- Grade 1: evidence of contractility (muscle fasciculation).
- Grade 0: no contractility.

• Decreased motor strength will indicate pathology of either upper (spinal cord) or lower motor (nerve root) neurons:

– Muscle tonicity and reflexes helpful in further delineating the type of lesion.

8.5 Reflexes (Tables 8.1, 8.2)

• Assessment of the integrity of the entire neural pathway (sensory, central, and motor):

– Some reflexes are physiologic, and some are pathologic:

- Deep tendon reflex, cutaneous, and sacral reflexes are physiologic.
- Babinski's and occasionally Hoffman's reflexes are pathologic.

• Five-point grading scale for deep tendon reflexes:

– 5+: sustained clonus.
– 4+: hyperreflexic with clonus.

Table 8.1 Cervical nerve roots and their predominant sensory, motor, and reflex functions

	Sensory	Motor	Deep Tendon Reflex
C5	Lateral shoulder and arm	Deltoid (shoulder abduction)	Biceps tendon
C6	Lateral arm, forearm and thumb	Biceps (elbow flexion)	Brachioradialis
C7	Index and middle finger	Triceps (elbow extension)	Triceps tendon
C8	Fourth and fifth digits	Hand intrinsics (finger abduction)	–
T1	Medial forearm and arm	Hand intrinsics (finger abduction)	–
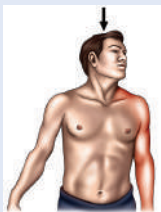
Table 8.2 Lumbosacral nerve roots and their predominant sensory, motor, and reflex functions

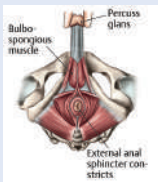|	Sensory	Motor	Deep tendon reflex
L1	Inguinal crease	Transversus abdominis and internal oblique (trunk flexion)	–
L2	Upper thigh	Psoas (hip flexion)	–
L3	Anterior to medial thigh	Quadriceps (leg extension)	Patellar tendon
L4	Lower anterior thigh and medial leg	Quadriceps and tibialis anterior (ankle dorsiflexion)	Patellar tendon
L5	Posterolateral thigh and lateral leg, plantar foot, first web space	Extensor hallucis longus	Medial hamstrings (rarely used)
S1	Lateral foot, lateral posterior thigh and leg	Gastrocnemius (ankle plantarflexion)	Achilles' tendon
S2–S4	Medial posterior thigh and leg, and perianal region	External and sphincter	Anal wink reflex and bulbocavernosus reflex

- – 3+: slightly hyperreflexic.
- – 2+: normal reflex.
- – 1+: weak normal.
- – 0: no contraction/reflex.
- • Hyperreflexia, spasticity, and clonus indicative of upper motor neuron pathology causing poor lower motor neuron inhibition:
  - – Hyperreflexia defined as increased brisk reflex with contraction of muscles not directly being assessed:
    - ◦ Example: contraction of thigh adductors during patellar tendon reflex.
  - – Clonus is involuntary rhythmic muscular contractions and relaxation, often accompanied with spasticity.

8.6 Special Maneuvers (Tables 8.3 and 8.4)

Table 8.3 Cervical tests

	How to perform	Indicates	Pathologic response
Spurling's maneuver	Rotate and laterally flex head to one side and then provide an axial load	Compression of a cervical nerve root of the ipsilateral side	Reproduction of a patient's radicular pain
L'hermitte's phenomenon	Flex neck toward chin	Compression of the cervical spinal cord	Electrical sensation radiating into back and extremities
Grip and release test	Have patient rapidly make a fist and release with both hands	Cervical myelopathy	Patient unable to perform at least 20 cycles of grip/release within 10 s
Hoffman's sign	Snapping/flicking patient's distal phalanx of middle finger	Cervical myelopathy (can be normal in young athletes or naturally hyperreflexive patients)	Flexion of distal phalanx of thumb and possibly other digits during maneuver
Finger escape sign	Ask patients to fully extend their fingers and maintain this position	Cervical myelopathy	Fourth and fifth digits begin to flex and abduct

Table 8.4 Lumbar tests

	How to perform	Indicates	Pathologic response
Straight leg raised (SLR) test	With patient supine, flex hip and dorsiflex ankle of the side with radicular pain	Compression of lumbar nerve root	Reproduction of patient's radicular pain at >60 degrees of hip flexion
Contralateral SLR	Flex the hip and ankle contralateral to the side of the patient's radiculopathy	Sequestered or large extruded disc herniation	Reproduction of the patient's radicular pain
Flip sign (sitting root test)	While patient is seated, distract patient and passively extend knee (assist in putting shoes back on)	True-positive SLR	Pain recreated with knee extension (patient will jerk backward)
Romberg's sign	Have the patient stand up with their feet together and eyes closed for 10 s	Posterior column injury	Patient is unable to maintain balance
Babinski's sign	Stroke the plantar surface of the patient's foot with a solid mildly sharp object	Upper motor neuron injury or myelopathy (cervical or lumbar)	Upgoing big toe/toes (physiological in infants)
Ankle clonus	Rapidly dorsiflex and plantarflex ankle	Upper motor neuron injury or myelopathy	Repetitive beats of clonus
Anal wink reflex	Stroke skin around anus to elicit contraction of external anal sphincter	Injury to sacral nerve roots	Absent anal sphincter contraction
Bulbocavernosus reflex	Squeeze patient's glans penis or clitoris or tug on indwelling Foley catheter, monitoring for anal external sphincter contraction	Injury to conus medullaris or sacral nerve roots S2–S4	Absent sphincter contraction
Waddell's sign	Thorough history and physical exam	Nonorganic pathology	Four findings: (1) exaggerated responses, (2) pain to light touch, (3) pain in a nonanatomic pattern, and (4) negative sitting root test with positive SLR

Suggested Readings

1. Greenberg MS. Handbook of Neurosurgery. 7th ed. New York, NY: Thieme; 2010
2. Netter FH. Atlas of Human Anatomy. 6th ed. Philadelphia, PA: Saunders; 2014
3. An HS, Singh K. Synopsis of Spine Surgery. 3rd ed. New York, NY: Thieme; 2016

9 Common Radiographic Measurements

Dustin H. Massel, Benjamin C. Mayo, William W. Long, Krishna D. Modi, and Kern Singh

9.1 Radiographic Measurements

9.1.1 Cervical Measurements (Fig 9.1, Table 9.1)

Cervical Lordosis

• Measured via a lateral radiograph.
• May be referred to as a C2–C7 Cobb angle.
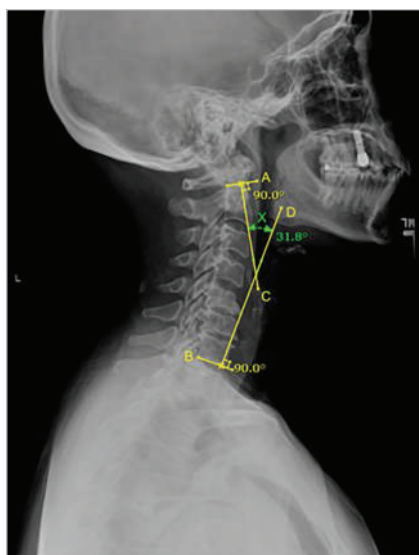
Fig. 9.1. Normal cervical lordosis. Line A: drawn in an anteroposterior (AP) direction at the superior end plate of C2. Line B: drawn in an AP direction at the inferior endplate of C7. Line C: drawn in an inferior direction, perpendicular to line A. Line D: drawn in a superior direction, perpendicular to line B. Angle X, measured between lines C and D, represents cervical lordosis.

Table 9.1 Normal cervical spine curvature measurements (**Fig. 9.1**)

Spine region	Curvature	Measurements
Cervical	Hypolordosis	< 20 degrees
	Lordosis	20–40 degrees
	Hyperlordosis	> 40 degrees

9.1.2 Thoracic Measurements (Fig 9.2, Table 9.2)

Thoracic Kyphosis

• Measured via a lateral radiograph.

9.1.3 Lumbar Measurements (Fig 9.3, Table 9.3)

Lumbar Lordosis

• Measured via a lateral radiograph.
• May be referred to as a L1–L5 Cobb angle.

9.1.4 Cobb Angle (Fig 9.4)

• Quantifies magnitude of spinal deformities (e.g., scoliosis).
  – Cobb angle ≥ 10 degrees = scoliosis.

For more information on scoliosis, see Chapter 12.

Fig. 9.2 Thoracic kyphosis. **(a)** Normal thoracic kyphosis. **(b)** Thoracic hyperkyphosis. Line A: drawn in an anteroposterior (AP) direction at the superior endplate of T4. Line B: drawn in an AP direction at the inferior end plate of T12. Line C: drawn in an inferior direction, perpendicular to line A. Line D: drawn in a superior direction, perpendicular to line B. Angle X, measured between lines C and D, represents thoracic kyphosis.

Table 9.2 Normal thoracic spine curvature measurements (**Fig. 9.2**)

Spine region	Curvature	Measurements
Thoracic	Hypokyphosis	< 20 degrees
	Kyphosis (**Fig. 9.2a**)	20–45 degrees (average 35 degrees)
	Hyperkyphosis (**Fig. 9.2b**)	> 45 degrees
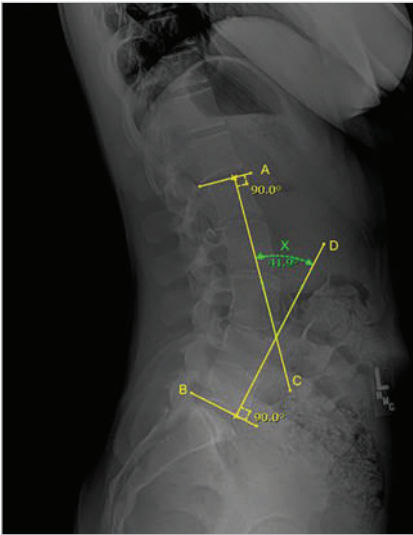
Fig. 9.3 Normal lumbar lordosis. Line A: drawn in an anteroposterior (AP) direction at the superior endplate of L1. Line B: drawn in an AP direction at the inferior end plate of L5. Line C: drawn in an inferior direction, perpendicular to line A. Line D: drawn in a superior direction, perpendicular to line B. Angle X, measured between lines C and D, represents lumbar lordosis.

Table 9.3 Normal lumbar spine curvature measurements (**Fig. 9.3**)

Spine region	Curvature	Measurements
Lumbar	Hypolordosis	< 40 degrees
	Lordosis	40–60 degrees
	Hyperlordosis	> 60 degrees

9.1.5 Coronal Balance (Fig 9.5, Table 9.4)

- Radiograph read as if patient standing with back to you (R on R, L on L).
- **C7 plumb line (C7PL) =** used as a reference to measure displacement of the vertebral bodies from each other and from midline (based on distance from the **central sacral vertical line [CSVL]**).
- **Coronal compensation =** C7 vertebral body directly above the S1 vertebral body (despite abnormal spinal curvature).
- Coronal decompensation = C7 vertebral body laterally displaced from above the S1 vertebral body.

9.1.6 Sagittal Vertical Axis (Fig 9.6, Table 9.5)

- Measured via a lateral radiograph.
- Used for cervical sagittal vertical axis (CSVA) or global spine (SVA) measurements.
- **C2 plumb line (C2PL) =** used as a reference to measure displacement of the cervical vertebral bodies from each other and from midline in a sagittal plane:
  - Primary measure of cervical sagittal alignment.
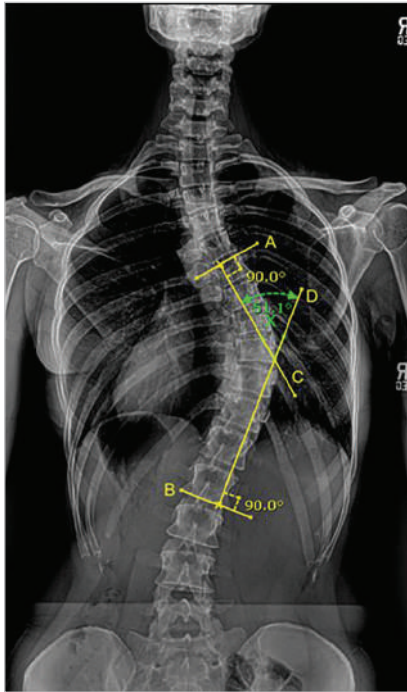
Fig. 9.4 Cobb's angle. Define upper and lower vertebral levels associated with curvature/deformity. Line A: drawn in an anteroposterior (AP) direction at the superior end plate of the upper vertebral level associated with curvature/deformity. Line B: drawn in an AP direction at the inferior end plate of the lower vertebral level associated with curvature/deformity. Line C: drawn in an inferior direction, perpendicular to line A. Line D: drawn in a superior direction, perpendicular to line B. Angle X, measured between lines C and D, represents Cobb's angle.
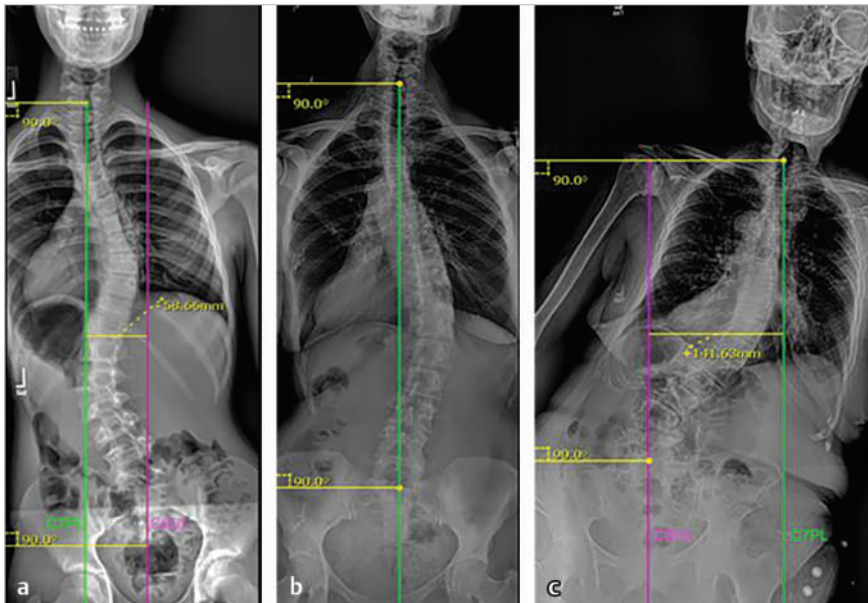
Fig. 9.5 Coronal balance. **(a)** Negative coronal balance. **(b)** Neutral coronal balance. **(c)** Positive coronal balance. C7 plumb line (C7PL): vertical line drawn from the center of the C7 vertebral body. Central sacral vertical line (CSVL): vertical line drawn from the center of the S1 vertebral body.

Table 9.4 Coronal balance (**Fig. 9.5**)

Figure	Compensation	Coronal balance	Equation
Fig. 9.5a	Decompensated	Negative	C7PL – CSVL= – X cm (sacrum to the right of the C7PL)
Fig. 9.5b	Compensated	Neutral	C7PL – CSVL = 0 cm
Fig. 9.5c	Decompensated	Positive	C7PL – CSVL = +X cm (sacrum to the left of the C7PL)

Abbreviations: C7PL, C7 plumb line; CSVL, central sacral vertical line.
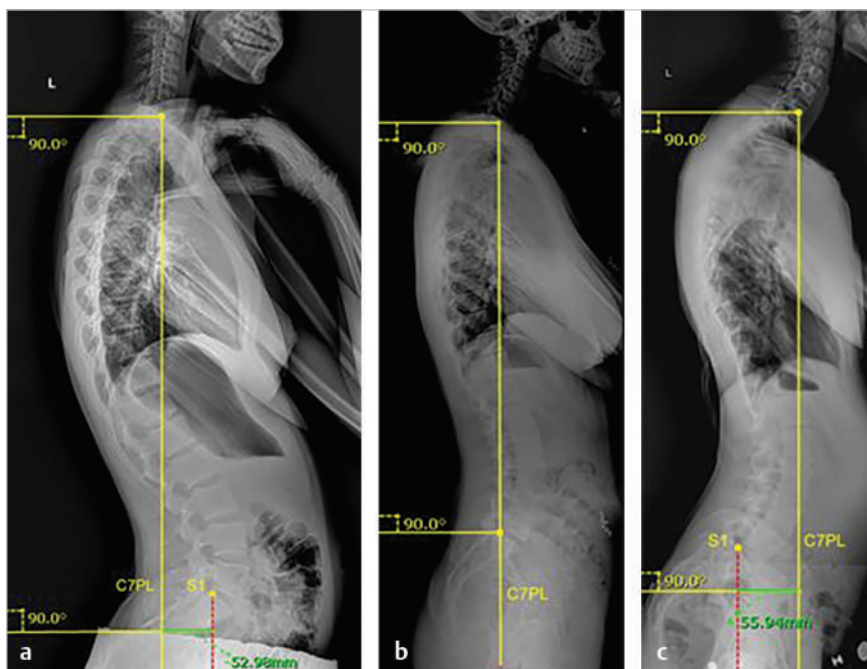
Fig. 9.6 Global sagittal vertical axis (SVA). **(a)** Negative sagittal vertical axis. **(b)** Normal sagittal vertical axis. **(c)** Positive sagittal vertical axis. C7 plumb line (C7PL): vertical line drawn from the center of the C7 vertebral body. Measure distance from the posterosuperior aspect of S1.

Table 9.5 Sagittal vertebral axis (**Fig. 9.6**)

Figure	Spine region	Sagittal balance	Course
–	Cervical	Negative	C2PL posterior to the PS aspect of C7
–	Cervical	Normal	C2PL runs through the PS aspect of C7
–	Cervical	Positive	C2PL anterior to the PS aspect of C7 (> 40 mm)
Fig. 9.6a	Global	Negative	C7PL posterior to the PS aspect of S1
Fig. 9.6b	Global	Normal	C7PL runs through the PS aspect of S1
Fig. 9.6c	Global	Positive	C7PL anterior to the PS aspect of S1 (> 50 mm)

Abbreviations: C2PL, C2 plumb line; C7PL, C7 plumb line; PS, posterosuperior.

- **C7 plumb line (C7PL)** = used as a reference to measure displacement of the thoracic and lumbar vertebral bodies from each other and from midline in a sagittal plane (in contrast to the C7PL for coronal balance).

9.1.7 Pelvic Parameters (Fig. 9.7, Table 9.6)

- Assessed using standing 36-inch lateral radiograph.

Pelvic rotation	Sacral slope	Pelvic tilt
Anteversion	High	Low
Retroversion	Low	High
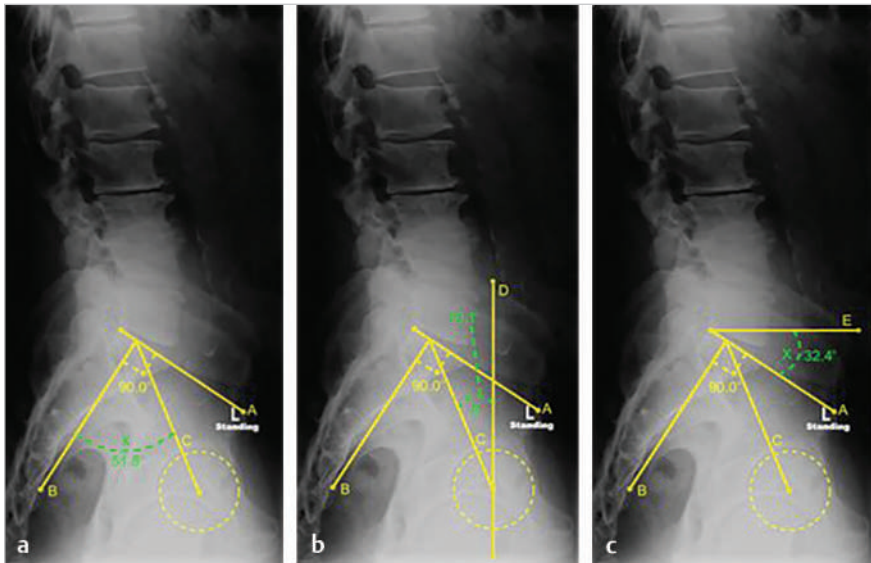
Fig. 9.7 Pelvic parameters. **(a)** Pelvic incidence (PI). Line A: drawn in an anteroposterior (AP) direction through the sacral end plate. Line B: drawn inferiorly, perpendicular to line A from the midpoint of the sacral plate. Line C: drawn from the midpoint of the sacral plate to the center of the femoral head. Angle X: measures the angle between lines B and C. **(b)** Pelvic tilt (PT). Line A: drawn in an AP direction through the sacral end plate. Line C: drawn from the midpoint of the sacral plate to the center of the femoral head. Line D: vertical line drawn from the center of the femoral head. Angel X: measures the angle between lines C and D. **(c)** Sacral slope (SS). Line A: drawn in an AP direction through the sacral end plate. Line E: horizontal line drawn from the posterosuperior aspect of the sacral plate. Angle X: measures the angle between lines A and E.

Table 9.6 Pelvic parameters (**Fig. 9.7**)

Figure	Parameter	Equation	Normal measurement
Fig. 9.7a	Pelvic incidence (PI)	PI = PT + SS	40–65 degrees; average = 51 degrees
Fig. 9.7b	Pelvic tilt (PT)	PT = PI – SS	10–25 degrees; average = 12 degrees
Fig. 9.7c	Sacral slope (SS)	SS = PI-PT	30–50 degrees; average = 39 degrees
Note: PT and SS are inversely correlated.			

9.2 Radiographic Findings

9.2.1 Ankylosing Spondylitis (Fig. 9.8)

• Chronic inflammatory disease of the spine that causes the vertebral bodies to fuse together. Classically causes "bamboo spine."

9.2.2 Arthrodesis (Fig. 9.9)

• Fusion of two or more vertebral bodies.
• CT scan arthrodesis is gold standard:

Fig. 9.8 Anteroposterior (AP) X-ray demonstrating the classic "bamboo spine" appearance of ankylosing spondylitis.
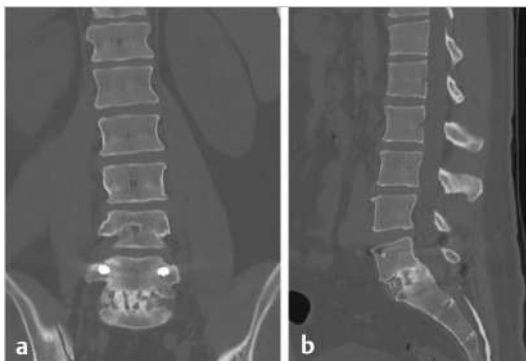
Fig. 9.9 CT scan arthrodesis. **(a)** Coronal CT demonstrating bony bridging at L5–S1. **(b)** Sagittal CT demonstrating bony bridging at L5–S1.

- Defined by the presence of bony bridging on three sequential cuts in the sagittal and coronal planes.
- The presence of subchondral cysts, end plate sclerosis, or haloing around the interbody cage(s) or pedicle screws are evaluated for possible pseudarthrosis.

9.2.3 Pseudarthrosis (Fig. 9.10)

• Nonunion or failed spinal fusion due to inadequate bone formation/bony healing following surgery.

9.2.4 Cauda Equina Syndrome

• Severe compression of spinal nerve roots at the end of the spinal cord requiring urgent treatment.

9.2.5 Intervertebral Disk Herniation/Herniated Nucleus Pulposus (Fig. 9.11)

• Condition in which the nucleus pulposus is forced through a weakened annulus fibrosus.
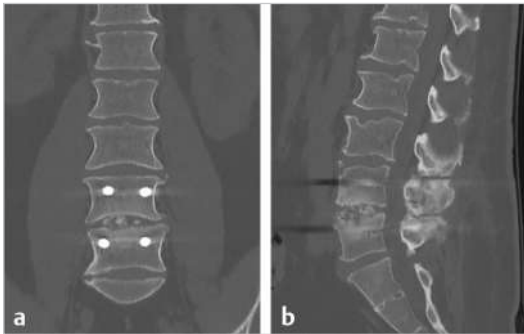
Fig. 9.10 Pseudarthrosis. **(a)** Coronal CT demonstrating absence of bony bridging at L4–L5. **(b)** Sagittal CT demonstrating absence of bony bridging at L4–L5.
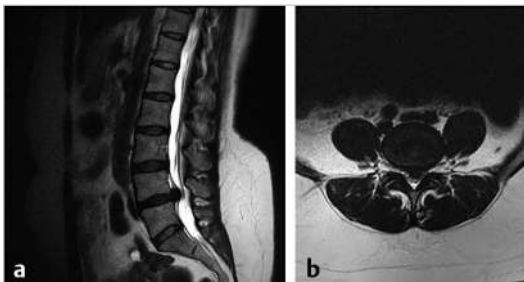
Fig. 9.11 Intervertebral disk herniation/herniated nucleus pulposus (HNP). **(a)** Sagittal T2-weighted MRI demonstrating HNP at L4–L5. **(b)** Axial T2-weighted MRI demonstrating HNP at L4–L5.

9.2.6 Neoplasms of the Spinal Cord

• Tumors located within the spinal cord (extradural and/or intradural).

For more information, see chapter X, page XX.

9.2.7 Osteoporosis (Fig. 9.12)

• Condition of reduced bone mass and weakened microarchitecture increasing susceptibility to fracture.

9.2.8 Scheuermann's Disease

• Abnormally kyphotic thoracic vertebral alignment.
• Sorenson's classification:
  – Thoracic kyphosis greater than 40 degrees *or* thoracolumbar kyphosis greater than 30 degrees (normal 0 degrees).
  – *And* ≥3 adjacent vertebrae with wedging of greater than 5 degrees.

9.2.9 Spinal Stenosis (Fig. 9.13)

• Abnormal narrowing of the spinal canal resulting in compression of the spinal cord (central stenosis) or exiting nerve roots (lateral stenosis).
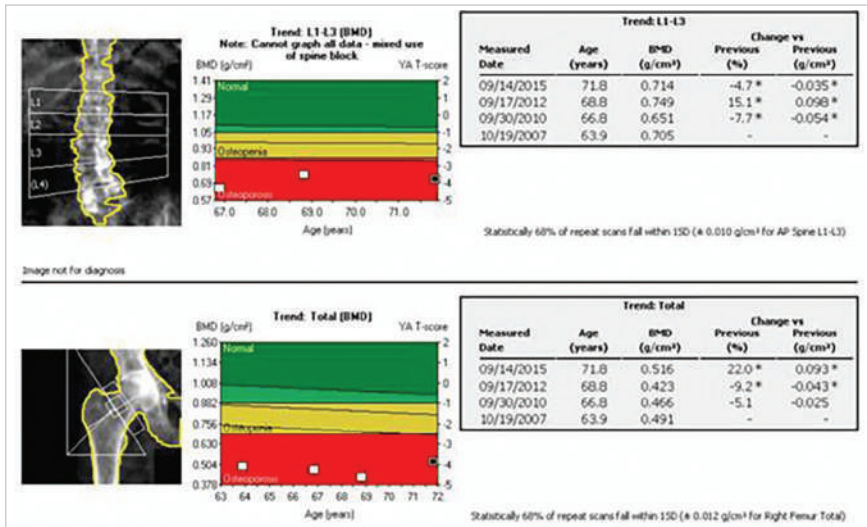
Fig. 9.12 Dual energy X-ray absorptiometry (DEXA) scan image of an osteoporotic lumbar spine and right hip. The study includes the L1–L4 vertebral bodies.

Fig. 9.13 Sagittal T2-weighted MRI demonstrating significant spinal stenosis as the result of HNP at L2–L3, L3–L4, L4–L5, and L5–S1.
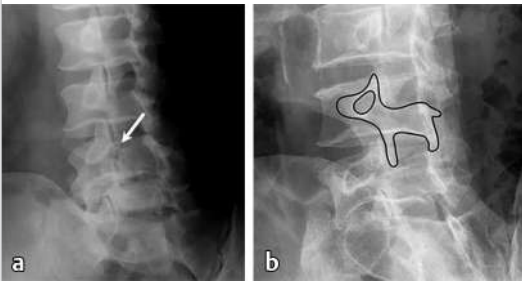
Fig. 9.14 Spondylolysis. **(a)** "Scotty dog with a collar" on oblique X-ray. **(b)** Outline of the "Scotty dog" on oblique X-ray. The transverse process represents the dog's nose. The pedicle represents the dog's eye. The inferior articular process represents the dog's front leg. The superior articular process represents the dog's ear. The pars interarticularis represents the dog's neck. The contralateral inferior articular process represents the dog's hind leg.

9.2.10 Spondylolysis (Fig. 9.14)

• Defect in the pars interarticularis:
  – Associated with isthmic spondylolisthesis.

9.2.11 Spondylolisthesis (Fig. 9.15, Table 9.7)

• Anterolisthesis = anterior displacement of vertebral body.
• Retrolisthesis = posterior displacement of vertebral body.
• Classification systems:
  – Wiltse = based on etiology.
  – Meyerding = based on percent slip (most widely used; **Table 9.8**).
  – Marchetti–Bartolozzi = based on etiology (**Table 9.9**).
• Slip angle = quantifies the degree of lumbosacral kyphosis:
  – Slip angle greater than 50 degrees correlates with an increased risk of progression of spondylolisthesis.

Fig. 9.15 Measuring spondylolisthesis percent slip. Line A: drawn from the posterosuperior aspect of the nondisplaced vertebrae to the anterosuperior aspect of the nondisplaced vertebrae. Line B: drawn from the posterosuperior aspect of the nondisplaced vertebrae to the posterior edge of the anterolisthetically displaced vertebrae. Divide line B/line A × 100 to determine % slip.

Table 9.7 Wiltse's classification

Type I	Dysplastic (congenital)
Type II	Isthmic (acquired)
IIA	Lytic
IIB	Elongated but intact pars fracture
IIC	Acute fracture
Type III	Degenerative
Type IV	Posttraumatic
Type V	Pathologic
Type VI	Iatrogenic/postsurgical

Table 9.8 Meyerding's classification

Designation	Grade	Percent slip
Low grade	I	< 25
	II	25–49
	III	50–74
High grade	IV	75–99
	V	Spondyloptosis > 100

Table 9.9 Marchetti–Bartolozzi classification

Developmental	High dysplastic	With lysis
		With elongation
	Low dysplastic	With lysis
		With elongation
Acquired	Traumatic	Acute fracture
		Stress fracture
	Postsurgical	Direct surgery
		Indirect surgery
	Pathologic	Local pathology
		Systemic pathology
	Degenerative	Primary
		Secondary

9.2.12 Sacral Inclination (Fig. 9.16)

Fig. 9.16 Measuring sacral inclination. Line A: drawn parallel to posterior aspect of sacrum. Line B: vertical line drawn intersecting line A. Angle X: measure the angle between the posterior aspect of line A and the superior aspect of line B. Normal sacral inclination = 40 to 50 degrees.

10 Cervical Disk Disease

Fady Y. Hijji, Ankur S. Narain, Philip K. Louie, Daniel D. Bohl, and Kern Singh

10.1 Background

- Disk disease is often described as a result of two pathologies:
  - Disk herniation characterized by herniated nucleus pulposus (HNP).
  - Degenerative disk disease (DDD).
- These conditions are common and commonly asymptomatic:
  - 10% of asymptomatic individuals younger than 40 years have HNP on magnetic resonance imaging (MRI).
  - 25% of asymptomatic individuals younger than 40 years have DDD on MRI.
- The progression of a pathologic intervertebral disk may result in compression of adjacent neural structures including the spinal cord and neural roots.

10.2 Etiology and Pathophysiology

- HNP:
  - Secondary to stress on annulus of disk:
    - Most often posterolateral as the supportive posterior longitudinal ligament (PLL) is weakest here.
  - Increased risk for herniation from aging and disk degeneration:
    - Decreased water content and proteoglycan content of nucleus pulposus.
  - Characteristics of herniation:
    - Protrusion:
      - Base (neck) wider than head of herniation.
      - Herniation of nuclear pulposus penetrates through annular fibers but remains within the annular margin.
    - Extrusion:
      - Base narrower than head of herniation.
      - Herniation tears through annular margin.
      - Can displace (migrate) cranially or caudally.
    - Sequestration:
      - Free disk fragment separated from original herniation.
- DDD (spondylosis):
  - Aging of disk results in biochemical component changes (**Fig. 10.1**):
    - Decreased cross-linking of collagen, decreased water content.
    - Decreased blood supply to outer annulus:
      - Lactate increases with resultant acidic changes, further degenerating disk.
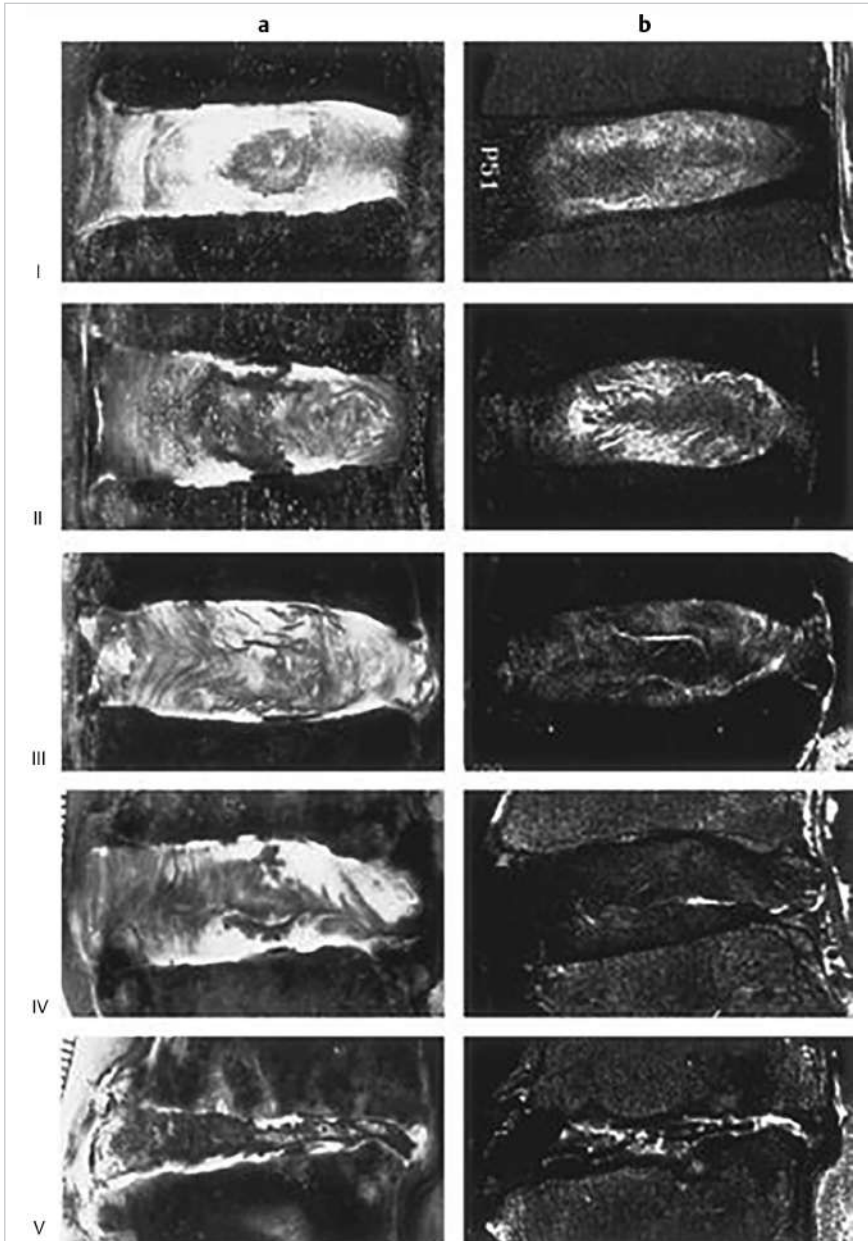
Fig. 10.1 Thompson disk degeneration staging (I–V). **(a)** Cadaveric examples of disk degeneration with associated **(b)** magnetic resonance imaging for each stage. Note grade I exemplifies characteristics of a healthy disk with appropriate disk height and high water content. Grade V illustrated by significant disk height loss, loss of water content, and bony sclerosis and osteophytes.

- – Decreased strength from degenerative changes leads to chronic tears throughout annulus.
- – Degenerative cycle includes the following:
  - ○ Disk degeneration (disk bulging, decreased disk space).
  - ○ Joint degeneration (facet arthrosis and uncinate spurring).
  - ○ Ligamentous alterations (ligamentum flavum thickening due to loss of disk height).
  - ○ Spinal deformity (kyphosis, following the loss of disk height and transfer of load to the uncovertebral and facet joints).

10.3 Symptoms and Clinical findings (Table 10.1)

- • Both DDD and HNP result in tearing of disks with eventual impingement of nearby neural elements including spinal cord.
- • Axial neck pain:
  - – Unclear etiology.
  - – Peripheral disk contains nociceptors and PLL:
    - ○ Annular tears and herniation potentially activates these receptors.
- • Radiculopathy:

Table 10.1 Classification of symptoms resulting from cervical disk disease

	Etiology	Symptoms	Physical examination
Axial pain	Inflammation and tears around intervertebral disk	• Central neck pain • With or without referred pain	• Noncontributory • Possible tenderness around paraspinal muscles
Radiculopathy	Compression and inflammation of nerve root in the spinal canal or neural foramen	• Radiating pain in dermatomal distribution ± axial neck pain • Numbness/tingling in the in upper extremities • Subjective upper extremity weakness	• ±Spurling's maneuver • ±Shoulder abduction relief • ±Decreased sensation in dermatomal pattern • ±Motor deficit associated with affected nerve root • ±Hyporeflexia
Myelopathy	Compression and inflammation of spinal cord within spinal canal	• ±Pain (dull ache to sharp pain) • Difficulty performing fine motor tasks (buttoning a shirt, writing, gripping) • Difficulty walking	• Upper extremity weakness • Glove-distribution sensory loss • Wide-based ataxic gait • Hyperreflexia • ±Hoffman's sign • ±Lhermitte's sign • ±Babinski's sign • Myelopathic hand syndrome (thenar atrophy, decreased dexterity of hands, +grip release test)

Fig. 10.2 T1 MRI sagittal and axial views of cervical spine. Note the decreased disk height, disk migration into the cervical canal with canal narrowing, and signal changes within the cord.

- Radiating pain in a pattern consistent with the nerve root involved:
  - With or without neurologic symptoms (lower motor neuron symptoms).
- Occurs from direct impingement of nerve roots exiting the spinal cord and vertebral column (**Fig. 10.2**):
  - Lateral HNP or osteophytes can compress exiting nerve root near neural foramen:
    - Known as neuroforaminal stenosis.
  - Cervical nerve root travels above the similar-named pedicle (i.e., the C5 nerve root travels above the C5 pedicle).
  - DDD osteophytes or narrowing of neural foramen, compressing nerve root.
- Inflammation from tears results in chemical radiculitis, furthering radicular symptoms.
• Myelopathy:
- Upper motor neuron symptoms:
  - Patients may present with classic findings:
    - Gait instability.
    - Weakness and clumsiness in manual dexterity.
    - Axial neck pain and stiffness.
    - Diffuse numbness/tingling not isolated to single dermatome.
- Occurs from central compression of spinal cord:
  - Herniation or osteophytic spurs causing narrowing of cervical spinal cord canal (**Fig. 10.2**):
    - Known as central stenosis.
    - Torg–Pavlov ratio: ratio of width of cervical canal to cervical body diameter:
      - ❖ <0.8 = central stenosis.
      - ❖ Normal is 1.0.
- Microtrauma from neck flexion/extension along with vascular injury furthers injury to spinal cord.

10.4 Imaging

• Plain radiography (anteroposterior [AP], lateral, and flexion and extension views):
  – Initial imaging choice due to cost, ease of access, and ability to evaluate for overall gross pathology.
  – Radiographic findings include the following:
    ◦ Narrowing of intervertebral disk space.
    ◦ Neuroforaminal narrowing.
    ◦ Degenerative changes (osteophytes at end plates or zygapophyseal joints).
  – Visualize alignment on AP and lateral views.
  – Visualize instability/subluxation on flexion and extension views.
• MRI:
  – Imaging of choice for disk disease.
  – Visualize soft-tissue and neurologic structures.
  – Measure space of cervical canal.
  – Can be difficult to distinguish disk from bone.
  – **Correlate with clinical symptoms:**
    ◦ Many asymptomatic patients exhibit degenerative changes.
• Computed tomography (CT):
  – Good for evaluating osseous details, poor for soft-tissue visualization.
  – Requires myelogram to appropriately assess neural pathology:
    ◦ Used when MRI is contraindicated (metal implants, pacemaker) or when time is limited.

10.5 Treatment

• Conservative therapy:
  – 70-80% of patients with radiculopathy will improve with conservative therapy.
  – Immediate conservative treatment (initial 2 weeks):
    ◦ Nonsteroidal anti-inflammatory medications.
    ◦ Short-term analgesics.
    ◦ Activity modification.
  – Intermediate treatment (3–4 weeks):
    ◦ Physical therapy.
    ◦ Epidural steroids for persistent radicular pain.
  – Rehabilitation (>4 weeks):
    ◦ Physical conditioning.
• Operative therapy:
  – Indications:
    ◦ Continuing or worsening symptoms consistent with nerve root or cord injury.
    ◦ Failure of conservative therapy (typically 3–4 months).
    ◦ Surgery typically avoided for isolated axial neck pain.

- Anterior surgical interventions:
  - Indications:
    - Central disk herniations.
    - Foraminal stenosis.
    - Anterior osteophytes.
    - Spondylotic myelopathy.
- Posterior surgical interventions:
  - Indications:
    - Disk herniation causing radiculopathy.
    - Ossification of the PLL.

Suggested Readings

1. Miyazaki M, Hong SW, Yoon SH, Morishita Y, Wang JC. Reliability of a magnetic resonance imaging-based grading system for cervical intervertebral disk degeneration. J Spinal Disord Tech 2008;21(4):288–292
2. Carette S, Fehlings MG. Clinical practice. Cervical radiculopathy. N Engl J Med 2005;353(4):392–399
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11 Lumbar Disk Disease

Fady Y. Hijji, Ankur S. Narain, Philip K. Louie, Daniel D. Bohl, and Kern Singh

11.1 Background

- Axial back pain extremely common:
  - Most common cause is muscle strain, followed by degenerative disease of spine.
- Natural aging and genetic predisposition lead to lumbar disk degeneration:
  - Decreased water content and blood supply to annulus of disk:
    ○ Results in acidic changes and degeneration of intervertebral disk.
    ○ After birth, the nucleus pulposus decreases in size and cellularity in proportion to the intervertebral disk.
- Lumbar disk degeneration can result in a mixture of pathologies:
  - Disk herniation characterized by herniated nucleus pulposus (HNP).
  - Spondylosis characterized by degeneration of intervertebral disk and osteophyte formation.
  - Spondylolisthesis characterized by slippage of vertebral body.
- Mean age of onset is 35 years:
  - Over 50% of individuals over 60 years of age exhibit degenerative changes on imaging.

11.2 Lumbar Disk Herniation

- Background and etiology
  - 90% of herniated disks occur at L4/L5:
    ○ Increased risk for herniation from aging and disk degeneration.
  - Chronic or significant acute stress on annulus of intervertebral disk:
    ○ Leads to annular tears and HNP.
    ○ Results in direct compression of neural elements.
- Characteristics of herniation *(see Chapter 11: Cervical Disk Disease)*.
  - Protrusion:
    ○ Herniation remains within annular margin.
  - Extrusion:
    ○ Herniation tears through annular margin but contained by posterior longitudinal ligament:
      ▪ Extends into spinal canal.
      ▪ Can displace cranially or caudally.
  - Sequestration:
    ○ Separation of herniated disk fragment from intervertebral disk.
- Symptoms and clinical findings:
  - Axial back pain:
    ○ Controversial etiology.

- Nociceptors along annulus and posterior longitudinal ligament thought to contribute to axial pain with annular tears.
  - Recurrent torsional strain may also lead to outer annulus tears.
  - Worse pain with lumbar flexion in the absence of lumbar spinal stenosis.
- Radiculopathy:
  - Radiating pain in distribution of affected nerve root dermatome:
    - Can be associated with sensory or motor deficits of compressed nerve root.
    - Decreased reflexes of involved nerve root.
  - Herniation impinging of exiting nerve roots:
    - In neuroforamen (neuroforaminal stenosis):
      - ❖ Far-lateral herniation.
      - ❖ Affects exiting nerve root.
      - ❖ Nerve roots exit below pedicle (L4 exits at L4–L5 disk).
  - Herniation of traversing nerve roots (**Fig 11.1**):
    - In spinal canal (spinal stenosis):
    - Paracentral/posterolateral herniation.
    - Affects nerve root traversing to exit at next disk level (L4–L5 paracentral herniation affects L5):
      - ❖ Improvement of leg pain with bending forward due to increased space within spinal canal:
        - ◇ Known as neurogenic claudication due to the intermittent symptomology.
        - ◇ Distinguish from vascular claudication: pain is not relieved by standing still.
- Cauda equina and conus syndromes (**Table 11.1**):
  - Orthopaedic emergencies.
  - Herniation compressing multiple lumbar and sacral nerve roots within the thecal sac or the conus medullaris (T12–L1):
    - Large central herniation.
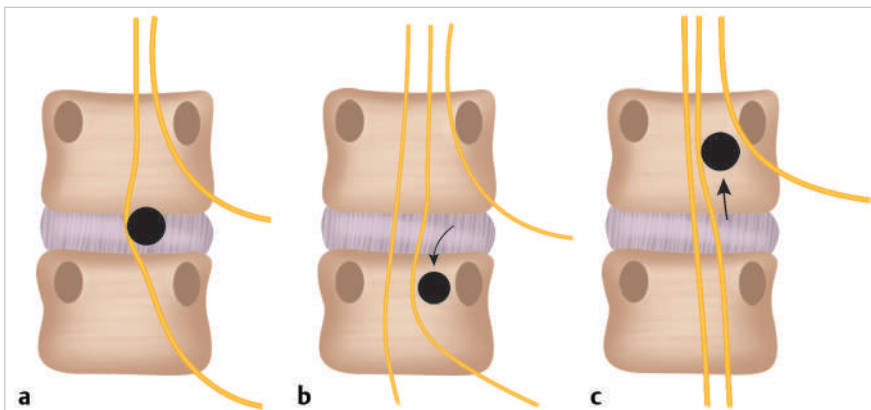
Fig. 11.1 (a) Left paracentral L5–S1 disk herniation affecting traversing S1 nerve root. **(b)** Extruded disk L5–S1 herniation migrating inferiorly, compressing the S1 nerve root. **(c)** Sequestered disk herniation migrating superiorly, impinging both L5 and S1 nerve roots.

Table 11.1 Conus medullaris versus cauda equina syndromes

	Conus medullaris syndrome	Cauda equina syndrome
Vertebral level	L1–L2	L2 sacrum
Spinal level	Sacral cord segment and roots	Lumbosacral nerve roots
Presentation	Sudden and bilateral	Gradual and unilateral
Radicular pain	Less severe	More severe
Low back pain	More	Less
Motor strength	Symmetrical, **less marked** hyperreflexic distal paresis of LL fasciculation	More marked asymmetric areflexic paraplegia, atrophy more common
Reflexes	Ankle jerks affected	Both knee and ankle jerks affected
Sensory	Localized numbness to perianal area, symmetrical, and bilateral	Localized numbness at saddle area, asymmetrical, and unilateral
Sphincter dysfunction	Early urinary and fecal incontinence	Tend to present late
Impotence	Frequent	Less frequent

- Imaging:
  - X-ray:
    - Initial evaluation for bony deformities.
    - Often first line for evaluating general degenerative lumbar pathology:
      - Assess for disk space narrowing.
      - Unable to determine disk pathology from plain radiographs.
    - AP and lateral for examining alignment.
    - Flexion/extension for examining instability.
  - MRI:
    - Modality of choice for assessing nerve root or spinal cord compression along with disk and ligamentous pathology:
      - Loss of T2 signal within disk nucleus (**Fig. 11.2**).
    - Modic's changes:
      - Describes vertebral degeneration seen on MRI:
        - ❖ Associated changes on T1- and T2-weighted MRIs with progressive degeneration (**Table 11.2**).
  - Computed tomography (CT) scan:
    - Limited use:
      - If MRI contraindicated.
- Treatment:
  - Conservative therapy:
    - Majority of patients will improve with nonoperative management.
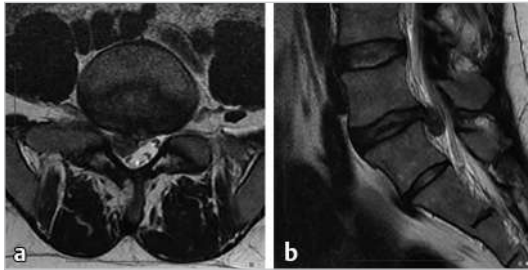
Fig. 11.2 Axial **(a)** and sagittal **(b)** lumbar T2 magnetic resonance imaging (MRI). Posterolateral disk extrusion of the L5–S1 disk. Note the significant narrowing of the spinal canal and the loss of signal of the posterior disk.

Table 11.2 Magnetic resonance imaging (MRI) Modic's classification

Type	Observation	T1-weighted	T2-weighted	Significance
IU	Normal disk height without dehydration	Hypointensity	Hyperintensity	Bone marrow edema and inflammation
II	Normal disk height with dehydration	Hyperintensity	Hyperintensity	Bone marrow ischemia
III	Decreased disk height	Hypointensity	Hyperintensity	Subchondral sclerosis

- ○ Decreasing mechanical stress, maintaining ideal body weight, and smoking cessation all associated with improved outcomes.
- ○ Nonoperative treatment includes rest, physical therapy (PT), anti-inflammatory medication (NSAIDs), muscle relaxants, and oral steroids. 90% of patients improve nonoperatively:
  - ▪ Corticosteroid injections are a second line therapy.
- – Operative management:
  - ○ Indications:
    - ▪ Failure of conservative therapy for at least 12 weeks.
    - ▪ Worsening or new onset of neurological deficits.
    - ▪ Removal of herniation (microdiskectomy), disk replacement (arthroplasty), or lumbar fusion.

11.3 Spondylosis

- • Background and etiology:
  - – Degeneration of intervertebral disk and articular facets:
    - ○ Broad term to describe osteoarthritic degeneration of the spine:
      - ▪ Result of biochemical degenerative changes and chronic stress and pressure.
      - ▪ Similar to degenerative process of cervical spine.
  - – Osteophytes may form, which may compress neural elements:
    - ○ Osteophytes commonly involve vertebral end plates and articular facets.
- • Symptoms and clinical findings:
  - – Axial back pain:

- ○ Facet arthropathy thought to be likely cause of pain.
- ○ Worse pain with lumbar extension.
- – Radiculopathy:
  - ○ Osteophytic compression of nerve roots:
    - ▪ In neuroforamen (neuroforaminal stenosis; **Fig. 11.3**):
      - ❖ Facet hypertrophy compressing exiting nerve roots.
    - ▪ In spinal canal (spinal stenosis):
      - ❖ Posterior end plate osteophytes narrowing spinal canal.
- – Cauda equina and conus syndromes:
  - ○ Osteophytic changes resulting in compression of lumbar and sacral nerve roots similar to lumbar herniations.
- • Imaging:
  - – X-ray:
    - ○ Initial imaging choice to evaluate for overall gross pathology and degenerative changes.
    - ○ Radiographic findings include the following (**Fig. 11.4**):
      - ▪ Narrowing of intervertebral disk space.
      - ▪ Neuroforaminal narrowing.
      - ▪ End plate osteophytes.
      - ▪ Facet hypertrophy.
    - ○ Radiographic classification (**Table 11.2**).
  - – MRI:
    - ○ Identify compression of neural structures:
      - ▪ Bony margins better evaluated on CT.
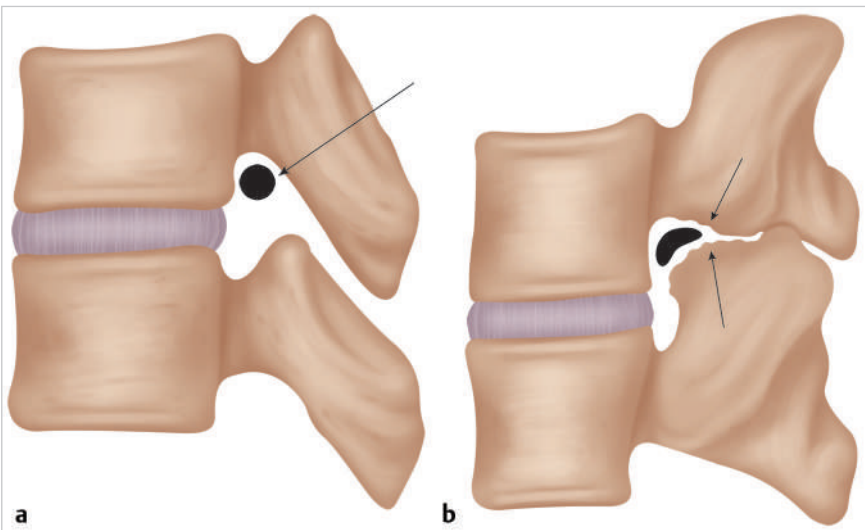
Fig. 11.3 (a) Location of nerve root within the neural foramen. **(b)** Compression of the nerve root due to spondylosis and osteophytes on the superior articular process.

Fig. 11.4 Anteroposterior **(a)** and lateral **(b)** radiographs. A 50-year-old woman with spondylosis of L5–S1 disk space. Note the neuroforaminal narrowing and loss of disk height.

- Treatment:
  - Conservative therapy:
    - Similar to conservative management for other lumbar pathologies.
  - Operative management:
    - Indications:
      - Progressive or new onset neurologic symptoms.
      - Failure of conservative management for minimum of 6 weeks.
    - Decompression:
      - Laminectomy, foraminotomy, facetectomy.

11.4 Spondylolisthesis

- Background/etiology:
  - Anterior or retrograde slippage of a vertebra over the inferior segment:
    - Often asymptomatic and found incidentally on imaging.
  - 90% of cases occur at L5, 5% at L4, and 3% at L3.
  - Degenerative spondylolisthesis prevalence: 5% in men and 9% in women.
  - Types:
    - Degenerative:
      - Typically develops after the age of 40 years.
      - Degeneration of facets and intervertebral disk:
        - ❖ Change in stiffness at lumbosacral junction and motion segment instability.
      - Absence of pars defect differentiates these patients from adult isthmic spondylolisthesis.
    - Isthmic (spondylolysis):
      - Most common among 7- to 20-year-olds.
      - Defect/fracture of the pars interarticularis:

❖ Pars interarticularis (between superior and inferior articular processes) susceptible to fatigue and stress fractures:

◇ Cyclic loading of the immature lumbar spine with symptoms occurring later in teenage years.

○ Congenital/dysplastic, traumatic, and iatrogenic spondylolistheses also occur.

• Classification:
  – Meyerding's classification (**Fig. 11.5**):
    ○ Grade I: 25% forward displacement.
    ○ Grade II: 25 to 50% forward displacement.
    ○ Grade III: 50 to 75% forward displacement.
    ○ Grade IV: greater than 75% forward displacement.
    ○ Grade V: 100% forward displacement (spondyloptosis).
  – Modified Wiltse:
    ○ Based on etiology of the spondylolisthesis (**Table 11.3**).
  – Spinal deformity study group L5–S1 classification (**Fig. 11.6**).
  – Based on pelvic parameters and orientation.
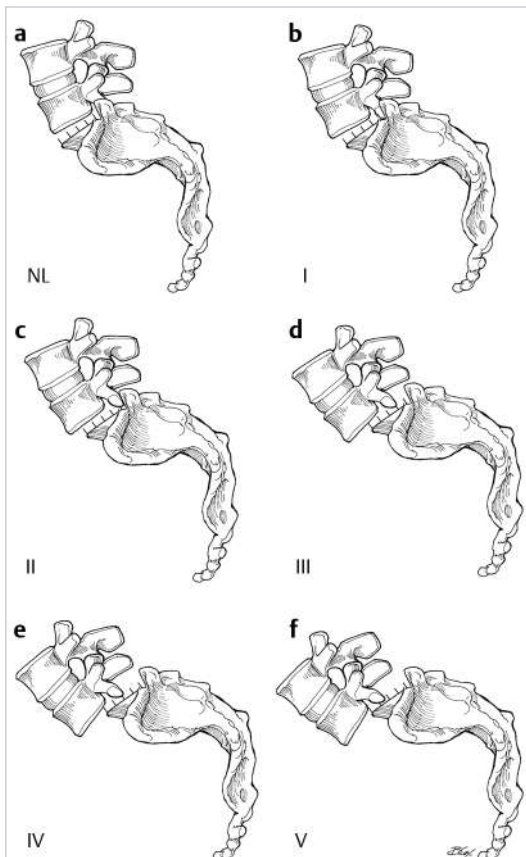
Fig. 11.5 Meyerding's classification. **(a)** Normal.
(b) Grade I, 0 to 25%.
(c) Grade II, 26 to 50%.
(d) Grade III, 51 to 75%.
(e) Grade IV, 76 to 100%.
(f) Grade V, spondyloptosis.

Table 11.3 Spondylosis grading

Grade 0	Grade 1	Grade 2	Grade 3	Grade 4
Normal healthy spine	Minimal anterior osteophyte formation	Anterior osteophyte formation	Anterior osteo-phyte formation	Large osteophyte formation
	No reduction in intervertebral (IV) disk height, no vertebral end plate sclerosis	Subtle reduction in IV disk height	Moderate narrowing of disk space	Severe disk plate narrowing
		Subtle sclerosis of endplates	Define sclerosis of endplates, and osteophyte sclerosis	Sclerosis endplate with irregularities
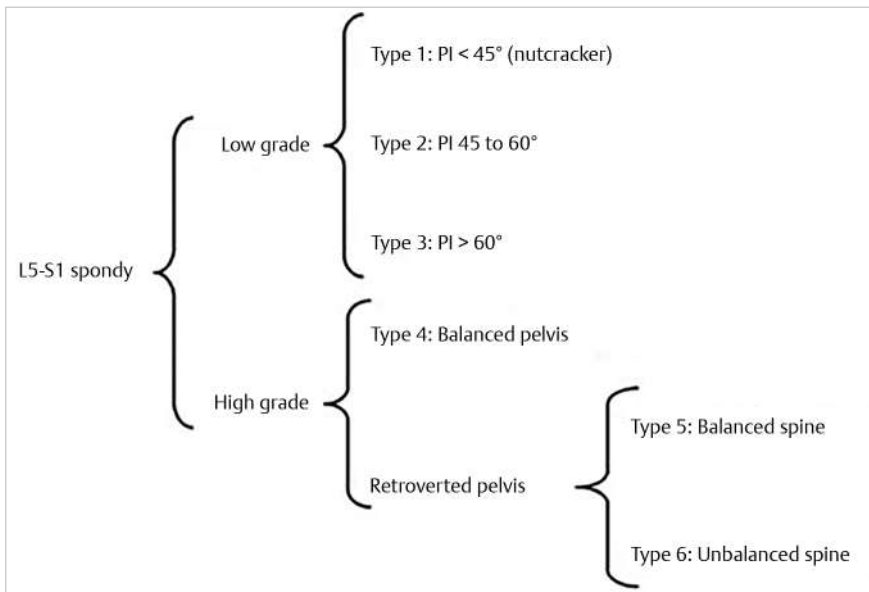
Fig. 11.6 Spinal deformity study group classification for L5–S1 spondylolisthesis. PI, pelvic incidence.

- – Types 1 and 2 exhibit lower risk of disease progression.
    - ∘ Higher types (types 5 and 6) indicative of surgical reduction.
- • Symptoms and clinical findings:
    - – Axial back pain:
        - ∘ Little to no back pain as a result of spondylolisthesis alone:
            - ▪ Associated degenerative processes (HNP, spondylosis) can cause concurrent pain.

- Radiculopathy:
  - Experienced by 50% of patients.
  - Narrowing of spinal canal and neuroforamen due to slippage of vertebral body:
    - Compression of traversing nerve roots.
- Neurogenic claudication:
  - May be unilateral or bilateral.
  - Buttock and leg pain/discomfort caused by upright walking; relieved by sitting.
  - Not relieved by standing in one place (vs. vascular claudication).
- Cauda equina and conus syndromes:
  - Similar to other pathologies resulting in compression of lumbar and sacral nerve roots.
• Imaging:
  - X-ray:
    - Assessment of degree of spondylolisthesis as well as other degenerative processes.
    - Identify isthmic spondylolisthesis:
      - Defect in pars interarticularis ("Scottie dog" projection); best evaluated on oblique views.
    - Slip angle (**Fig. 11.7**):
      - Angle between superior end plate of L5 and a perpendicular line through the posterior border of the sacrum.
      - Provides indication of potential stability:
        ❖ Surgical reduction involves correction of slip angle and resulting lumbosacral kyphosis:
          ◇ Complete reduction not crucial for clinical success, and actually involves significant risks.
          ◇ Improves surgical fusion rate.
    - Flexion–extension views (**Fig. 11.8**):
      - Identifies lumbar instability.
      - Greater than 4 mm or 10 of vertebral motion is indicative of dynamic instability.
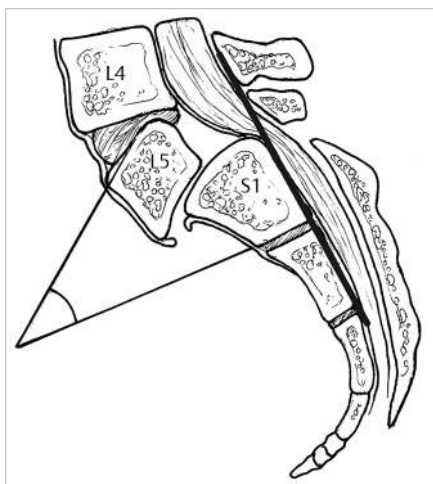
Fig. 11.7 Slip angle in spondylolisthesis. Angle is formed between the line parallel to superior end plate of L5 and line perpendicular to posterior border of sacrum. (Reproduced with permission from Anderson D, Vaccaro A, eds. Decision Making in Spinal Care. 2nd ed. New York, NY: Thieme; 2012.)
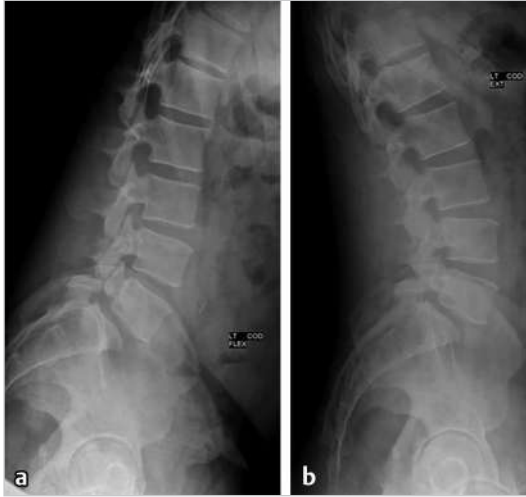
Fig. 11.8 (a,b) Flexion-extension radiographic views. Grade 1 L5–S1 isthmic spondylolisthesis. Note the anterolisthesis of the L5 vertebrae over the sacrum with a defect in the pars interarticularis of L5.

- MRI:
  - Evaluation of compression of neural structures from slipping vertebral disk.
- Treatment:
  - Conservative therapy:
    - Similar to other pathologies causing compression of neural structures.
  - Operative:
    - Indications:
      - Persistent or worsening neurologic symptoms.
      - High-grade slippage in the setting of pain or radicular symptoms.
    - Lumbar decompression and instrumented fusion:
      - Posterior approach is most common.
      - Decompression via laminectomy.
    - Lumbar decompression alone: only recommended for patients that cannot tolerate instrumentation:
      - 31% percent of patients have progressive instability.

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12 Scoliosis

Lauren M. Sadowsky, Ankur S. Narain, Fady Y. Hijji, Philip K. Louie, Daniel D. Bohl,
and Kern Singh

12.1 Introduction

Spinal deformities such as scoliosis represent some of the most challenging cases for spinal surgeons. Scoliosis has a variety of potential etiologies, and progresses in severity from childhood to adulthood. Significant functional and cosmetic deficits can occur without proper screening, diagnosis, and treatment of this disorder. As such, it is important to understand the unique clinical history, radiographic techniques and measurement, and surgical strategies that present or are utilized in cases of scoliosis.

12.2 Background and Etiology

- Scoliosis is defined as a lateral curvature of the spine ≥10 degrees, typically accompanied with a variable degree of vertebral rotation.
- Etiologies include idiopathic (80–85%), congenital, neuromuscular, and syndromic:
  - Idiopathic:
    - Categorized based on age of presentation:
      - Infantile: 0 to 3 years.
      - Juvenile: 4 to 10 years.
      - Adolescent: 11 to 17 years.
      - Adult: ≥18 years (after skeletal maturity).
  - Congenital:
    - Present at birth.
    - Can include failure of formation (e.g., hemivertebra) or failure of segmentation (e.g., congenital fusion):
      - Often associated with genitourinary deformities.
  - Neuromuscular:
    - Due to muscular tone abnormalities (imbalance and lack of trunk control):
      - Etiologies include cerebral palsy, myelomeningocele, myopathies, spinal cord trauma, and muscular dystrophies.
  - Syndromic:
    - Includes any syndrome presenting with scoliosis that is not neuromuscular or congenital:
      - Associated syndromes include Marfan's syndrome, osteogenesis imperfecta, skeletal dysplasias, Prader–Willi syndrome, Ehler–Danlos syndrome, and neurofibromatosis.
- Risk factors for acquired scoliosis:
  - 2-4% of all adolescents have adolescent idiopathic scoliosis (AIS):
    - Females and males affected equally.

- ◦ Risk of curve progression affects females 10 times more than males:
  - ▪ Larger Cobb's angles in females than in males.
- – Genetics: 97% of AIS patients have a family history of scoliosis.
- – Age: up to 68% of adults older than 60 years have scoliosis due to progression of degenerative changes of the spine.
- Progression of deformity:
  - – Physiologic changes due to compressive forces on intervertebral disks and vertebrae on concave side → reduced growth and continued asymmetry.

12.3 History and Clinical Findings

- History:
  - – Age at onset:
    - ◦ Peak growth occurs in males at 13.5 years and in females at 11.5 years.
    - ◦ Scoliosis may progress during peak growth spurt.
  - – Presence of back pain and stiffness:
    - ◦ 23% of AIS patients present with pain.
  - – Muscle fatigue from muscle strain and compensated posture.
  - – Shortness of breath/difficulty breathing due to severe thoracic scoliosis.
  - – Family history:
    - ◦ Incidence increases seven times with a first-degree relative with scoliosis.
- Inspection:
  - – Any truncal imbalance in height/symmetry of shoulders, scapulae, spine, and waistline.
  - – Head misaligned over sacrum (trunk shift).
  - – Findings suggestive of other diagnoses: café au lait spots (neurofibromatosis type 1), axillary freckling (neurofibromatosis type 1), and hair tufts (spina bifida).
  - – Sexual maturity measured by Tanner's grading stages.
- Height measurement:
  - – Monitor progression and skeletal growth.
- Adams' forward bend test (**Fig. 12.1**):
  - – Patient bends forward until waist is 90 degrees.
  - – Positive findings include unilateral prominence (thoracic or lumbar), rotational deformity, misaligned shoulders/hips, and asymmetry.
  - – Specific for rotational component of scoliosis.
- Scoliometer measurements:
  - – Obtained successively during the Adams' forward bend test at three areas of interest both standing and sitting:
    - ◦ Upper thoracic (T3–T4).
    - ◦ Main thoracic (T5–T12).
    - ◦ Thoracolumbar (T12–L1 or L2–L3).
  - – Measurements ≠ 0 are abnormal and define asymmetry.
- Pelvic tilt:
  - – Lateral pelvic tilt is associated with compensation for scoliosis or leg length discrepancy.
  - – Sagittal pelvic tilt is associated with compensation for curve deformities.

Fig. 12.1 Adams' forward bend test with scoliometer measurements. (Reproduced with permission from Albert TJ, Vaccaro, AR, eds. Physical Examination of the Spine. 2nd ed. New York, NY: Thieme; 2016.)

- Neurologic examination:
  - Deficits may include abnormalities of gait and coordination, sensory changes, weakness, or incontinence.
  - Presence of neurological symptoms may suggest etiologies other than idiopathic.

12.4 Imaging

- Plain radiography:
  - Initial evaluation with standing posteroanterior (PA) and lateral views from the cervical to sacral regions:
    - Determination of curve patterns:
      - Curve direction is determined by convexity:
        - ❖ Major curve: largest.
        - ❖ Minor curve: smaller.
    - Identification of apical vertebral:
      - Most laterally deviated vertebra from the vertical axis.
    - Determination of the central sacral vertical line (CSVL):
      - Vertical line drawn from the center of the sacrum.
- Cobb's angle:
  - Measured from the proximal and distal end vertebrae of each curve.
  - Measurement protocol:
    - Identify the end plates of the associated end vertebrae.
    - Draw a parallel line extending from each end plate.

- Draw a line at 90 degrees to each parallel line.
- The angle of intersection for those lines = Cobb's angle.
- Risser's sign:
  - Measures skeletal maturity based on the degree of iliac apophysis ossification on PA radiographs:
    - Grade 0: no ossification.
    - Grade 1: less than 25% ossification.
    - Grade 2: 25 to 50% ossification.
    - Grade 3: 50 to 75% ossification.
    - Grade 4: 75 to 100% ossification.
    - Grade 5: full bony fusion of apophysis to ileum.
  - Lower Risser's grade = greater risk for curve progression.
- Neutral and stable vertebrae:
  - Neutral vertebrae = vertebrae without axial rotation (not within a curve).
  - Stable vertebrae = vertebrae most closely bisected by the CSVL (within a curve).
- Plumb line:
  - Vertical line drawn inferiorly from the midpoint of C7.
  - Measures coronal balance (with AP radiographs):
    - Determine distance between CSVL and plumb line.
  - Measures sagittal balance (with lateral radiographs):
    - Determine distance between posterosuperior S1 and plumb line.
  - Abnormal finding (for both coronal and sagittal balance measurements) is distance greater than 2 cm.
- Lenke's classification system (**Fig. 12.2**):
  - Standing anteroposterior (AP), standing lateral, and right- and left-bending PA radiographs required.
  - Classification includes three components: (1) curve type, (2) lumbar spine modifier, and (3) thoracic sagittal modifier:
    - Curve type:
      - Based on location of curve apices and curve type:
      - Major curve: largest Cobb's angle, structural:
        - ❖ Structural curves have greater than 25-degree Cobb's angle on AP side-bending views.
      - Minor curves: all other angles, structural or nonstructural.
    - Lumbar spine modifier:
      - Based on location of CSVL in relation to lumbar curve apex.
    - Thoracic sagittal modifier:
      - Based on the angle of thoracic (T5–T12) kyphosis.
  - Lenke's classification helps guide management, specifically denoting levels of fusion with operative treatment.

12.5 Treatment

- Factors to consider for surgical decision making:
  - Degree and type of deformity:

Curve Type

Type	Proximal Thoracic	Main Thoracic	Thoracolumbar / Lumbar	Curve Type
1	Nonstructural	Structural (major)	Nonstructural	Main thoracic (MT)
2	Nonstructural	Structural (major)	Nonstructural	Double thoracic (DT)
3	Nonstructural	Structural (major)	Structural	Double major (DM)
4	Structural	Structural (major)	Structural	Triole major (TM)
5	Nonstructural	Nonstructural	Structural (major)	Thoracolumbar / lumbar (TL/L)
6	Nonstructural	Structural	Structural (major)	Thoracolumbar / lumbar structural MT

Structural Criteria

Proximal thoracic: - Side bending cobb ≥ 25°
· T2 – T5 kyphosis ≥ + 20°

Main thoracic : Side bending cobb ≥ 25°

Thoracolumbar / lumbar : - Side bending cobb ≥ 25°
· T10 – L2 kyphosis ≥ + 20°

Location of Apex (SRS definition)

Curve	Apex
Thoracic	T2 – T11–12 DISC
Thoracolumbar	T2 – L1
Lumbar	L1–2 DISC – L4

Modifiers

Lumbar Spino Modifier	CSVL to Lumbar Apex
A	CSVL between pedicles
B	CSVL touches apical body(ies)
C	CSVL completely medial

Thoracic Sagittal Profile T5 - T12		
—	(hypo)	< 10°
N	(normal)	10°-40°
+	(hyper)	> 40°

Curve type (1-6) + Lumbar spine modifier (A, B, or C) + Thoracic sagittal modifier (–, N, or +)
Classification (e.g. 1B+): _____

Fig. 12.2 Lenke's classification system. (Reproduced with permission from Lenke LG, Betz RR, Harms J, et al. Adolescent idiopathic scoliosis: a new classification to determine extent of spinal arthrodesis. J Bone Joint Surg Am 2001;83-A:1169- 1181.)

- ◦ Cobb's angle.
- ◦ Radiographic measurements: cervical lordosis, thoracic kyphosis, lumbar lordosis, coronal balance, sagittal vertical axis, pelvic incidence, pelvic tilt, and sacral slope (see Chapter 9).
- – Risk for curve progression (Risser's sign).
- – Patient maturity and concerns for cosmesis.
- • Nonoperative treatment:
  - – Observation:
    - ◦ Cobb's angle of less than 20 degrees.
    - ◦ Requires radiographic monitoring every 6 to 12 months.
  - – Orthosis:
    - ◦ A 20- to 40-degree Cobb's angle.
    - ◦ Monitoring of progression:
      - ▪ Twenty to thirty degrees initially → start bracing when progression is greater than 5 degrees between consecutive visits.

- Thirty to forty-five degrees initially with Risser's grade ≤ 2 → start bracing at first visit.
  - Thoracolumbosacral orthosis (TLSO) braces:
    - Full-time wear braces.
    - Wilmington brace (total contact TLSO):
      - ❖ Custom-fitted plastic jacket.
      - ❖ Corrects curves with apices at or below T7.
    - Boston brace ("underarm" brace):
      - ❖ Prefabricated sizes modified to individual patients.
      - ❖ Indicated for cervicothoracic, thoracic, thoracolumbar, and lumbar curves.
  - Nighttime braces:
    - Indicated for flexible, single structural thoracolumbar and lumbar curves.
    - Charleston brace ("side-bending" orthosis):
      - ❖ Custom-fitted to provide an "overcorrected" position.
    - Providence brace:
      - ❖ Computer-assisted design brings apices toward vertical axis.
  - Flexible braces:
    - SpineCor brace:
      - ❖ A Cobb angle of ≥15 degrees, full-time wear.
      - ❖ Indicated for single structural thoracolumbar and lumbar curves.
      - ❖ Plastic pelvic base with cotton/elastic corrective bands.
- Operative treatment (**Fig. 12.3**):
  - A Cobb angle of ≥45 to 50 degrees.
  - Indications include failure of conservative therapy, disabling pain, or imbalance.
  - Spinal fusion with instrumentation:
    - Intended to prevent or control curve progression.
    - Anterior and posterior surgical approaches:
      - All major and structural minor curves should be included in the fusion.
      - Neutral/stable vertebrae mark the limits of fusion.

Fig. 12.3 (a) Preoperative anteroposterior and lateral radiographs demonstrating significant right thoracic and left lumbar scoliosis. **(b)** Postoperative anteroposterior and lateral radiographs demonstrating correction via fusion with posterior instrumentation.

- Posterior fusion with instrumentation (combination of rods, hooks, and pedicle screws) is the gold standard.
- Anterior fusion may allow for better results with shorter fusion segments.

• Growth-friendly options:
  - Indications include potential for axial growth, deformity of greater than 50-degree Cobb's angle, and flexible spinal column.
  - Serial casting (every 8–16 weeks).
  - Distraction-based implants:
    ◦ Growing rods.
    ◦ Vertical expandable prosthetic titanium rib (VEPTR).
    ◦ Guided-growth implants.
    ◦ Compression-based implants.

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13 Spinal Trauma and Fractures

Ankur S. Narain, Fady Y. Hijji, Philip K. Louie, Daniel D. Bohl, and Kern Singh

13.1 General Principles

- Background:
  - Cervical injury occurs in 2 to 3% of blunt trauma cases.
  - Thoracolumbar injury represents 75 to 90% of spinal trauma.
  - Sacral fractures often present with pelvic injuries (30–45%).
- Initial management:
  - Primary survey and neurologic assessment:
    - ABCDE: **A**irway, **B**reathing, **C**irculation, **D**isability, **E**xposure.
  - Secondary survey:
    - Evaluate for spinal shock: check bulbocavernosus reflex:
      - Intact if anal sphincter contraction is observed in response to squeezing the glans penis or pulling on a Foley catheter.
    - Evaluate for neurologic shock:
      - Loss of sympathetic tone leads to circulatory collapse.
      - Signs include hypotension, relative bradycardia:
        - ❖ Utilize vasopressors, fluid resuscitation as necessary.
    - Determine neurologic level of the injury:
      - Defined by lowest level with intact sensation and 3+/5 motor strength.
    - Assessment of degree of neurologic injury:
      - Magnitude of spinal cord involvement (**Table 13.1**).
      - American Spinal Injury Association (ASIA) impairment scale (**Table 13.2**).

Table 13.1 Incomplete spinal cord injury manifestations

Syndrome	Deficits	Etiology
Anterior cord syndrome	Paraplegia (bilateral) Pain and temperature	Injury to the anterior spinal artery
	(bilateral) Urinary retention	
Central cord syndrome	Motor weakness (bilateral – arms > legs)	Hyperextension injury (i.e., syringomyelia)
Posterior cord syndrome	Vibration and proprioception (bilateral)	Tabes dorsalis, epidural metastases
Brown-Séquard	Motor (ipsilateral) Vibration and proprioception (ipsilateral) Pain and temperature 2–3 levels below lesion (contralateral)	Trauma: knife or bullet wound

Table 13.2 Summary of the American Spinal Injury Association (ASIA) impairment scale

ASIA grade	Type of injury	Definition
A	Complete	Complete loss of motor and sensory function
B	Incomplete	Motor function preserved below level of injury
C	Incomplete	Motor function preserved, but key muscles below the level of injury have a muscle grade < 3
D	Incomplete	Motor function preserved, but key muscles below the level of injury have a muscle grade > 3
E	Normal	No deficits

- Standard imaging:
  - Orthogonal radiographs: anteroposterior (AP) and lateral of cervical, thoracic, and lumbar spine.
  - Computed tomography (CT) scan: sagittal and coronal reconstructions:
    - Improves visualization of occipital-cervical and cervicothoracic junctions, bony structures, and occult fractures.
  - Magnetic resonance imaging (MRI):
    - Required in cases of neurologic impairment.
    - Improves visualization of ligamentous structures.
    - Short tau inversion recovery (STIR) sequence heightens demonstration of edema.

13.2 Cervical Trauma and Fractures

13.2.1 Occipital Condyle Fracture (Fig. 13.1)

- Background and etiology:
  - Caused by high-energy trauma:
    - Axial compression or rotation.
    - Lateral bending.
    - Direct blow.

Fig. 13.1 Coronal section. CT scan demonstrating type III occipital condyle fracture.

- Anderson and Montesano classification system:
    - Type I (15%): collapse due to axial compression; stable.
    - Type II (50%): basilar skull fracture; stable.
    - Type III (35%): avulsion injury near alar ligament attachment; potentially unstable.
- Presentation:
  - High cervical neck pain and stiffness.
  - Motor paresis.
  - Possible cranial nerve deficit.
- Imaging:
  - Plain radiographs: avoid traction:
    - Open-mouth odontoid view.
    - AP and lateral views often inadequate due to superimposition of nearby structures (maxilla, occiput, mastoid processes).
  - CT scan: cranial CT including views of the craniocervical junction.
- Management:
  - Based on presence of ligamentous injury and craniocervical stability:
    - Stable: cervical orthosis.
    - Unstable: occipitocervical fusion; rigid posterior segmental stabilization with instrumentation from the occiput to C2/C3.

13.2.2 Atlanto-Occipital Dissociation (Figs. 13.2, 13.3)

- Background and etiology:
  - Traumatic: due to high-energy, rotational or flexion–extension force causing ligamentous injury.
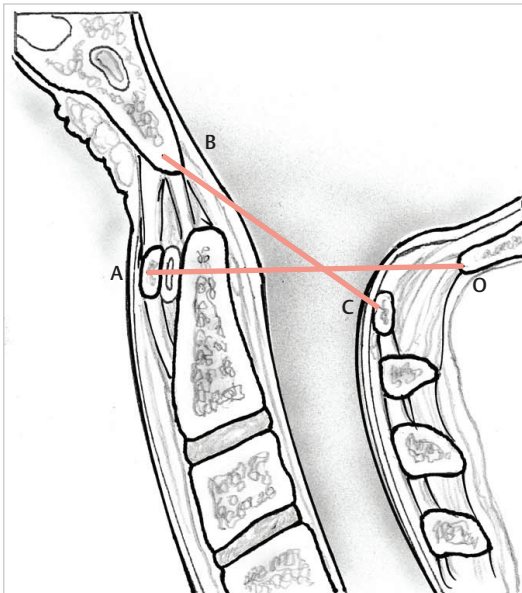
Fig. 13.2 Lateral view. Depiction of measurements comprising the Powers ratio. A, anterior arch of C1; B, basion; C, posterior arch of C1; O, opisthion. (Reproduced with permission from Khanna AJ, ed. MRI Essentials for the Spine Specialist. New York, NY: Thieme; 2014.)

Fig. 13.3 Sagittal section. CT scan showing a case of atlanto-occipital dissociation with a widened basion-dens interval.

  – Acquired: due to bony dysplasia or ligament and soft-tissue laxity (i.e., Down's syndrome).
  – Results in separation of the spinal column from the occiput.
• Presentation:
  – Neurologic deficits and possible quadriparesis.
  – Cardiorespiratory derangement.
  – Commonly fatal due to brainstem destruction.
• Imaging:
  – Plain radiography and CT scan: lateral/sagittal views:
    ◦ Harris' lines: suggestive of injury if:
      ▪ Basion-dens interval (BDI) is greater than 10 mm.
      ▪ Basion-axial interval (BAI) is greater than 12 mm.
      ▪ Atlantodental interval (ADI) is greater than 3 mm.
      ▪ Powers' ratio: C–D/A–B.
        ❖ A–B: distance from anterior arch to opisthion.
        ❖ C–D: distance from basion to posterior arch.
        ❖ Powers' ratio greater than 1: indicative of anterior subluxation/dislocation.
        ❖ Powers' ratio less than 1: indicative of posterior dislocation, odontoid fracture.
    ◦ Wackenheim's line:
      ▪ Line from the posterior surface of clivus to the upper cervical canal:
        ❖ Line behind odontoid: posterior dissociation.
        ❖ Line in front of odontoid: anterior dissociation.
  – MRI:
    ◦ Used to evaluate for spinal cord and ligamentous injury.
• Management:
  – Stable: fluoroscopy-guided reduction and halo vest; avoid traction.
  – Unstable: operative posterior fusion from the occiput to at least C2.

13.2.3 Atlas (C1) and Jefferson's Fractures (Fig. 13.4)

- Background and etiology:
  - Due to hyperextension and axial loading causing fracture of the anterior or posterior arch of C1:
    - Combination fracture of the anterior and posterior arches is known as a **Jefferson's fracture**.
- **Presentation:**
  - Typically presents without neurologic deficits.
  - In severe fractures, possible medullary dysfunction can occur.
- Imaging:
  - Plain radiographs:
    - Open-mouth odontoid view:
      - Spence rule: greater than 7 mm composite overhang between lateral masses of C1 and C2 (39% sensitivity).
    - Lateral:
      - Atlantodental interval:
        - Less than 3 mm: normal.
        - 3–5 mm: injury to transverse ligament with intact alar and apical ligaments.
        - Greater than 5 mm: injury to transverse, alar ligament, and tectorial membrane.
  - CT scan: coronal and sagittal reconstructions:
    - Further delineate fracture pattern.
    - Aids in identifying associated injuries in the cervical spine.
    - CT angiography (CTA) to rule out vertebral artery injury.
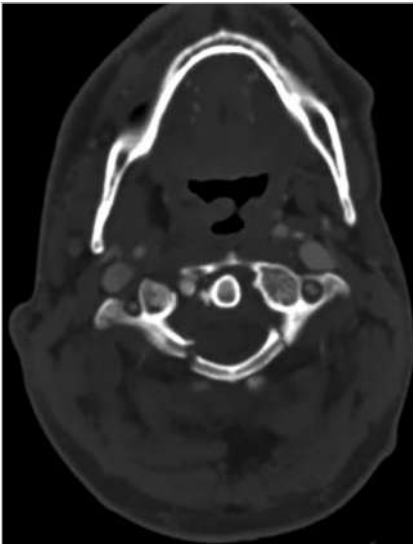
Fig. 13.4 Axial section. CT scan showing a comminuted Jefferson fracture involving the anterior and posterior C1 arches.

- MRI:
  - Used to assess transverse of atlantal ligament (TAL).
  - Significant for possible surgical planning.
- Management: based on the patency of the TAL:
  - TAL intact: rigid cervical orthosis.
  - TAL incompetent: C1–C2 fusion.

13.2.4 Traumatic Spondylolisthesis of C2 (Hangman's Fracture; Fig. 13.5)

- Background and etiology:
  - Associated with high-velocity trauma.
  - Mechanistic pattern: hyperextension → compression → rebound flexion:
    - Results in bilateral fracture of the lamina and pedicles.
  - Second most common axis fracture (38%).
- Presentation:
  - Asymptomatic if nonangulated and nondisplaced.
  - Cerebellar findings (nausea, vomiting, ataxia, asymmetric neurological examination) if vertebral artery injury is present.
- Imaging:
  - Plain radiography:
    - Flexion and extension views to evaluate for subluxation.
  - Levine and Edwards radiographic classification:
    - Type I: less than 3-mm displacement.
    - Type II: greater than 3-mm displacement and greater than 11-degree angulation.
    - Type IIa: less than 3-mm displacement and greater than 11-degree angulation.
    - Type III: associated facet dislocation.
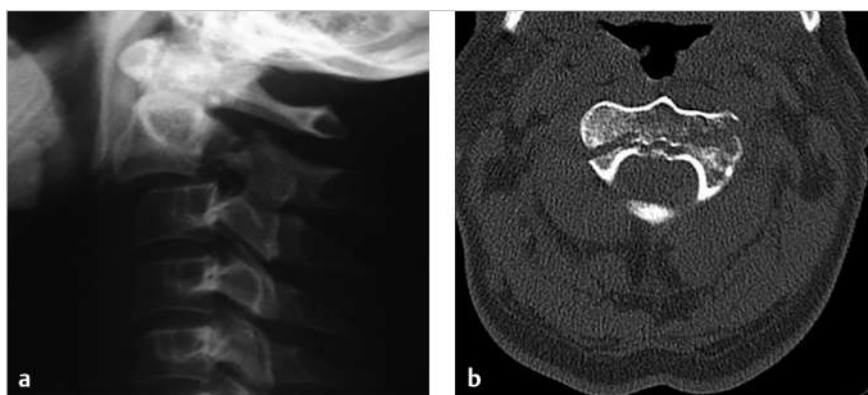
Fig. 13.5 (a) Lateral view. Plain radiograph demonstrating a hangman fracture at C2. **(b)** Axial section. CT scan demonstrating a comminuted hangman fracture of C2.

- CT scan with coronal and sagittal reconstructions:
    - Bilateral lamina and pedicle fracture.
    - Anterolisthesis of C2 on C3.
    - CTA to rule out vertebral artery injury.
- Management:
    - Dependent on classification:
        - Type I: halo brace for 12 weeks.
        - Type II: reduction via cervical traction and halo brace for 10 to 12 weeks.
        - Type IIa: reduction in extension followed by halo brace; avoid traction.
        - Type III: anterior C2–C3 or posterior C1–C3 fusion.

13.2.5 C2 Dens Fracture (Fig. 13.6)

- Background and etiology:
    - Caused by hyperflexion or hyperextension:
        - Elderly: falls.
        - Young patients: blunt trauma.
- Presentation:
    - Neck pain and tenderness to palpation.
    - Neurologic deficits usually not present.
- Imaging:
    - Radiographs: AP, lateral, and open-mouth odontoid views:
        - Anderson and D'Alonzo imaging classification:
            - Type I: avulsion fracture at the tip.
            - Type II: at the odontoid base.
            - Type III: within the C2 body.
        - Rule out os odontoideum:
            - Appears similar to a type II fracture.
            - Possible failure of fusion at base of odontoid, may be residual of an old traumatic process.
    - CT scan with sagittal and coronal reconstructions:
        - CTA required to determine vertebral artery location prior to operative therapy with posterior instrumentation.
    - MRI:
        - Used to assess integrity of the cruciate ligament.

Fig. 13.6 Coronal section. CT scan demonstrating a type II Dens fracture encompassing the base.

- Management:
  - Type 1 fractures: stable; treated with rigid cervical collar.
  - Type 2 fractures: most unstable, requires surgical treatment:
    - Anterior odontoid screw fixation.
    - Posterior C1–C2 instrumented fusion.
  - Type 3: stable; treated with halo brace or rigid cervical collar.

13.2.6 Subaxial Injury Classification System (Table 13.3)

- Categorizes injury based on morphology and integrity of discoligamentous complex.
- Assigned score can guide management decisions:
  - 1–3: nonoperative therapy.
  - Greater than 5: operative therapy consisting of realignment, decompression, and stabilization.

Table 13.3 Subaxial injury classification

Characteristics	Points
Injury morphology	
No abnormality	0
Compression	1
Burst	2
Distraction	3
Translation	4
Integrity of the discoligamentous complex	
Intact	0
Indeterminate	1
Disrupted	2
Neurological status	
Intact	0
Nerve root injury	1
Complete	2
Incomplete	3
Persistent cord compression	+1

Fig. 13.7 Lateral view. Plain radiograph showing multiple flexion teardrop fractures at C2 and C4.

13.2.7 Subaxial Flexion–Compression Fracture (Flexion Teardrop; Fig. 13.7)

- Background and etiology:
  - Caused by flexion–compressive forces (diving, motor vehicle collision) leading to fracture of the anteroinferior vertebral body.
- Presentation:
  - Can range from mild neurological deficits to significant radiculopathies.
  - If significant retropulsion occurs, can lead to anterior cervical cord syndrome ± quadriplegia.
- Imaging:
  - Plain radiography: lateral view:
    - Fracture of the anteroinferior vertebral body ("teardrop").
    - Loss of anterior vertebral body height.
    - Possible displacement of posterior vertebral body into the canal.
  - CT scan:
    - CTA indicated to determine possibility of blunt cerebrovascular injury.
- Management:
  - Prognosis dependent on level of spinal cord injury.
  - Stable: rigid cervical orthosis.
  - Unstable: surgical:
    - Posterior fusion.
    - Anterior corpectomy with strut graft and anterior cervical discectomy and fusion (ACDF).

Fig. 13.8 Lateral view. Plain radiograph showing extension teardrop fracture at C3.

13.2.8 Subaxial Extension–Compression Fracture (Extension Teardrop; Fig. 13.8)

- Background and etiology:
  - Caused by forced extension of the neck leading to avulsion of the anteroinferior aspect of the vertebral body via disruption of the anterior longitudinal ligament (ALL).
- Presentation:
  - Can range from mild neurological deficits to significant radiculopathies.
- Imaging:
  - Plain radiography: lateral view:
    - Anteroinferior corner fracture: usually from the ALL to the inferior corner of the vertebral body ("teardrop").
    - Widening of anterior disk space.
  - CT:
    - To determine presence of additional fractures.
    - CTA: investigation of blunt cerebrovascular injury.
- Management:
  - Typically a stable fracture: nonoperative management with rigid cervical orthosis.

13.2.9 Subaxial Vertical Compression (Burst) Fracture (Fig. 13.9)

- Background and etiology:
  - Caused by vertical compressive forces arising from significant trauma (i.e., diving, fall from a significant height, landing on feet).
  - Results in disruption of the anterior and posterior vertebral body cortex.
  - Often associated with posterior ligamentous injury.
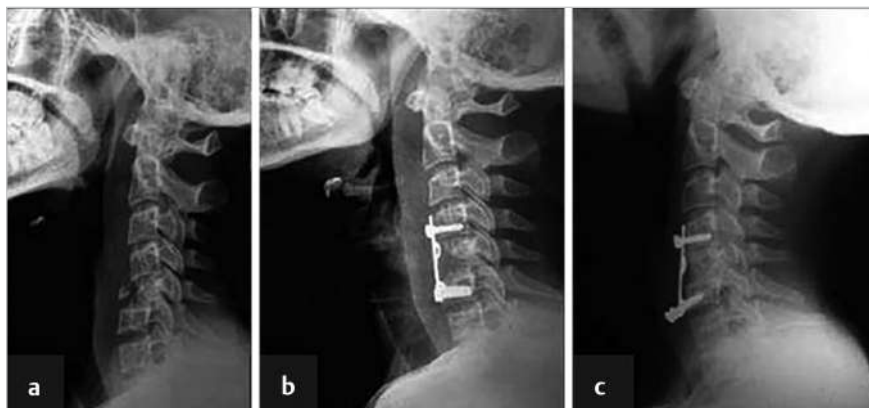
Fig. 13.9 Lateral view. **(a)** Plain radiograph showing burst fracture of C5. **(b,c)** Plain radiograph showing corpectomy with anterior grafting and plate fixation.

- Presentation:
  - Can range from mild neurological deficits to significant radiculopathies.
  - If retropulsion occurs, can present with anterior cord syndrome.
- Imaging:
  - Plain radiography: lateral views:
    - Loss of vertebral height, anterior greater than posterior.
  - CT scan:
    - Burst vertebral body.
    - Retropulsed fragments into the spinal canal.
  - MRI:
    - Assesses for cord contusion.
- Management:
  - Stable: rigid cervical orthosis.
  - Unstable: surgical therapy:
    - Corpectomy, anterior grafting, and plate fixation.

13.2.10 Bilateral Facet Dislocation

- Background and etiology:
  - Caused by flexion–rotation forces.
  - 10-40% percent of cases have disk herniation into the spinal canal.
- Presentation:
  - Focal neurologic deficits and radiculopathy.
- Imaging:
  - Plain radiography:
    - Loss of apposition at the facet joint.
    - Anterolisthesis ≥ 50%.
    - Increased interspinous distance.

- MRI:
  - ○ Indications include the following:
    - ▪ Significant spinal cord deficits, paresthesias, declining mental status.
    - ▪ Following dislocation reductions.
    - ▪ Prior to operative treatment in neurologically stable patients.
- Management:
  - All patients require initial reduction:
    - ○ Awake, cooperative patient, no significant neurological deficits: reduction, followed by MRI.
    - ○ Obtunded, intoxicated patient: MRI prior to reduction to rule out disk herniation.
  - Definitive treatment requires surgical stabilization:
    - ○ ACDF ± posterior stabilization.

13.2.11 Unilateral Facet Dislocation (Fig. 13.10)

- Background and etiology:
  - Caused by flexion/distraction and rotation forces, leads to inferior articular facet of the superior vertebrae moving over the superior facet of the inferior vertebrae.
  - 10% of cases cause spinal cord impingement.
- Presentation:
  - Neck pain.
  - Radiculopathy (70%).
- Imaging:
  - Plain radiograph: lateral view.

Fig. 13.10 Lateral view. Plain radiograph showing unilateral facet dislocation with characteristic bow tie sign.

- Bow tie sign: vertebral bodies appear lateral below level of injury and oblique above level of injury.
    - Anterolisthesis less than 25%.
    - Interspinous widening at the affected level.
  - CT scan:
    - Useful in the detection of concomitant fractures.
  - MRI:
    - Used for detection of soft-tissue injuries, disk herniation, contusion.
- Management:
  - Stable: halo bracing for 12 weeks.
  - Unstable or presenting with radiculopathy: surgical management similar to bilateral facet dislocation:
    - ACDF ± posterior fusion.

13.2.12 Clay-Shoveler's Fracture

- Background and etiology:
  - Spinous process fracture caused by:
    - Stress fracture (chronic).
    - MVAs, Direct blow to posterior spine (acute).
  - Most commonly at C7 (midpoint between the lamina and spinous tip).
  - Often occurs as an isolated injury.
- Presentation:
  - Often asymptomatic.
- Imaging:
  - Plain radiography: lateral view:
    - Vertical or oblique lucency in the spinous processes:
      - Most commonly present in the lower cervical or upper thoracic areas.
    - Possible posterior displacement of fracture fragment.
- Management:
  - Stable fracture: cervical collar.

13.2.13 Lateral Mass Fracture (Fig. 13.11)

- Background and etiology:
  - Mechanism includes hyperextension, lateral rotation, and compression:
    - Motor vehicle accident, falls, objects falling on head.
  - Ipsilateral fracture of the pedicle and lamina.
  - Affects two adjacent motion segments due to involvement of the facet joints.
- Presentation:
  - High degree of instability leading to neurological deficits (66%).
- Imaging:
  - Plain radiography:
    - Poor sensitivity: 38%.
    - Disk space narrowing and instability.
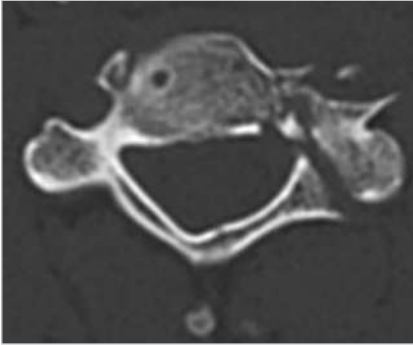
Fig. 13.11 Axial section. CT scan showing a cervical lateral mass fracture involving the pedicle and lamina.

- CT:
  ◦ Translation of fractured and adjacent vertebrae in multiple planes.
  ◦ Vertebral body destruction.
  ◦ Used for evaluation of translation of fractured vertebrae.
- MRI:
  ◦ Disruption of ligaments:
    ▪ ALL: 50 to 75%.
    ▪ PLL: 30 to 35%.
    ▪ Interspinous and supraspinous ligaments: 10 to 75%.
• Management:
  - Stable injuries without neurologic deficits: halo vest.
  - Most cases are unstable: require surgical treatment:
    ◦ Posterior decompression with two-level instrumented fusion.

13.3 Thoracolumbar Fractures

13.3.1 General Background

• The most common location is the T11–L2 region:
  - Susceptible to injury due to transition from fixed, kyphotic thoracic spine → mobile, lordotic lumbar spine.

• Operative indications include the following:
  - Instability due to posterior ligamentous injury.
  - Focal neurologic deficits or progressive decrease in neurologic status.

13.3.2 Thoracolumbar Injury Classification System (Table 13.4)

• Categorizes injuries based on injury morphology, neurologic injury, posterior ligamentous complex integrity.
• Management recommendations are based on total score:
  - 3 or lower: nonoperative treatment.
  - 4: indeterminate.
  - 5 or higher: operative intervention.

Table 13.4 Injury classification system for thoracolumbar spine

Component	Qualifiers	Score
Morphology type		
Compression		1
Burst		1
Translational/rotational		3
Distraction		4
Neurological involvement		
Intact		0
Nerve root		2
Cord, conus medullaris	Complete	2
	Incomplete	3
Cauda equina		3
Posterior ligamentous complex		
Intact		0
Injury suspected/indeterminate		2
Injured		3

13.3.3 Compressive Thoracolumbar Fracture (Fig. 13.12)

- Background and etiology:
  - Most common fragility fracture, often secondary to osteoporosis; often a result of a fall.
- Presentation:
  - Localized pain (25%).
  - Mortality increases with concomitant hip fracture.
  - Important to rule out metastatic disease (atypical radiograph, failure to thrive, fracture in a young patient without trauma, fractures above T5 level).
- Imaging:
  - Plain radiographs:
    - Loss of vertebral height of at least 20%.
    - Unstable fractures are those with greater than 50% loss of vertebral height, greater than 30 degree angulation, greater than 30 degree focal kyphosis.
  - CT and MRI generally not necessary for diagnosis:
    - MRI can be used to identify chronicity of injury, assess for spinal cord compression, edema, or hemorrhage.
- Management:
  - Full medical workup.
  - Stable fractures: thoracolumbosacral orthosis (TLSO) or Lewitt extension bracing.
  - Unstable fractures with pain or loss of mobility: vertebroplasty or kyphoplasty.

Fig. 13.12 Sagittal section. CT scan showing a compression fracture of the thoracolumbar spine.

Fig. 13.13 Lateral view. Radiograph showing a chance fracture with significant anterior wedging.

13.3.4 Chance Fracture ("Seatbelt Fracture"; Fig. 13.13)

- Background and etiology:
  - Flexion–distraction mechanism; often occurs in motor vehicle accidents in backseat passengers wearing a seatbelt.
  - Fracture traversing all three columns of the vertebrae.
  - Can be isolated bony or ligamentous injury.
- Presentation:
  - Associated with a high rate of gastrointestinal injury (50% of cases present with concomitant perforated viscus).

- Imaging:
  - Radiography: lateral view:
    - Anterior wedge fracture of the vertebral body.
    - Horizontal fracture through posterior elements or distraction of spinous processes and facet joints.
  - CT:
    - Used to evaluate for retropulsion of bony fragments into the spinal canal.
  - MRI:
    - Used to evaluate posterior elements.
- Management:
  - Stable fracture without ligamentous injury: TLSO body brace or cast.
  - Unstable fracture with ligamentous injury: posterior spinal fusion.

13.3.5 Thoracolumbar Burst Fracture (Fig. 13.14)

- Background and etiology:
  - Caused by axial loading, resulting in disruption of the posterior vertebral body cortex.
  - Most commonly occurs at the thoracolumbar junction.
- Presentation:
  - Canal compromise leads to initial neurologic dysfunction and possible anterior cord syndrome.
  - Other spinal fractures also occur in 20% of cases.
- Imaging:
  - Plain radiographs: AP and lateral views:
    - Widening of interpedicular space.
    - Vertebral collapse.
    - Kyphosis.
    - Possible retropulsed fragments.
  - CT:
    - Required if neurologic deficit present in lower extremity.

Fig. 13.14 Sagittal section. CT scan showing a thoracolumbar burst fracture with retropulsion.

– MRI:
   ◦ Spinal cord compression, contusion, edema, hemorrhage.
   ◦ Posterior ligamentous complex injury.
• Management:
  – Stable fractures: less than 50% vertebral collapse, less than 30 degree kyphosis, less than 50% lumbar canal collapse, neurologically intact:
    ◦ Thoracolumbar orthosis.
  – Unstable fractures: surgical decompression with spine stabilization:
    ◦ Combined anterior and posterior approach.

13.4 Sacral Fracture (Fig. 13.15)

• Background and etiology:
  – Occurs after a fall from a height (elderly) or during high-energy trauma.
  – Often appears along with pelvic injuries (30–45%).
• Presentation:
  – Peripelvic pain.
  – Neurologic deficits based on location.
  – If sacral roots are involved: bowel and bladder dysfunction.
  – Denis' classification:
    ◦ Zone 1: fracture lateral to the sacral foramina:
      ▪ Most common type of sacral fracture.
      ▪ Less than 10% with neurologic injury, affects L5.
    ◦ Zone 2: through sacral foramina:
      ▪ Causes unilateral neurologic deficits.
    ◦ Zone 3: through the body, medial to the sacral foramina:
      ▪ Most commonly presents with neurologic deficits (56%).
• Imaging:
  – Radiographic views: AP, inlet, outlet, lateral:
    ◦ Multiple views required as these fractures are commonly missed (only 30% shown on radiographs).
  – CT reconstruction: gold standard:
    ◦ Coronal and sagittal reconstructions.
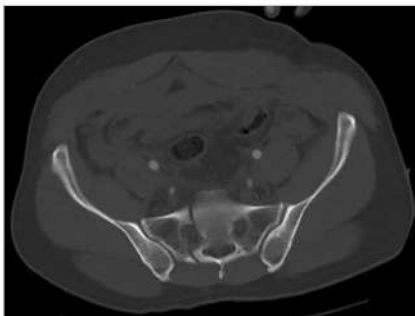
Fig. 13.15 Axial section. CT scan showing a zone II fracture of the sacrum.

- MRI: recommended when neurologic deficits are present or compromise is expected.
• Management:
  - Prognosis and outcome directly related to the presence of neurologic injury.
  - Stable fractures: less than 1 cm displacement, no neurologic deficits:
    ◦ Nonoperative therapy: progressive weight bearing and orthosis.
  - Unstable fractures: greater than 1 cm displacement, persistent pain, soft-tissue involvement:
    ◦ Surgical reduction and fixation.
    ◦ Iliopelvic reconstruction may be required to allow for adequate weight bearing.

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14 Primary and Metastatic Spinal Tumors

Ankur S. Narain, Fady Y. Hijji, Philip K. Louie, Daniel D. Bohl, and Kern Singh

14.1 Introduction

Primary and metastatic spinal neoplasms represent a series of complex pathologies that range from benign to life threatening. Detection of spinal neoplasms is further hindered by their indolent progression and vague symptomatology. As such, it is important for the practitioner to understand the nuances in examination and radiographic findings that are present in these patients. Furthermore, as these cases are often complex, understanding of the appropriate timing of nonoperative versus operative management is necessary to ensure the best possible clinical outcome.

14.2 Background and Etiology

- Metastatic spinal lesions are much more common than primary lesions.
- 10-30% of new cancer diagnoses have spinal metastases at discovery:
  - Spine is the most common site of metastatic bone disease.
- Affects thoracic spine (68–70%) > lumbosacral spine (16–22%) > cervical spine (8–15%).

14.3 Presentation and Physical Examination Findings (Table 14.1)

- Most common clinical presentation is axial back pain (85–96%).
- Progressive, nonmechanical, nighttime pain.
- Neurological symptoms: radiculopathy or myelopathy:
  - Changes in fine motor skills.
  - Gait and balance instability.

Table 14.1 Classic physical examination findings in metastatic spine tumors

Primary tumors	Physical examination findings
Breast	Fixed, hard, nontender breast mass Nipple retraction
Prostate cancer	Nodularity in the prostate on digital rectal examination
Thyroid cancer	Painless, palpable thyroid
Lung cancer	Cough, hemoptysis
Renal cell carcinoma	Hematuria, flank pain, abdominal mass

- – Bowel and bladder dysfunction.
- – Pathologic reflexes.
- • Pathologic fractures with subsequent kyphosis.
- • Weight loss.

14.4 Imaging

- • Plain radiography:
  - – Odontoid, swimmer's, and upright views of the entire spine.
  - – Assesses spinal alignment, stability, presence of metastatic lesions, and presence of compression fractures.
  - – Identifies osteolytic and osteoblastic lesions:
    - ◦ Osteolytic: areas of severe bone loss due to excess osteoclast activity, appears as area of radiolucency.
    - ◦ Osteoblastic: areas of excess bone formation due to osteoblast activity, appears as areas of radiodensity.
  - – "Winking owl" sign: lysis of pedicular cortical bone (high sensitivity).
  - – Osseous lesions often not visible on plain radiographs until destruction of greater than 50% of the vertebral body has occurred.
- • Computed tomography (CT):
  - – Useful for surgical planning and visualization of bone destruction.
  - – Myelography to evaluate for impingement.
  - – Imaging of the chest, abdomen, and pelvis is required for staging.
  - – Poor overall sensitivity (66%).
- • Magnetic resonance imaging (MRI) ± gadolinium contrast:
  - – T1, T2, and short tau inversion recovery (STIR) weighted images (98.7% sensitivity).
  - – Pedicular involvement, edematous regions with defined borders, noncontiguous involvement are common findings.
  - – Contrast aids in the evaluation of soft tissue, epidural space, and spinal cord.
- • Bone scintigraphy: technetium-99m:
  - – Shows increased uptake in regions of neoplastic involvement.
  - – Low sensitivity for differentiating metastatic disease from osteoporotic compression fractures, infection, or degenerative changes.

14.5 Diagnosis and Staging

- • CT-guided biopsy:
  - – Gold standard for tissue analysis:
    - ◦ 76% sensitivity for sclerotic lesions; 93% sensitivity for lytic lesions.
  - – Percutaneous approach preferred; open approach may be utilized when percutaneous biopsy is negative but concern for tumor burden remains high.
  - – If the lesion is metastatic, biopsy of primary disease site is preferred.
- • Staging:
  - – Weinstein–Boriani–Biagini system (**Fig. 14.1**):
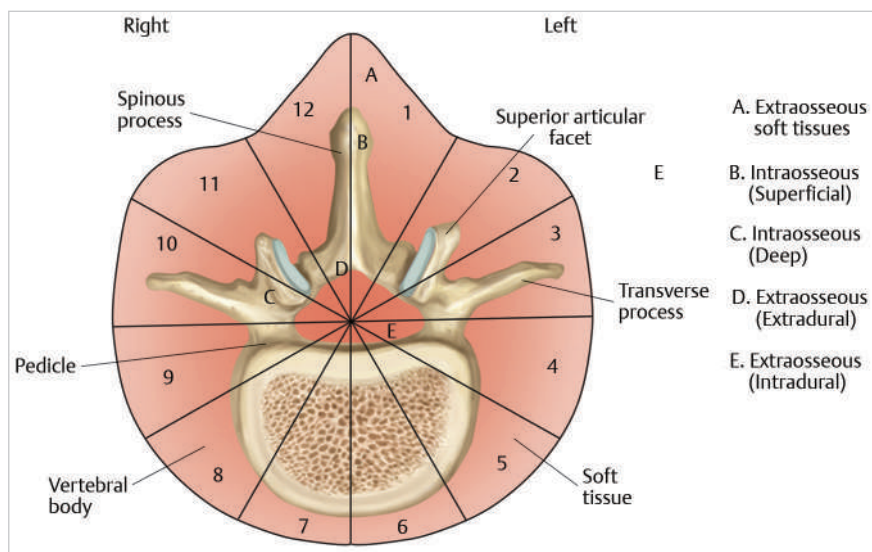
Fig. 14.1 Weinstein–Boriani–Biagini staging system for spinal neoplasms. (Reproduced with permission from An HS, Singh K, eds. Synopsis of Spine Surgery. 3rd edition. New York, NY: Thieme; 2016).

- ◦ Three-dimensional description of tumor invasion:
  - ▪ Twelve pielike zones rotating in a clockwise fashion starting at the spinous process.
  - ▪ Notes involvement of different vertebral layers: extraosseous soft tissue (A), superficial intraosseous (B), deep intraosseous (C), extradural extraosseous (D), intradural extraosseous (E).
  - ▪ Specifies the involved spinal segment.

14.6 Primary Spinal Tumors (Figs. 14.2, 14.3, Tables 14.2–14.5)

14.6.1 Metastatic Spinal Tumors (Fig. 14.4)

- • Background and etiology:
  - – Highest incidence between ages of 40 and 60 years.
  - – Affects males more often than females.
  - – Most common metastatic primary neoplasms:
    - ◦ Breast cancer.
    - ◦ Lung cancer.
    - ◦ Thyroid cancer.
    - ◦ Prostate cancer.
    - ◦ Renal cell carcinoma (RCC).
  - – Can spread via primary neoplasms by hematogenous, direct, or cerebrospinal fluid (CSF) extension:
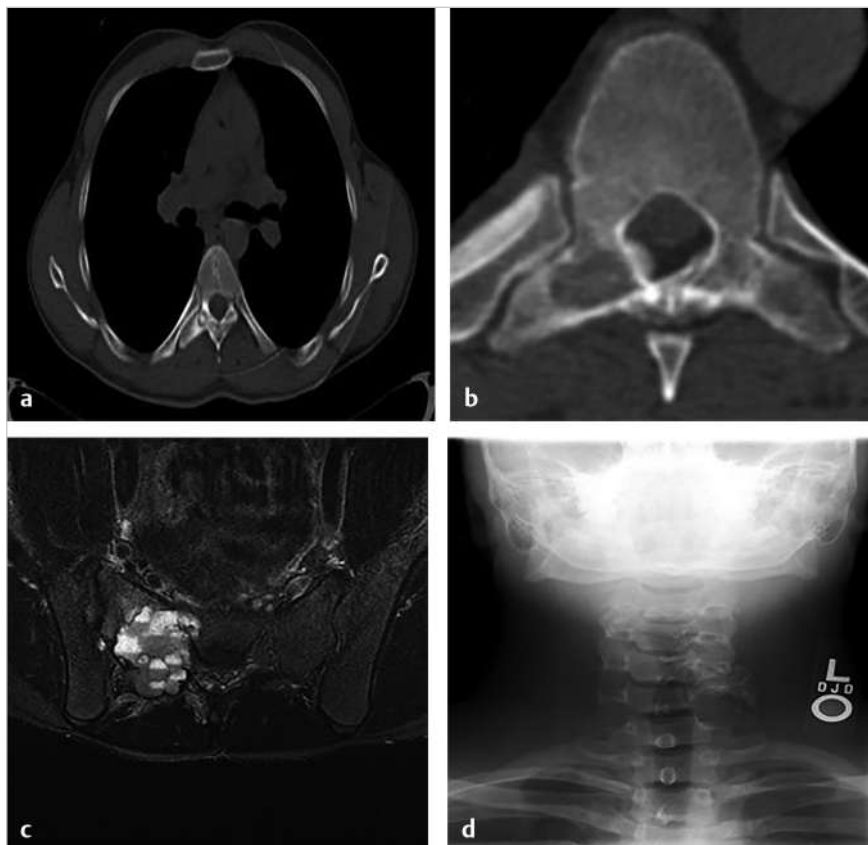
Fig. 14.2 Primary benign tumors of the spine. **(a)** Axial section. CT scan showing osteoid osteoma of the thoracic spine. Note the lesion in the right-sided posterior elements. **(b)** Axial section. CT scan showing osteoblastoma of the thoracic spine. Note the lesion in the right-sided posterior elements. **(c)** Axial section. CT scan showing a giant cell tumor of the right-sided sacrum. **(d)** Anteroposterior view. Radiograph depicting an osteochondroma at the left-sided C5–C6 levels. (Reproduced with permission from An HS, Singh K, eds. Synopsis of Spine Surgery. 3rd ed. New York, NY: Thieme; 2016.)

- Hematogenous extension can affect multiple levels via Baton's venous plexus.
- Most mechanistic evidence points toward tumor cell disassociation from a primary mass, penetration of the surrounding extracellular matrix, travel through lymphatic or blood vessels, and seeding of a distant site.
- Lesions often located in one of three compartments:
  - Extradural: most common.
  - Intradural–extramedullary.
  - Intramedullary.
- Presentation:
  - Similar to primary neoplasms:
    - Pain (83–95%).
    - Constitutional symptoms.
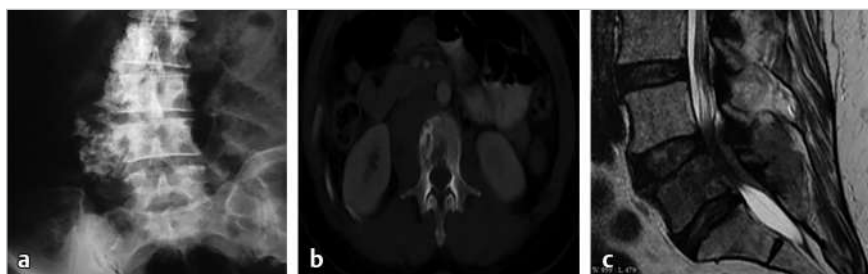
Fig. 14.3 Primary malignant tumors of the spine. **(a)** Anteroposterior view. Radiograph showing a large chondrosarcoma of the transverse processes of the lumbar spine. **(b)** Axial section. CT scan showing Ewing's sarcoma of L2. Note the mixed lytic and blastic lesions present in the right lateral aspect of the vertebral body. **(c)** Sagittal section. T2-weighted MRI showing primary lymphoma affecting L5, leading to complete replacement of normal bone marrow and compression of the cauda equina.

Table 14.2 Benign neoplasms of the spine

Tumor	Age	Gender	Location	Radiographic findings	Symptoms	Treatment
Osteoid osteoma	< 30 y	M > F	Posterior elements	Sclerosis surrounding a radiolucent nidus (15- to 20-mm diameter)	Back pain Pain relieved by anti-inflammatories (salicylates, NSAIDs, COX-2 inhibitors)	Anti-inflammatories En bloc resection if fixed spinal deformity
Osteoblas-toma	< 30 y	M > F	Posterior elements Lumbar spine pre-dominant	Similar to osteoid osteoma Radiolucent nidus > 20 mm diameter	Dull back pain ±Neural compression	En bloc resection ± Fusion if instability present
Aneurysmal bone cyst	< 20 y	F > M	Posterior elements 70% in thora-columbar region	Axial deformity	Slowly pro-gressive pain Palpable mass Possible deformity	En bloc resection ± stabilization if instability present
Osteochon-droma	> 30 y	M > F	Posterior elements Primarily cervical region	Deformity Mature cortical and medullary bone continual with underlying bone	Pain and swelling in affected areas	En bloc resection ± stabilization
Giant cell tumor	20–50 y	F > M	Vertebral body	Expansile, lytic lesion with sclerotic rim Compression fractures	Back pain ± radiating pain Spinal cord compression	En bloc resection ± Adjuvant therapy if resection not viable

(Continued)

Table 14.2 (*Continued*)

Tumor	Age	Gender	Location	Radiographic findings	Symptoms	Treatment
Eosinophilic granuloma	< 10 y	M > F	Vertebral body Thoracic region	Lytic lesions in vertebral body Vertebra plana	Persistent back pain Restricted ROM Deformity Diabetes insipidus (pituitary involvement)	Rest ± analgesics as necessary
Hemangioma	Variable	M=F	Thoracic and lumbar spine	Corduroy patterns with vertical striations	Often asymptomatic Possible pain, neurodeficits	Only if symptomatic Radiation therapy Transarterial embolization Vertebroplasty/ kyphoplasty

Abbreviations: COX-2, cyclooxygenase-2; NSAIDs, nonsteroidal anti-inflammatory drugs; ROM, range of motion.

Table 14.3 Primary malignant tumors of the spine

Tumor	Age	Gender	Location	Radiographic findings	Symptoms	Treatment
Solitary plasmacytoma	> 50 y	M > F	Vertebral body	Punched-out lytic lesions	Spinal cord compression Pathologic fractures Possible paraparesis	Radiotherapy ± surgical stabilization Follow response to treatment via M light chain levels on serum protein electrophoresis
Chordoma	< 40 y	M > F	Sacrum, C1–C2	T2-weighted MRI is the modality of choice High T2 signal intensity, soft-tissue tumor extension	Nonspecific low back pain Rectal dysfunction Radiculopathy	En bloc resection with clear margins Must warn patients of possible bladder, bowel, and sexual dysfunction
Primary lymphoma	40–60 y	M > F	Vertebral body	Osteolytic lesions Ivory vertebrae	Local pain Spinal cord compression	Decompression via laminectomy + systemic chemo- and radiotherapy

Table 14.3 (*Continued*)

Tumor	Age	Gender	Location	Radiographic findings	Symptoms	Treatment
Chondro-sarcoma	> 40 y	M > F	Vertebral body	Bony destruction Soft-tissue mass with matrix calcification	Pain Neurologic deficit	En bloc surgical resection
Osteosar-coma	< 20 y	M > F	Vertebral body	Mixed lytic and sclerotic lesions with cortical destruction	Pain Neurologic deficit due to cord compression	En bloc local excision Radiation and chemotheapy
Ewing's sarcoma	< 20 y	M > F	Vertebral body	Mottled, moth-eaten appearance Irregular bone destruction with ill-defined margins Soft-tissue mass	Pain, swelling Systemic symptoms (fever) Neurologic deficits due to cord compression	Combined radiation and chemotherapy Surgery reserved for cases with instability and neurologic deficit

Abbreviation: MRI, magnetic resonance imaging.

Table 14.4 Intraspinal neoplasms or cysts

Tumor	Age	Gender	Radiographic findings	Treatment	Symptoms	Notes
Schwanno-ma	20-50 y	M = F	Circular filling defect on myelogram	Surgical excision	Shooting pain and paresthesias upon nerve palpation	Most common spinal nerve or cord tumor Common in patients with neurofibromatosis (67%)
Meningi-oma	40–50 y	F > M	Solid, well-circumscribed lesion with broad dural attachment	Surgical excision	Pain, not reproducible on palpation	Primarily solitary lesions (90%) Involve multiple nerve fascicles and travel parallel to the nerve
Neurofibro-ma	20–30 y	-	Dumb-bell-shaped, circular defect Vertebral erosion and rib thinning	Surgical excision Adjuvant therapy if resection is incomplete	Pain ± weakness, possible paralysis Possible deformity	80–90% of spinal involvement is in the thoracic region More commonly intracranial

Table 14.5 Intradural intramedullary tumors

Tumor	Age	Gender	Radiographic findings	Treatment	Symptoms	Notes
Astrocytoma	40–60 y	M > F	Expansile lesions with ill-defined borders Spans multiple vertebral segments	Surgical excision	Pain Sensory deficits Motor deficits distal to the spinal levels of involvement	Arise from glial cell transformation
Ependymoma	30–40 y	M = F	Areas of cystic change with cord expansion High-signal intensity intraparenchymally	Surgical excision	Back pain Paresthesia Sensory loss Lower extremity spasticity	Arise from cuboidal ependymal cells Most common adult primary spinal parenchymal neoplasm
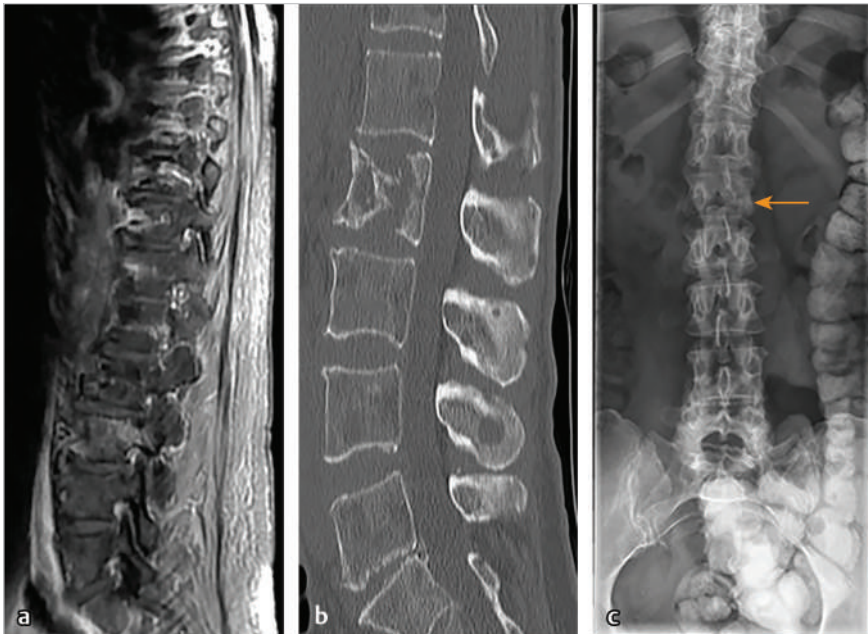
Fig. 14.4 Metastatic tumors of the spine. **(a)** Sagittal view. T1-weighted MRI showing multiple lytic metastatic lesions derived from renal cell carcinoma. **(b)** Sagittal section. CT scan showing multiple lytic lesions arising from breast cancer. Note the presence of a pathologic fracture in the L2 vertebral body. **(c)** Anteroposterior view. Radiograph showing the classic winking owl sign at L2 (*arrow*), associated with lytic activity within pedicular bone. This sign is often associated with metastatic spinal lesions.

- Motor, autonomic dysfunction due to metastatic spinal cord compression.
- Sensory and motor dysfunction.
- Imaging:
  - Plain radiographs:
    - Osteolytic lesions in the majority of cases.
    - Osteoblastic lesions if primary lesion is prostate or breast cancer.
    - Pathologic and compression fractures.
    - Deformity.
  - Bone scan:
    - Can reveal other metastatic lesions at an earlier stage than plain radiography.
  - CT scan:
    - Improved visualization of bony anatomy.
    - Important for determination of primary neoplasm and other areas of metastasis.
  - MRI:
    - Gold standard: allows for superior resolution of soft tissue, disk space, spinal cord, and nerve roots.
    - The degree of cord compression has been objectified via the metastatic epidural spinal cord compression scale:
      - Grade 0: bone disease only.
      - Grade 1a: epidural impingement without thecal sac deformation.
      - Grade 1b: deformation of the thecal sac without spinal cord abutment.
      - Grade 1c: deformation of the thecal sac and spinal cord abutment, but without cord compression.
      - Grade 2: spinal cord compression with visible CSF around the cord.
      - Grade 3: spinal cord compression with no visible CSF around the cord.
  - Angiography:
    - Required when primary tumors are highly vascular (thyroid, RCC).
    - Allows for surgical planning and possible preoperative embolization to control hemorrhage.

14.6.2 Management (Table 14.6)

- Decision framework for treatment of metastatic spine disease:
  - The Neurologic, Oncologic, Mechanical Instability, and Systemic Disease (NOMS) framework: approach to the treatment of spinal metastatic tumors.
  - Provides a framework via four functional assessments: neurologic, oncologic, mechanical, and systemic diseases.
- Symptomatic therapy:
  - Analgesia.
  - Corticosteroids:
    - Reduce pain via decreasing tumor inflammation and edema.
  - Bisphosphonates:
    - Reduces the risk of pathologic fracture, pain due to lytic lesions.
    - Lowers hypercalcemia of malignancy.

Table 14.6 The NOMS framework for treatment of metastatic spine disease

Neurologic
Radiographic evidence of epidural spinal cord compression Clinical assessment of myelopathy Clinical assessment of functional radiculopathy
Oncologic
Expected response to treatment Durability of response to various treatments, including: SRS, EBRT, immunotherapy, biologics, chemotherapy, hormone treatment
Mechanical instability
Associated with pathologic fractures Treatment options include: brace, percutaneous cement, and/or pedicle screw augmentation, open surgery
Systemic disease
Presence of medical comorbidities Ability to tolerate proposed treatment modalities Overall expected survival based on disease severity and tumor histological factors
Abbreviations: EBRT, external beam radiation therapy; NOMS, Neurologic, Oncologic, Mechanical Instability, and Systemic Disease; SRS, stereotactic radiosurgery.

- Radiation therapy:
  - Mainstay of therapy.
  - Indications include the following:
    - Radiosensitive tumors (hematopoietic, prostate, breast) without spinal instability.
    - Diffuse spinal involvement.
    - Contraindication or inability to tolerate surgery.
- Targeted medical treatments:
  - Efficacy varies with oncologic diagnosis.
  - Combinations of tyrosine kinase inhibitors, monoclonal antibodies, and other targeted immunotherapy drugs have shown improved outcomes compared to traditional cytotoxic chemotherapy.
- Preoperative embolization:
  - Necessary for hypervascular metastatic lesions:
    - An accurate mapping of the arterial geography is crucial.
    - Often performed within 48 hours of the planned procedure.
- Hormonal therapy:
  - Used for metastatic spinal lesions:
    - Prostate cancer: gonadotropin-releasing hormone (GnRH) agonists ± flutamide.
    - Breast cancer: estrogen antagonists and aromatase inhibitors.
- Stereotactic radiosurgery:
  - Delivers high doses of radiation to small foci of tissue.
  - Novel approach that allows for greater lesion targeting and minimization of radiation exposure to normal tissues.
  - Can be administered in an outpatient setting.

• Surgical therapy with adjuvant radiotherapy:
  – Indications include the following:
    ◦ Tumors resistant to radiation therapy or a previously failed radiation therapy course.
    ◦ Curative excision.
    ◦ Rapid neurological decline or epidural cord compression.
    ◦ Anatomic instability.
    ◦ Necessity of tissue diagnosis.
    ◦ Intractable pain.
  – Approach can be anterior or posterior depending on the tumor location:
    ◦ Anterior approach: vertebral body involvement.
    ◦ Posterior approach: used if instrumented stabilization is needed.
  – Vertebroplasty or kyphoplasty can also be used for the treatment of pain, pathologic fractures:
    ◦ Kyphoplasty may also improve spinal kyphosis due to balloon expansion.

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15 Spinal Infections

Ankur S. Narain, Fady Y. Hijji, Philip K. Louie, Daniel D. Bohl, and Kern Singh

15.1 Introduction

Spinal infections require early diagnosis in order to prevent both structural and neurologic compromises. The differential diagnoses related to symptoms associated with infection include degenerative disease, neoplasm, trauma, and vascular compromise. As such, knowledge of the specific clinical and imaging findings associated with infectious etiologies of the spine is crucial to ensure timely recognition of disease presentation and initiation of treatment (**Table 15.1**).

15.2 Vertebral Osteomyelitis and Diskitis

- Background and etiology:
  – Infection of the vertebral body or intervertebral disk.
  – Most commonly caused by hematogenous spread of *Staphylococcus* or *Streptococcus* spp.

Table 15.1 Summary of infections

Infection	Presentation	Clinical evaluation	Imaging evaluation	Primary treatment
Vertebral osteomyelitis and diskitis	• Axial pain • Fever • Neurologic symptoms	• WBC, ESR, CRP • Blood cultures • UA, urine	• MRI: edema and fluid within disk space	• IV antibiotics 6–8 weeks
Spinal epidural abscess	• Axial pain • Motor weakness • Pain	• WBC, ESR, CRP • Blood cultures • Open biopsy	• MRI: fluid within the epidural space	• Surgical with adjuvant antibiotics
Spinal TB	• Insidious onset • Paraplegia • Spinal deformity • Back pain	• ESR, CRP • Blood culture • PPD • AFB stain	• MRI: destruction of vertebral bodies with disk sparing • CXR: pulmonary disease	• 6–12 months of multidrug antibiotic therapy
Surgical site/ postoperative infection	• Erythema • Fluctuance • Drainage from incision	• ESR, CRP, WBC • Wound culture	• CT: abscesses • MRI: fluid collections	• Prophylactic antibiotics • Open irrigation and debridement with antibiotics

Abbreviations: AFB, acid-fast bacilli; CRP, C-reactive protein; CT, computed tomography; CXR, chest X-ray; ESR, erythrocyte sedimentation rate; IV, intravenous; MRI, magnetic resonance imaging; PPD, purified protein derivatives; TB, tuberculosis; UA, urinalysis; WBC, white blood cell.

○ Spread from vascular end plates to:
  ▪ Avascular disk space (diskitis).
  ▪ Vertebral bodies (osteomyelitis).
– Most commonly affects lumbar (58%) > thoracic (30%) > cervical (11%) vertebrae.
– Risk factors include diabetes mellitus, intravenous drug use, corticosteroid therapy.
• Presentation:
– Common symptoms include axial pain (86%) and fever (35–60%).
– Neurologic symptoms (34%):
  ○ Radiculopathy, limb weakness, dysesthesia, urinary retention.

• Clinical evaluation:
– Inquire about constitutional symptoms, travel history, recent spinal procedures with or without instrumentation.
– Labs:
  ○ White blood cell (WBC), erythrocyte sedimentation rate (ESR), C-reactive protein (CRP).
    ▪ ESR and CRP highly specific (98–100%).
    ▪ CRP correlates with response to treatment.
  ○ Blood cultures:
    ▪ Positive in 58% of cases.
  ○ Urinalysis and urine culture:
    ▪ To determine if urinary tract infection (UTI) is a source of the primary infection.

• Radiographic evaluation:
– Plain radiographs: findings occur several weeks after infection onset:
  ○ Regional osteopenia, periosteal reaction/thickening, focal bone lysis or cortical loss, endosteal scalloping, loss of bony trabeculae.
– Magnetic resonance imaging (MRI; 94% sensitivity): preferred imaging modality if neurologic deficit is present:
  ○ T2-weighted imaging shows edema and fluid within disks and adjacent soft tissue (**Fig. 15.1**).
– Computed tomography (CT) scan (94% sensitivity): performed if MRI contraindicated:
  ○ Superior to plain radiographs and MRI at analyzing bony margins and identifying involucrum/sequestrum.
– Bone scan (67% sensitivity): positive within a few days of symptom onset, nonspecific.

• Treatment:
– Medical treatment:
  ○ Preferred initial therapeutic option.
  ○ Intravenous (IV) antibiotics for 6 to 8 weeks, initial broad coverage with narrowing to pathogen-specific regimen pending susceptibilities.
– Surgical therapy:
  ○ Indications:
    ▪ Failure of medical management.
    ▪ Drainage of abscesses and debridement of infected tissue.
    ▪ Development of neurological deterioration.
    ▪ Decompression of neural structures.
    ▪ Spinal instability.
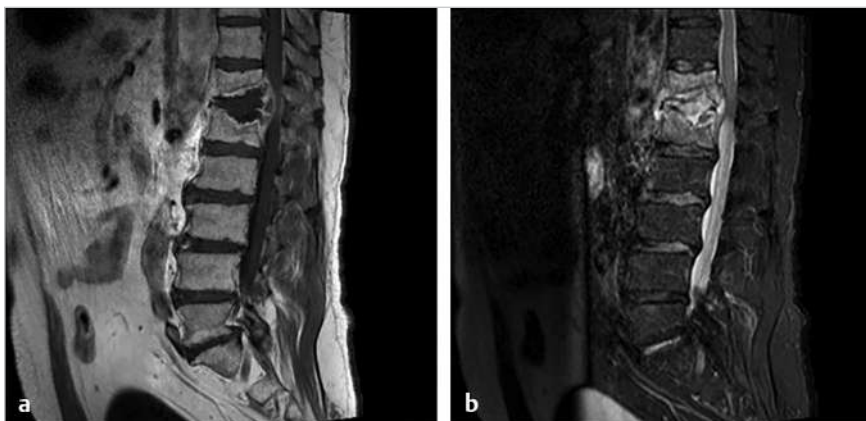
Fig. 15.1 (a) Sagittal T1-weighted MRI showing osteomyelitis involving the T12–L1 disk space, vertebral bodies, and surrounding soft tissue. **(b)** Sagittal T2-weighted MRI showing osteomyelitis involving the T12–L1 disk space, vertebral bodies, and surrounding soft tissue.

15.3 Spinal Epidural Abscess

• Background and etiology:
  – Infection of the epidural space.
  – Source:
    ◦ Direct inoculation.
    ◦ Contiguous spread:
      ▪ Adjacent osteomyelitis or diskitis.
    ◦ Hematogenous extension.
  – *S. aureus* is the most common pathogen (64%).
  – Affects lumbar (48%) > thoracic (31–33%) > cervical (22–24%) spine.
  – Risk factors: intravenous drug use (IVDU; 22–23%), diabetes mellitus (27–28%).
• Presentation:
  – Most common symptoms include axial pain (67%), neuromuscular complaints (52%), fever (44%).
  – Large lesions can compress neural elements and lead to focal neurologic deficits.
• Clinical evaluation:
  – Labs:
    ◦ WBC, ESR, CRP.
    ◦ Blood cultures.
  – Possible open biopsy to identify specific organism.
• Radiographic evaluation:
  – Plain radiographs: may show disk narrowing and/or bone lysis.
  – MRI (high sensitivity and specificity): clearly demonstrates fluid collection within the epidural space (**Fig. 15.2**).
• Treatment:
  – Surgical intervention with adjuvant antibiotics:
    ◦ Indicated if neurologic deficit is present.

Fig. 15.2 Sagittal T1-weighted MRI showing an epidural abscess in the thoracic spine.

- ○ Irrigation and debridement with neurologic decompression.
- ○ Approach based on location and etiology:
  - ▪ Posterior: laminectomy.
  - ▪ Anterior: ventral abscess or vertebral osteomyelitis.
- ○ Arthrodesis if instability suspected.
- – Medical therapy with antibiotics only:
  - ○ Indicated if neurologic deficits are absent.
  - ○ High conversion rate to surgical therapy (10–49%).

15.4 Spinal Tuberculosis (Pott's Disease)

- Background and etiology:
  - – Granulomatous infection of the spine.
  - – Distant source or latent reactivation leads to inoculation within the peridiskal metaphysis of the vertebral end plate:
    - ○ Inflammatory response leads to caseating granuloma formation.
    - ○ Active bone destruction (spondylosis).
    - ○ Often spreads via the anterior longitudinal ligament to nearby levels.

- Spine is the most common site of skeletal tuberculosis (TB) involvement (1% of all TB cases, 50% of those with musculoskeletal involvement):
  - Thoracic and upper lumbar levels most commonly affected.
- Presentation:
  - Insidious progression of disease over weeks to years.
  - Paraplegia and spinal deformity (70%):
    - Kyphosis due to anterior vertebral body collapse.
  - Back pain.
  - Constitutional complaints.
  - Symptoms of pulmonary TB:
    - Persistent cough, hemoptysis.
- Clinical evaluation:
  - Inquire about current TB infection or previous TB exposure.
  - Labs:
    - ESR, CRP, blood cultures.
    - Tuberculin purified protein derivative (PPD) skin test.
    - Sputum, bone tissue, abscess aspirate for acid-fast bacilli stain:
      - Abscess aspirates obtained via CT- or ultrasound-guided biopsy.
- Radiographic evaluation:
  - Chest X-ray: to evaluate for pulmonary disease, extensive bony lesions, focal kyphosis.
  - Plain radiography: findings require more than 30% of vertebral body destruction; can be delayed up to 6 months after infection:
    - Reduction in vertebral height often with irregularity of the anterosuperior end plate.
    - Subligamentous extension with further progression, resulting in irregularity at the anterior vertebral margin.
  - MRI (highly sensitive and specific): destruction of vertebral bodies with intervertebral disk sparing:
    - T1: hypointense marrow in adjacent vertebrae (**Fig. 15.3a**).
    - T2: hyperintense marrow, disk, soft-tissue involvement (**Fig. 15.3b**).
- Treatment:
  - Medical therapy:
    - Multidrug treatment of 6 to 12 months:
      - Rifampin.
      - Pyrazinamide.
      - Streptomycin or ethambutol.
      - Isoniazid.
  - Surgical therapy:
    - Indications:
      - Failure of medical therapy.
      - Instability.
      - Deformity.
      - Neurologic decline.
      - Intractable pain caused by abscess.
    - Anterior reconstruction ± supplemental posterior fixation to prevent deformity.
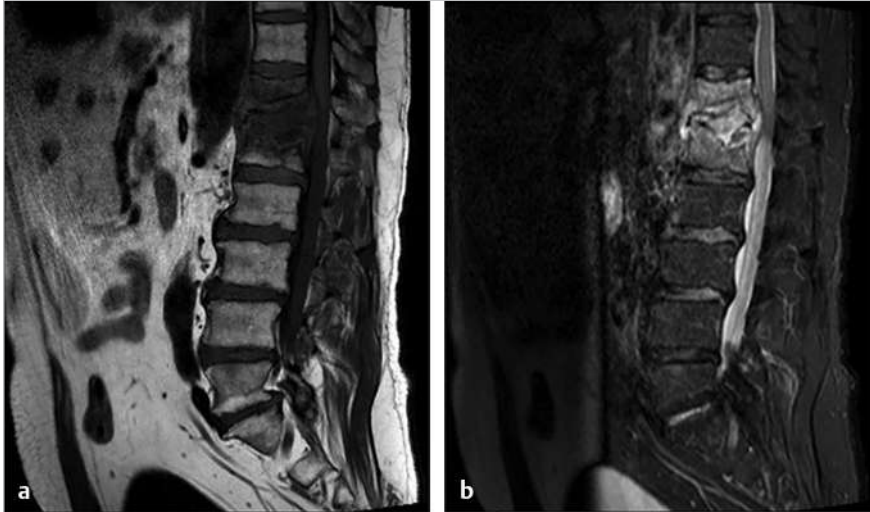
Fig. 15.3 (a) Sagittal T1-weighted MRI showing spinal TB infection involving T12–L1. **(b)** Sagittal T2-weighted MRI showing spinal TB infection involving T12–L1.

15.5 Surgical Site and Postoperative Infections

- Background and etiology:
  - Direct inoculation of exposed wound by skin flora.
  - Occurs in 0.7 to 12% of spinal operations in adults:
    - Leads to increased morbidity, mortality, health care costs.
  - Risk factors include diabetes, previous surgical site infection, spinal deformity, longer operative times, multiple-level fusion, posterior surgical approaches, combined anteroposterior surgical approaches, estimated blood loss greater than 1 L.
- Presentation:
  - Location:
    - Superficial: contained within the skin and subcutaneous tissues without fascial involvement (suprafascial).
    - Deep: deep to the lumbodorsal fascia (lumbar) or ligamentum nuchae (cervical).
  - Erythema, palpable fluctuance, drainage from the incision.
- Clinical evaluation:
  - Labs:
    - ESR, CRP, WBC.
  - Wound culture:
    - Intraoperative cultures are best.
    - Deep cultures are best since they are not contaminated with skin flora.

- Radiographic evaluation:
  - Plain radiographs: often without obvious abnormalities.
  - CT scan: reveals abscesses.
  - MRI: superior soft-tissue resolution allows for enhanced views of fluid collections (**Figs. 15.4, 15.5**).
- Treatment:
  - Prevention:
    - ◦ Prophylactic antibiotics within 60 minutes prior to procedure start.
    - ◦ Redosing if the procedure is prolonged (~3–4 hours).
  - Irrigation and debridement with subsequent 6-week course of antibiotics:
    - ◦ Collect intraoperative deep wound cultures before antibiotic administration.
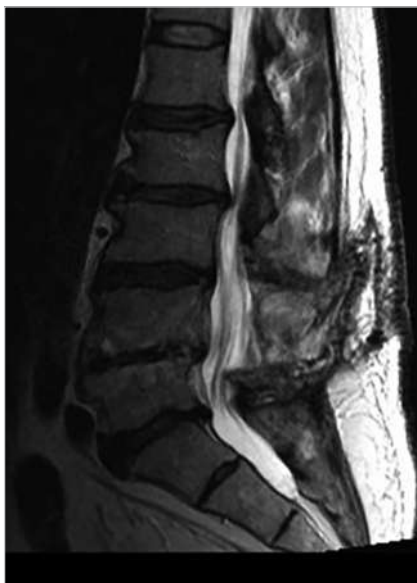
Fig. 15.4 Sagittal STIR-weighted MRI showing postoperative infection at the lumbosacral junction with soft-tissue involvement.
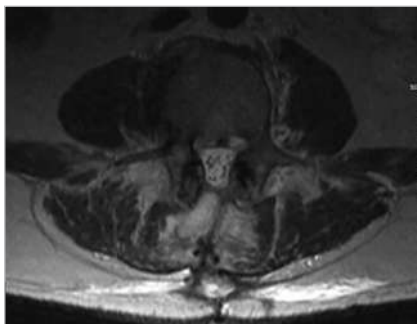
Fig. 15.5 Axial T2-weighted MRI showing postoperative infection extending into posterior musculature.

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16 Pediatrics

Jonathan Markowitz, Ankur S. Narain, Fady Y. Hijji, Philip K. Louie, Daniel D. Bohl, and Kern Singh

16.1 Background

- Most congenital spinal pathologies affect the upper cervical or lumbar regions:
  - Due to defective spina cord embryogenesis and/or vertebral malformation.
- Neural tube defect (NTD):
  - Incomplete fusion of the neural tube during fetal development.
  - Myelodysplasia is the most common type of NTD:
    - These include spina bifida occulta, meningocele, myelomeningocele, and rachischisis.
- Spine bifida affects approximately 1,500 births annually in the United States:
  - Highest rates of NTDs are found in China, Ireland, Great Britain, Pakistan, India, and Egypt.

16.2 Myelodysplasia (Spina Bifida)

- Background and etiology:
  - Incomplete closure of the caudal end of the neural tube during spinal cord development and lack of fusion of vertebral arches:
    - Development of the vertebrae and spinal column begin in the third week of embryonic development.
    - The neural tube is created by the inward folding and fusing of the neural plate (primary neurulation).
    - Neural tube is the embryo's precursor to the central nervous system.
  - Results in an open lesion or sac (spina bifida cystica) that can contain the spinal cord, nerve roots, and meninges:
    - Varying degrees of myelodysplasia depending on level of failed closure.
  - Environmental causes:
    - Maternal folic acid deficiency.
    - Maternal use of folic acid antagonists (dihydrofolate reductase inhibitors): aminopterin, methotrexate, sulfasalazine, pyrimethamine, triamterene, and trimethoprim.
    - Antiepileptic drugs: carbamazepine, valproate, phenytoin, primidone, and phenobarbital.
    - Maternal hyperthermia.
    - Maternal diabetes.

- Types of myelodysplasia:
  - Spina bifida occulta:
    - Mildest form.
    - Unfused vertebral arch.
    - Meninges do not herniate through the opening in the spinal canal.
  - Meningocele:
    - A subset of spina bifida cystica:
      - Spinal elements are contained within a sac.
    - Herniation of the meninges (excluding the spinal cord), through the opening in the spinal canal.
  - Myelomeningocele:
    - A subset of spina bifida cystica.
    - Herniation of the meninges and the spinal cord through the opening in the spinal canal.
  - Rachischisis:
    - Neural elements exposed with no covering.
- Presentation:
  - Mild forms (i.e., spina bifida occulta) may be asymptomatic:
    - Occasional abnormal tuft of hair or small dimple at the site of the spinal malformation.
  - Meningocele or myelomeningocele will present with a cyst containing neural elements.
  - Neurological symptoms can include bladder, motor, and sensory paralysis below the level of the spinal lesion.
  - Often associated with latex allergy.
  - Functional status is primarily related to the level of the defect (**Table 16.1**):

Table 16.1 Clinical presentation associated with level of myelodysplasia

Level	Hip deformity	Knee deformity	Foot deformity	Degree of ambulation[a]	Muscles involved	Orthosis
L1	Flexion/external rotation	–	Equinovarus	Nonambulatory	–	HKAFO
L2	Flexion/adduction	Flexion	Equinovarus	Nonambulatory	Quadriceps	HKAFO
L3	Flexion/adduction	Recurvatum	Equinovarus	Household	Iliopsoas and hip adductors	KAFO
L4	Flexion/adduction	Extension	Cavovarus	Household, some community	Quadriceps and tibialis anterior	AFO
L5	Flexed	Limited flexion	Calcaneal valgus	Community	EHL, EDL and gluteus medius and minimus	AFO
S1	–	–	Foot deformity	Normal	Gastrocsoleus	Shoes

Abbreviations: AFO, ankle–foot orthosis; EDL, extensor digitorum longus; EHL, extensor hallucis longus; HKAFO, hip–knee–ankle–foot orthosis; KAFO, knee–ankle–foot orthosis.
Note: Level of myelodysplastic defect and corresponding deformity and functional status.
[a]Community ambulation defined as locomotion outdoors that includes activities necessary to live independently.

- ◦ Deformities that occur in patients with myelomeningocele are secondary to unbalanced/asymmetric muscle action around joints, paralysis, and decreased sensation in the lower extremities.
- ◦ Lesion of L3 or above are mostly confined to a wheelchair.
  - Changes in functional level should alert the physician to the possibility of tethered cord syndrome:
    - ◦ Formation of fibrous attachments between the spinal cord and spinal canal:
      - ▪ Results in stretching of the spinal cord and progressive cord damage and neurologic deficit.
- • Clinical evaluation:
  - Examination should include assessment of level and degree of motor and sensory function, range of motion (ROM), spinal deformity, integrity of the skin, and associated deformities and contractures.
  - Prenatal laboratory diagnosis:
    - ◦ Maternal screening of serum alpha fetoprotein (AFP) levels:
      - ▪ Performed ideally at 16 to 18 weeks of gestation, but can be performed as early as 15 weeks or as late as 20 weeks.
      - ▪ First trimester screening is not recommended because of low sensitivity.
  - Magnetic resonance imaging (MRI) or computed tomography (CT) may be performed to get a more precise understanding of the underlying defect (**Fig. 16.1**):
    - ◦ Dysplasia of the spinal cord and nerve roots may lead to bowel, bladder, motor, and sensory paralysis below the level of the lesion.
- • Treatment and prevention:
  - Maternal consumption of 0.4 mg (400 µg) of folic acid a day for ≥3 months before conception, decrease the chance of NTD by 70 to 80%.
  - Aim of treatment is to enable the child to reach the highest degree of strength, function, and independence:
    - ◦ Spina bifida occulta:
      - ▪ Patients usually do not need surgery.
      - ▪ Conservative management and watchful monitoring is recommended.
    - ◦ Meningocele:
      - ▪ Surgical treatment for the removal of the cyst is typically recommended.
      - ▪ If later orthopedic surgical intervention is necessary, it usually focuses on balancing of the muscles and correction of deformities.
    - ◦ Myelomeningocele and rachischisis:
      - ▪ Early treatment with antibiotics is necessary in order to prevent infection of the spinal cord.
      - ▪ Requires surgery within the first few days of life to correct the spinal defect and prevent infection and further injury to the exposed spinal cord/nerve roots.
      - ▪ Most common complications with surgery are tethered spinal cord and hydrocephalus.
      - ▪ In utero surgical intervention may be considered.
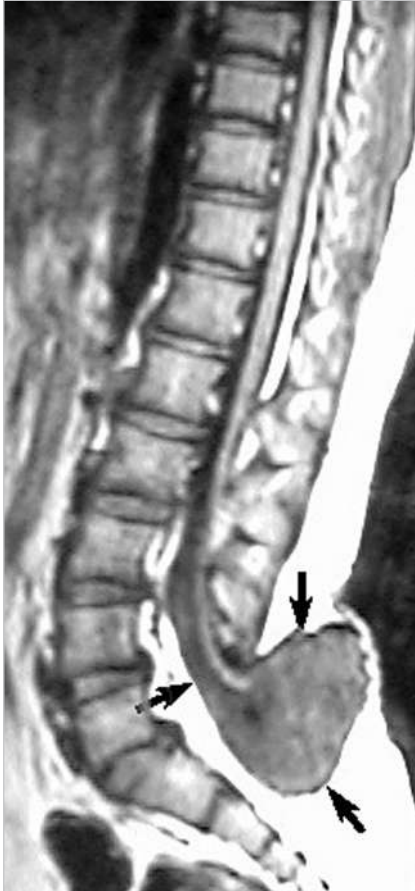
Fig. 16.1 Sagittal T1-weighted MRI demonstrating myelomeningocele contiguous with spinal canal contents (*arrows*). (Reproduced with permission from Khanna AJ, ed. MRI Essentials for the Spine Specialist. New York, NY: Thieme; 2014.)

16.3 Congenital Torticollis

- Background and etiology:
  - Contracture of the sternocleidomastoid (SCM).
  - 0.3 to 2% of newborns.
  - More common in males (1.5:1).
  - Etiology unknown:
    - Possibly due to malposition of the head in utero and injury to the SCM muscle resulting in fibrosis.
  - Usually evident by 2 to 4 weeks of age:
    - Not to be confused with acquired, which usually occurs due to injury, inflammation, or medications.
  - Three types of congenital torticollis:
    - Postural: no muscle tightness or restriction to passive ROM, but infant has a postural preference.

- ◦ Muscular: tightness of SCM with limitation in passive ROM.
    - ◦ SCM mass: palpable pseudotumor or swelling in the body of SCM, limited in passive ROM.
- Clinical presentation:
    - – Characterized by lateral neck flexion (head tilted to affected side) and neck rotation (chin pointed to contralateral side):
        - ◦ Reduced cervical ROM.
        - ◦ Infant usually has a preferred head position during feeding and sleeping.
        - ◦ Right SCM more commonly affected.
    - – Associated with facial asymmetry.
- Clinical evaluation and imaging:
    - – A diagnosis of congenital muscular torticollis can be made on the basis of history and physical examination.
- Treatment:
    - – Nonoperative treatment:
        - ◦ Passive stretching exercises:
            - ▪ Rotate infant's chin to ipsilateral shoulder while simultaneously tilting the head toward so that the ear touches the contralateral shoulder.
        - ◦ Adjunctive use of soft cervical collar.
    - – Surgical treatment:
        - ◦ Recommended when patient has persistently restricted ROM.
        - ◦ Lengthens the contracted SCM through a unipolar release, bipolar release, endoscopic release, and subperiosteal lengthening.
        - ◦ Postoperative physical therapy consisting of ROM exercises.
        - ◦ A cervical collar may be worn postoperatively.

16.4 Klippel–Feil Syndrome

- Background and etiology:
    - – Congenital skeletal disorder characterized by abnormal union or fusion of two or more cervical vertebrae:
        - ◦ Failure of normal segmentation or formation of cervical vertebrae precursors at 3 to 8 weeks.
- Classification:
    - – No universally agreed upon classification system.
    - – Samartzis' classification system:
        - ◦ Type I: single-level fusion.
        - ◦ Type II: multiple, noncontiguous fused segments.
        - ◦ Type III: multiple, contiguous fused segments.
- Clinical presentation:
    - – Classic triad (seen in <50% of cases):
        - ◦ Short neck.

  ◦ Low posterior hairline.
  ◦ Decreased cervical ROM.
- Commonly associated with other congenital abnormalities (**Table 16.2**).
- Degenerative cervical disk disease is seen in almost 100% of patients.

• Clinical evaluation and imaging:
  - Radiographs and CT: anteroposterior (AP)/axial, lateral/sagittal, and odontoid views of cervical spine (**Fig. 16.2**):
    ◦ Fusion of at least two cervical vertebrae.
  - Consider MRI to rule out intraspinal cord abnormalities.

• Treatment and prevention:
  - Conservative management.
  - Avoid contact sports.
  - If patient has chronic pain and/or myelopathy, surgical decompression and fusion is recommended.

Table 16.2 Spectrum of anomalies known to be associated with Klippel-Feil syndrome

Anomaly	Percentage of patients
Congenital scoliosis	>50
Sensorineural hearing impairment	30
Genitourinary abnormalities	25–35
Sprengel's deformity	20–30
Facial asymmetry	20
Torticollis	20
Ptosis, horizontal nystagmus, and cleft palate	Common
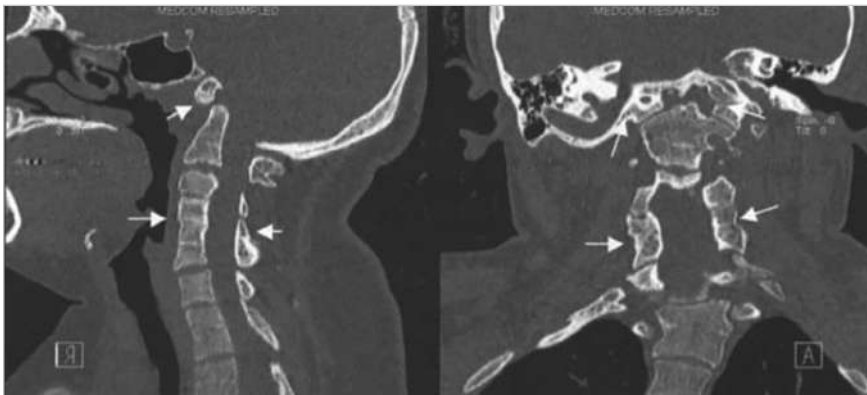
Fig. 16.2 CT scan of sagittal and coronal slices demonstrates fused cervical segments (*arrows*), indicating Klippel–Feil syndrome.

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17 Anterior Cervical Diskectomy and Fusion

Ankur S. Narain, Fady Y. Hijji, Philip K. Louie, Daniel D. Bohl, and Kern Singh

17.1 Case Presentation: Presentation and Preoperative Imaging

A 38-year-old man presents to the office with long-standing neck pain radiating into the bilateral upper extremities. He notes numbness and tingling in the forearms bilaterally. He also has weakness along with decreased grip strength and upper extremity dexterity bilaterally. He denies any recent trauma or infections. Conservative therapy with home exercises, nonsteroidal anti-inflammatory drugs (NSAIDs), and oral steroids have only provided temporary relief.

17.2 Indications

- Symptomatic cervical disk herniation with radiculopathy or myelopathy (**Fig. 17.1**).
- Cervical spondylosis with radiculopathy or myelopathy.
- Ossification of the posterior longitudinal ligament present with myelopathy.
- Unstable cervical fractures.
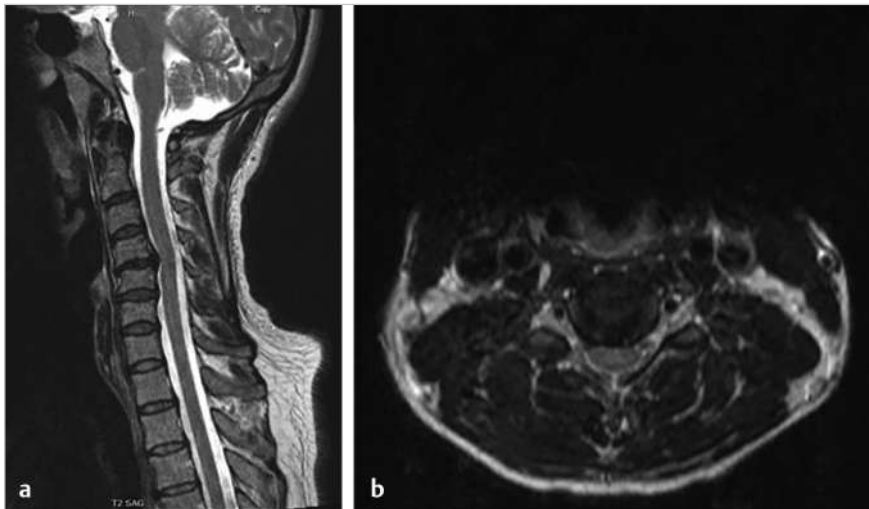
Fig. 17.1 (a,b) Sagittal and axial T2-weighted MRI demonstrating a herniated nucleus pulposus at C4–C5 with spinal cord compression.

17.3 Positioning

• Supine.
• Superficial landmarks include the following:
  – Lower border of mandible (C2–C3.)
  – Hyoid bone (C3).
  – Thyroid cartilage (C4–C5).
  – Cricoid cartilage (C6).

17.4 Approach

• Superficial dissection:
  – Skin incision at the level of pathology: oblique from midline to the posterior border of the sternocleidomastoid (SCM):
    ◦ Incise the fascial sheath over the platysma; split the platysma longitudinally
    ◦ No internervous plane is present as the platysma, which is innervated by the facial nerve, is divided beneath the fascial sheath.
  – Identify the anterior border of the SCM and incise the fascia immediately anterior to it; gently retract the SCM laterally .
  – Retract the strap muscles and tracheoesophageal structures medially. An internervous plane is present between the SCM (CN XI) and the strap muscles (C1–C3).
• Deep dissection:
  – The carotid sheath is now exposed; develop a plane between the carotid sheath and midline structures.
  – Retract the carotid sheath and SCM laterally.
  – After development of a plane deep to the pretracheal fascia, the cervical vertebrae should be visible.
  – Split the longus colli muscles longitudinally (**Fig. 17.2**):
    ◦ The recurrent laryngeal nerve is at risk during this approach; protect it with placement of retractors under the medial edge of the longus colli.

17.5 Implants and Hardware

• Structural bone grafts are placed after the diskectomy is performed:
  – Bone grafts can be auto- or allograft.
  – Grafts can also be alternative materials such as polyetheretherketone (PEEK) or carbon fiber filled with local bone obtained from the osteophyte resection or from bone graft substitutes.
• Anterior cervical plate and screws are used to stabilize the vertebral levels directly adjacent to the resected disk space.
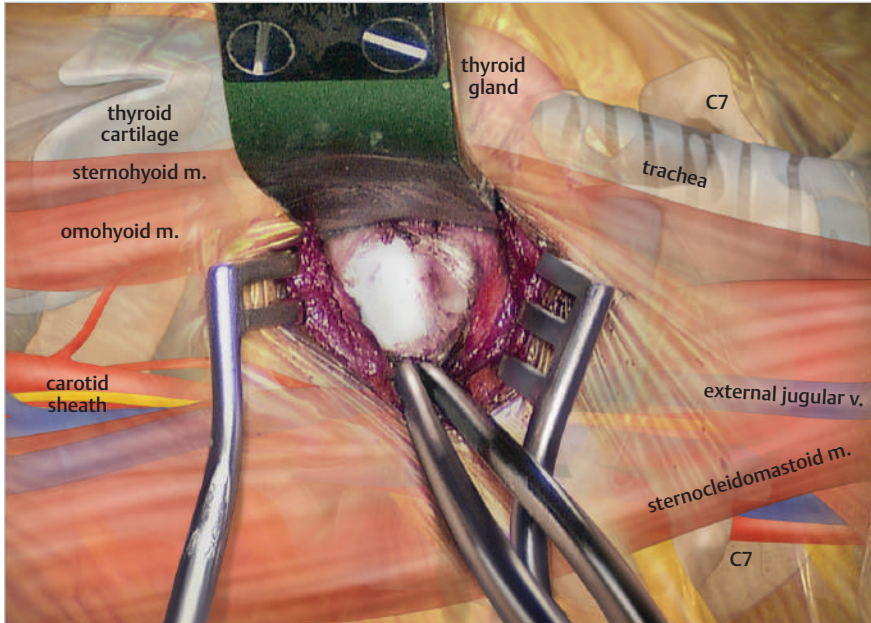
Fig. 17.2 Top-down view. Deep exposure showing the exposed vertebral body and adjacent disk spaces after retraction of the longus colli muscles. (Reproduced with permission from Singh K, Vaccaro AR, eds. Pocket Atlas of Spine Surgery. 2nd ed. New York, NY: Thieme; 2018.)

17.6 Case Presentation: Postoperative Imaging and Outcome

The patient underwent a C4–C5 anterior cervical diskectomy and fusion (ACDF) with placement of an interbody graft, anterior plate, and screw instrumentation. At 6-month follow-up, the patient reported minimal neck pain, with greatly reduced numbness and tingling in the bilateral upper extremities. Postoperative computed tomography (CT) and plain radiographs demonstrated adequately placed instrumentation with solid bony fusion at 6 months postoperatively (**Fig. 17.3**).

17.6.1 Complications

• Horner's syndrome:
  – Due to irritation of the sympathetic nerves or stellate ganglion:
    ◦ Most commonly associated with cervical retractors that are placed above the longus coli.
  – Presents with ptosis, anhydrosis, miosis, and loss of ciliospinal reflex.
• Hoarseness:
  – Irritation to the recurrent laryngeal nerve.

Fig. 17.3 (a,b) Sagittal postoperative CT and plain radiograph images demonstrating placement of anterior cage and screw instrumentation with bony fusion. **(c,d)** Coronal and anteroposterior postoperative CT and plain radiograph images demonstrating proper screw placement with bony fusion.

- Prevention:
  - Place retractors under the medial edge of the longus colli.
- Dysphagia:
  - Caused by excessive retraction of the esophagus:
    - Most commonly associated with increased operative time, number of surgical levels, and exposures at C3–C4 and C7–T1.
    - Not associated with side of surgical exposure (i.e., right vs. left).
  - Prevention:
    - Intermittent relaxation of self-retaining retractors during the procedure, partially deflating the endotracheal cuff once the cervical retractors are in position.
- Retropharyngeal hematoma:
  - Presents with respiratory difficulty and a tense neck mass.
  - Prevention:
    - Placement of a cervical drain in those at risk (older age, smoking history, increased operative levels).
  - Treatment:
    - Requires emergent decompression.

18 Posterior Cervical Laminoplasty with Instrumentation

Ankur S. Narain, Fady Y. Hijji, Philip K. Louie, Daniel D. Bohl, and Kern Singh

18.1 Case Presentation

A 70-year-old man presents to the clinic complaining of worsening ambulation. He also notes the pain radiates to his left scapula and left arm and is associated with numbness and paresthesia of his left lateral forearm and thumb. He also notes weakness and difficulty with fine motor tasks such as buttoning his shirt. On physical examination, the patient exhibits decreased sensation of his left lateral forearm, thumb, and index finger. He exhibits full strength on shoulder abduction, elbow flexion and extension, and wrist flexion and extension. He has a positive Spurling test, with a positive Hoffman sign. He is unable to perform the grip release test with 20 cycles of grips and releases within 10 seconds. The patient's radiographs and magnetic resonance imaging (MRI) are provided in **Figs. 18.1** and **18.2**. The patient is subsequently scheduled to receive a posterior cervical laminoplasty with instrumentation from C3 to C6.

18.2 Indications

• Paracentral cervical disk herniations.
• Cervical spinal stenosis at multiple levels.
• Cervical tumors.

18.3 Positioning

• Prone.
• Landmarks:
  – Spinous processes:
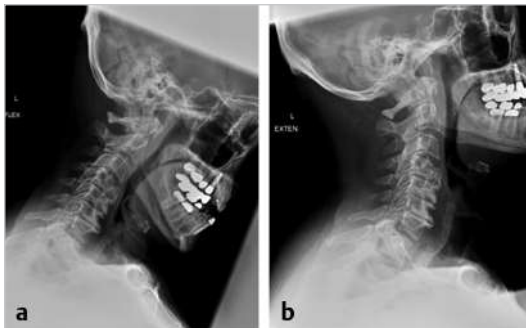
Fig. 18.1 Flexion **(a)** and extension **(b)** of cervical radiographs. There is significant cervical spondylosis of C3–T1 with C3–C4 and C7–T1 spondylolisthesis.

Fig. 18.2 Sagittal **(a)** and axial T2-weighted **(b)** cervical MRI. There is C3–T1 spondylosis with moderate to severe spinal stenosis.

- C2, C7, and T1 are largest spinous processes in the cervical region.
- C7 and T1 difficult to differentiate via palpation.

18.4 Approach

18.4.1 Superficial Dissection

- The skin incision is made midline over the targeted cervical levels:
  - Intraoperative imaging and needle placement is necessary to confirm the correct level of decompression.
  - The internervous plane is located between the paraspinal cervical muscles of either side. The dorsal rami of the cervical roots supply this region.
- The paracervical muscles are stripped subperiosteally to avoid bleeding:
  - Only the medial portion of the lamina/facet junction is exposed.
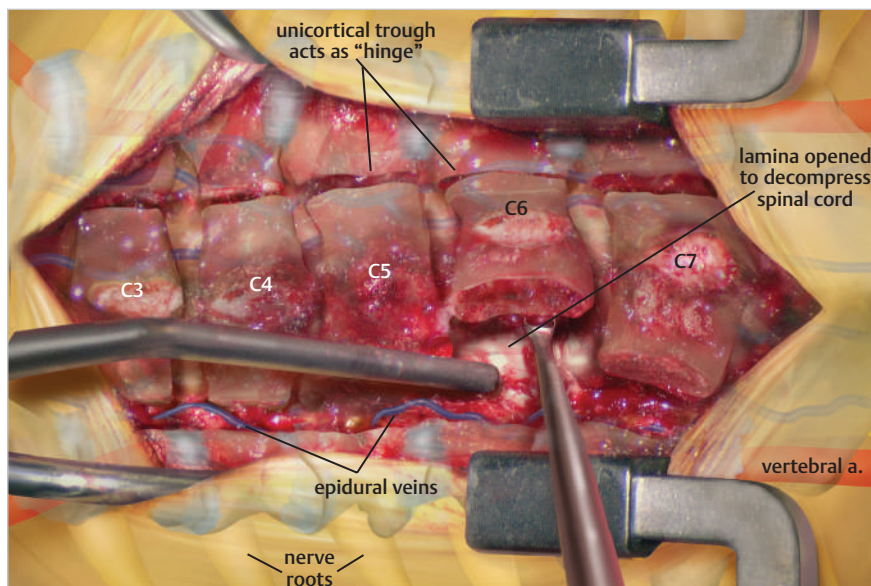
Fig. 18.3 Top-down view. A bicortical and unicortical trough have been created and the lamina has been opened to decompress the spinal cord. (Reproduced with permission from Singh K, Vaccaro AR, eds. Pocket Atlas of Spine Surgery. 2nd ed. New York, NY: Thieme; 2018.)

18.4.2 Deep Dissection

- Spinous processes are removed for the desired levels.
- The junction between the lamina and facets is identified and an opening is created (**Fig. 18.3**):
  - This opening is bicortical and penetrates completely through the bone.
- A similar trough is made on the contralateral side; however, this side is unicortical:
  - Serves as a hinge.

18.5 Implants and Hardware

- The lamina is lifted using the unicortical trough as a hinge.
- Plates are secured to the free end into the lateral mass (**Fig. 18.4**).

18.6 Case Presentation: Postoperative Outcome, and Imaging

The patient underwent a C3 to C6 posterior cervical laminoplasty with instrumentation. At 6-week follow-up, the patient notes significant improvement in his pain and complete resolution of his sensory and motor deficits. Postoperative radiographs demonstrate appropriate instrument positioning (**Fig. 18.5**).
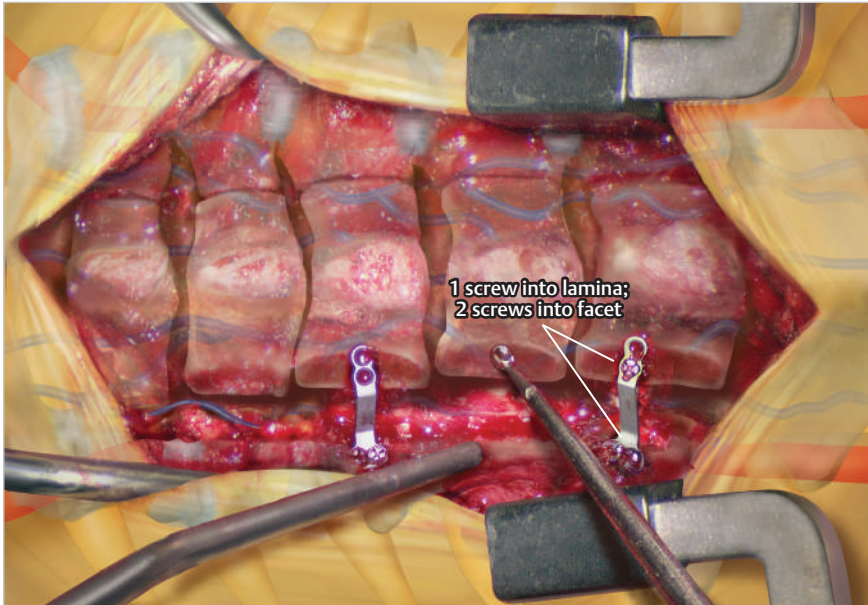
Fig. 18.4 Top-down view. A midline exposure has been performed with subperiosteal elevation of the paracervical muscles up the medial facet joints. (Reproduced with permission from Singh K, Vaccaro AR, eds. Pocket Atlas of Spine Surgery. 2nd ed. New York, NY: Thieme; 2018.)

Fig. 18.5 Lateral **(a)** and anteroposterior **(b)** radiographs. Six-week postoperative radiographs following posterior cervical laminoplasty demonstrating instrumentation placed at the C4 and C6 laminae.

18.7 Complications

• C5 nerve root palsy:
  – Incidence of 0.5 to 13.3%.
  – Unclear etiology:
    ◦ Thought to be due to posterior translation of the spinal cord following decompression:

- ▪ The short C5 nerve root experiences subsequent stretching.
  - ◦ No clear method for avoidance at this time.
  - – Risk factors:
    - ◦ Associated with significant spinal cord rotation.
    - ◦ Excessive posterior spinal cord drift.
    - ◦ Narrow foramina.
    - ◦ Ossified posterior longitudinal ligament.
  - – Presents with:
    - ◦ Biceps and deltoid weakness.
    - ◦ Sensory loss of the lateral upper arm.
    - ◦ Presents 48 to 72 hours following surgery.
  - – Treatment:
    - ◦ Self-limited; most resolve within 6 months.
- Postoperative neck pain and stiffness:
  - – Incidence of 40 to 60% and 20 to 50% for neck pain and stiffness, respectively. However, this incidence is based upon older literature where patients were immobilized for 6 to 12 weeks postoperatively.
  - – Unclear etiology:
    - ◦ Attributed to excessive paracervical periosteal stripping and postoperative immobilization.
  - – Risk factors:
    - ◦ Intraoperative facet joint disruption.
  - – Prevention:
    - ◦ Maintaining exposure medial to the facet capsules to avoid direct damage.
- Postoperative hematoma:
  - – Damage to thin-walled epidural vessels in the cervical canal can result in excessive bleeding.
  - – Treatment:
    - ◦ Control bleeding with hemostatic sponges intraoperatively.
  - – Prevention:
    - ◦ Obtain adequate hemostasis prior to closure.
    - ◦ Placement of wound drains while routinely performed may not prevent the formation of a hematoma.

Suggested Readings

1. Ratliff JK, Cooper PR. Cervical laminoplasty: a critical review. J Neurosurg 2003;98(3, Suppl):230–238
2. Gu Y, Cao P, Gao R, et al. Incidence and risk factors of C5 palsy following posterior cervical decompression: a systematic review. PLoS One 2014;9(8):e101933
3. Hosono N, Yonenobu K, Ono K. Neck and shoulder pain after laminoplasty. A noticeable complication. Spine 1996;21(17):1969–1973

19 Posterior Cervical Laminectomy and Fusion

Ankur S. Narain, Fady Y. Hijji, Philip K. Louie, Daniel D. Bohl, and Kern Singh

19.1 Case Presentation and Preoperative Imaging

A 61-year-old woman presents to your office with chronic neck pain and numbness in her right hand. The numbness is exacerbated by turning her head to the right, looking up, and overhead reaching. She has 5/5 strength and intact reflexes in the upper extremities bilaterally, with no clonus or spasticity. Hoffman's sign is positive bilaterally. Conservative therapy with heat and ice packs, and physical therapy have provided minimal pain relief. Magnetic resonance imaging (MRI) scan of the cervical spine was recommended (**Fig. 19.1**).

19.2 Indications

- Degenerative cervical disk disease with central stenosis, neuroforaminal stenosis, or myelopathy.
- Tumor.
- Epidural abscess.
- Ossification of the posterior longitudinal ligament with stenosis.

Fig. 19.1 Sagittal T2-weighted magnetic resonance imaging (MRI) demonstrating central spinal stenosis at C4–C5 and C5–C6.

19.3 Positioning

• Prone.
• Landmarks:
  – Spinous processes:
    ◦ C2, C7–T1 are the most prominent.

19.4 Approach

• Superficial dissection:
  – Straight incision is made in the midline:
    ◦ Internervous plane is in the midline; paracervical muscles are segmentally innervated by the left and right posterior rami.
    ◦ Minimal bleeding may emanate from the venous plexuses.
  – Dissection is performed through the ligamentum nuchae:
    ◦ Continuous with the supraspinous ligament.
• Deep dissection:
  – Remove paracervical muscles subperiosteally (**Fig. 19.2**):
    ◦ Excessive bleeding may occur from the segmental arterial vessels.
  – Perform laminectomy at the junction between the lamina and lateral mass of each side:
    ◦ The epidural veins are thin and may bleed copiously.
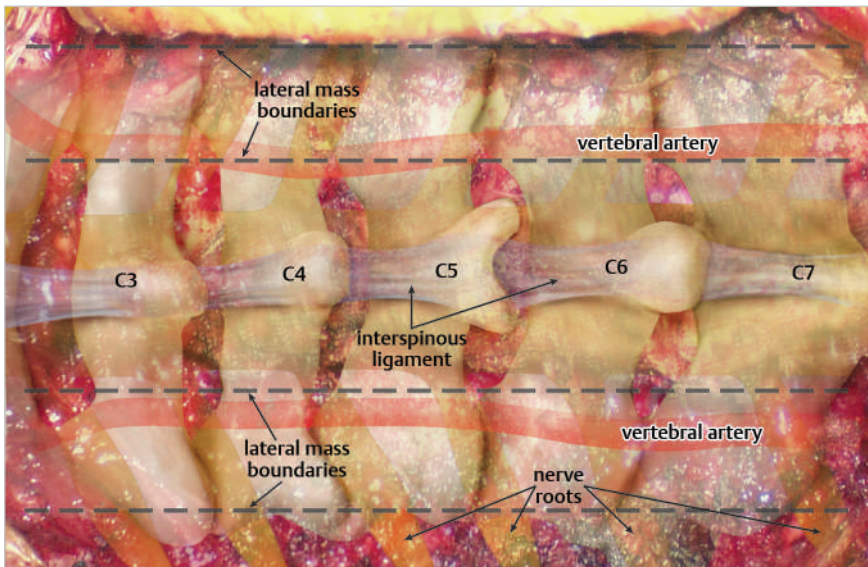
Fig. 19.2 Top-down view. Deep dissection and subperiosteal removal of paracervical muscles with adequate exposure of the lateral mass's superior, inferior, medial, and lateral borders. (Reproduced with permission from Singh K, Vaccaro AR, eds. Pocket Atlas of Spine Surgery. 2nd ed. New York, NY: Thieme; 2018.)

19.5 Implants and Hardware

• Lateral mass screws are placed and connected via rods and cross-connectors.

19.6 Case Presentation: Postoperative Imaging and Outcomes

The patient underwent a posterior cervical laminectomy and fusion (PCLF) at C3–C7 with bilateral lateral mass screw instrumentation for fixation. The patient noted significant symptom improvement at 6 months postoperatively, with decreases in pain, numbness, and tingling from her initial presentation. Postoperative radiographs demonstrated adequate placement of instrumentation without evidence of loosening (**Fig. 19.3**).

19.7 Complications

• Nerve root injury:
  – Direct damage during foraminotomy or lateral mass screw placement.
  – C5 palsy is the most common (0.5–8%).
  – Prevention:
    ◦ Maintain a cranial and lateral trajectory for screw placement.
  – Treatment:
    ◦ Nerve palsy is usually self-limited and resolves within 6 to 12 months.
• Durotomy:
  – Tear of the dura resultant from direct damage during laminectomy.
  – Presents with orthostatic headache, nausea, vomiting.
  – Prevention:
    ◦ Care should be taken when placing large instruments near the central canal.
  – Treatment:
    ◦ Primary repair with nonabsorbable sutures.
    ◦ Head elevated to reduce pressure on the repair.
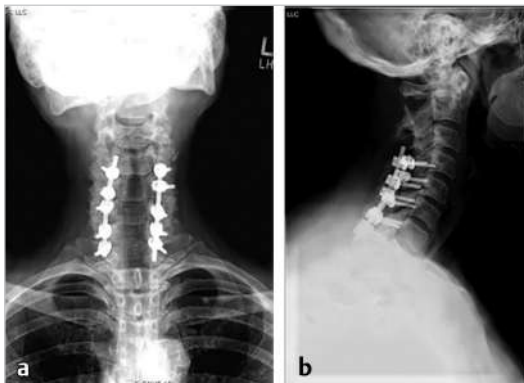
Fig. 19.3 Anteroposterior **(a)** and lateral **(b)** cervical postoperative radiographs showing posterior cervical laminectomy and fusion with lateral mass screw placement with rod connectors.

- Vertebral artery injury:
  - Often occurs from misdirected lateral mass screws.
  - Presents with hemorrhage, possible central nervous system ischemia.
  - 4-8% incidence.
  - Prevention:
    - Ensure adequate surgical planning via use of preoperative imaging to determine arterial course.
  - Treatment:
    - Aggressive intravenous (IV) fluid resuscitation, placement of the head in a neutral position.
    - Hemostasis via digital pressure, Gelfoam.
    - Definitive surgical interventions: primary repair versus bypass versus sacrifice:
      - Nondominant vertebral artery can often be safely sacrificed without complication.
- Postoperative epidural hematoma:
  - Accumulation of postoperative edema and bleeding.
  - Presents with gradual postoperative neurologic deficit.
  - Risk factors include increasing number of surgical levels, history of coagulopathies or vascular anomalies.
  - Prevention:
    - Placement of subfascial cervical drains prior to closure.

Suggested Readings

1. Awad JN, Kebaish KM, Donigan J, Cohen DB, Kostuik JP. Analysis of the risk factors for the development of post-operative spinal epidural haematoma. J Bone Joint Surg Br 2005;87(9):1248–1252
2. Schroeder GD, Hsu WK. Vertebral artery injuries in cervical spine surgery. Surg Neurol Int 2013;4(Suppl 5):S362–S367

20 Open Posterolateral Lumbar Fusion

Ankur S. Narain, Fady Y. Hijji, Philip K. Louie, Daniel D. Bohl, and Kern Singh

20.1 Case Presentation

A 59-year-old woman presents to the clinic complaining of a 9-month history of bilateral lower extremity pain and dysesthesias radiating into her right lateral thigh and medial calf. She describes her pain as constant and only improved when leaning forward. She states her pain is worsened with activity including standing and walking for extended periods of time. She denies any improvement in her pain after 6 months of physical therapy and epidural injections. On physical examination, the patient demonstrates weakness in great toe extension in the right foot and sensory deficits at the dorsum of the foot. There is no hyper- or hyporeflexia when eliciting the right Achilles' tendon reflex. The patient's radiographs and magnetic resonance imaging (MRI) are presented in **Figs. 20.1, 20.2**. The patient was scheduled to undergo an open posterolateral lumbar fusion (PLF) of the L4–L5 interspace.

20.2 Indications

• Lumbar nerve root compression.
• Lumbar instability.
• Posterior lumbar tumors.
• Posterior lumbar infection or abscess.
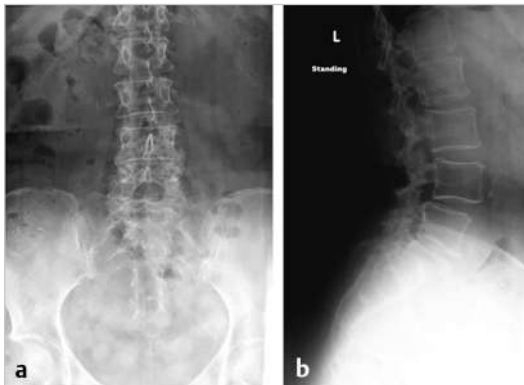
Fig. 20.1 Anteroposterior **(a)** and lateral **(b)** radiographs. There is a grade 1 degenerative spondylolisthesis at the L4–L5 disk level with spinal stenosis and neuroforaminal narrowing.

Fig. 20.2 Sagittal **(a)** and axial **(b)** cuts of a T2-weighted lumbar MRI. There is a grade 1 L4–L5 degenerative spondylolisthesis with moderate spinal stenosis.

20.3 Positioning

• Prone position.
• Superficial landmarks include the following:
  – Iliac crest:
    ◦ Typically lies at the L4–L5 intervertebral disk level.
  – Spinous processes:
    ◦ The ideal method of identifying the level of interest is to insert a needle into the spinous process and obtain a radiograph via fluoroscopy.

20.4 Approach

• Superficial dissection:
  – Skin incision is made midline at the desired level.
  – The fascia is identified and opened in the midline over the spinous process.
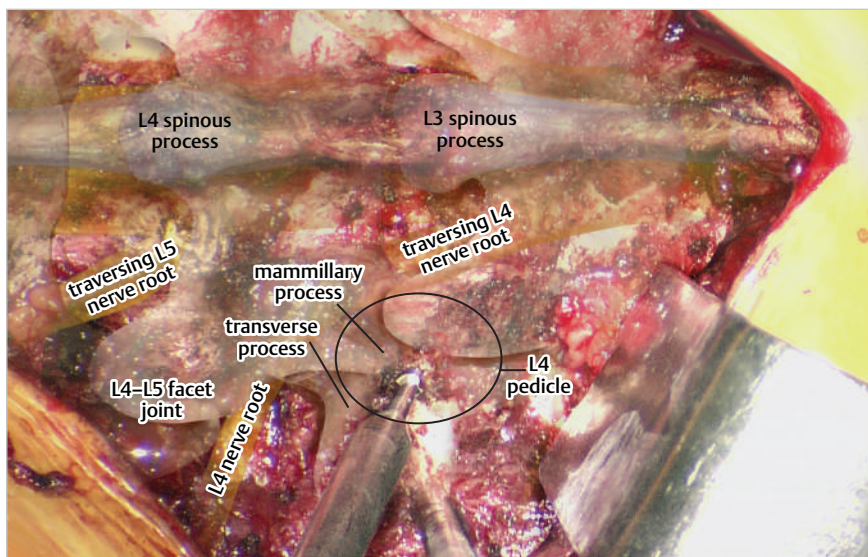
Fig. 20.3 The pedicle start points are located at the mammillary process at the junction of the inferolateral corner of the facet joint. (Reproduced with permission from Singh K, Vaccaro AR, eds. Pocket Atlas of Spine Surgery. 2nd ed. New York, NY: Thieme; 2018.)

– Subperiosteal dissection of the lumbar paraspinal musculature is performed, exposing the facet joints:
  ◦ The internervous place is located along the line of incision between the left and right paraspinal muscles:
    ▪ The lumbar dorsal primary rami supply these muscles.
• Deep dissection:
  – The facet joint is resected and the superior articular process and transverse process of the caudad vertebrae are exposed (**Fig. 20.3**).
  – The pedicle screw starting point is located:
    ◦ Indicated by the mammillary process:
      ▪ Junction of the transverse process, lateral pars interarticularis, and super facet.

20.5 Implants and Hardware

• The pedicle is tapped and measured:
  – The pedicle screw trajectory ranges from 5 to 20 degrees medially (depending on the lumbar level), increasing with caudal progression.
• Once the pedicle track has been created, it is important to confirm a complete intraosseous trajectory by pedicle and body palpation using a pedicle-sounding device:
  – Subsequent fluoroscopic imaging may be used for confirmation of proper trajectory.
• An appropriate diameter and length screw is inserted (**Fig. 20.4**).
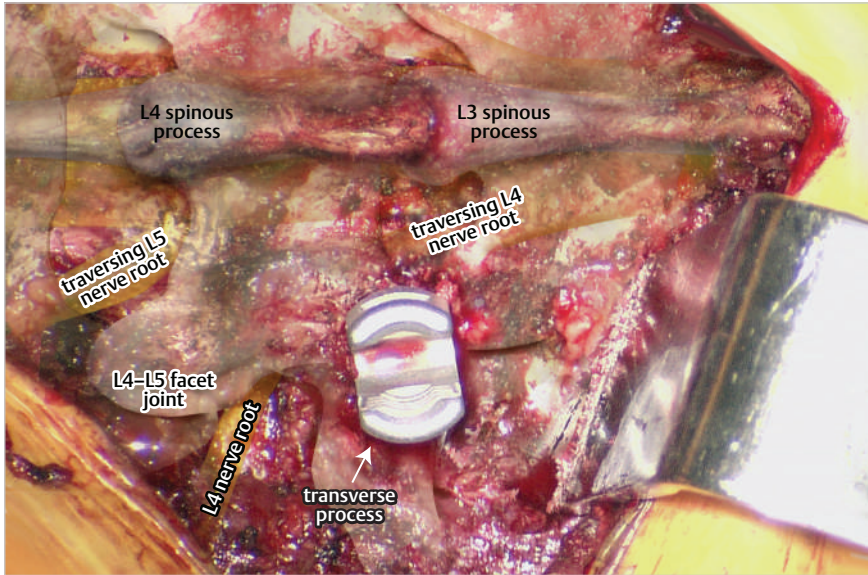
Fig. 20.4 Posterior view. The pedicle screw has been placed within the boundaries of the pedicle wall. Note the medial and slightly caudal trajectory. (Reproduced with permission from Singh K, Vaccaro AR, eds. Pocket Atlas of Spine Surgery. 2nd ed. New York, NY: Thieme; 2018.)

• This is repeated for each desired level.
• Rods are inserted to connect the screws.

20.6 Case Presentation: Postoperative Outcomes and Imaging

The patient underwent a L4–L5 PLF with placement of unilateral pedicle screws at the right L4 and L5 pedicles. At 6-month follow-up, the patient reports resolution of her radiculopathy with improved strength and sensation. The patient also notes improvement in her low back pain. Postoperative imaging demonstrates stable posterior instrumentation with no evidence of screw loosening or cutout (**Fig. 20.5**).

20.7 Complications

• Screw misplacement:
  – Screw positioning beyond the pedicle, resulting in injury to nearby structures:
    ◦ Incidence of approximately 5%.
    ◦ Presents with possible back pain, neurologic dysfunction, dural tears, vascular injury, visceral injury, and/or loss of long-term spinal fixation.
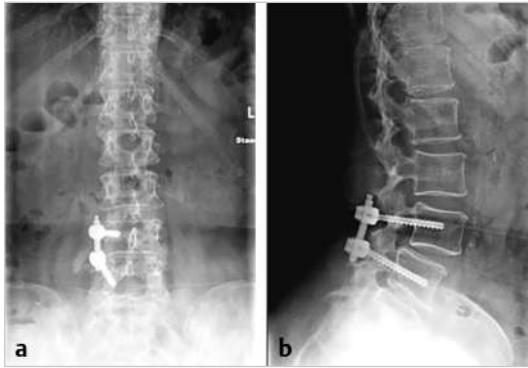
Fig. 20.5 Anteroposterior **(a)** and lateral **(b)** radiographs. Six-month postoperative radiographs following L4–L5 posterolateral lumbar fusion (PLF) demonstrating appropriate positioning and fixation of unilateral pedicle screws.

  - Prevention:
    ◦ Maximize exposure size by performing laminectomy or facetectomy.
    ◦ Utilize preoperative imaging to select for appropriately sized implant based on patient's pedicle width and angulation.
    ◦ Confirm screw placement with intraoperative fluoroscopy.
• Pedicle fracture:
  - Fracture of the lateral wall during pedicle screw placement:
    ◦ Prevents proper anchoring of pedicle screw for appropriate fixation.
  - Risk factors:
    ◦ Osteoporosis.
    ◦ Female sex.
    ◦ Smoking.

Suggested Readings

1. Inoue M, Inoue G, Ozawa T, et al. L5 spinal nerve injury caused by misplacement of outwardly-inserted S1 pedicle screws. Eur Spine J 2013;22(Suppl 3):S461–S465
2. Esses SI, Sachs BL, Dreyzin V. Complications associated with the technique of pedicle screw fixation. A selected survey of ABS members. Spine 1993;18(15):2231–2238, discussion 2238–2239
3. Amato V, Giannachi L, Irace C, Corona C. Accuracy of pedicle screw placement in the lumbosacral spine using conventional technique: computed tomography postoperative assessment in 102 consecutive patients. J Neurosurg Spine 2010;12(3):306–313
4. Lattig F, Fekete TF, Jeszenszky D. Management of fractures of the pedicle after instrumentation with transpedicular screws: a report of three patients. J Bone Joint Surg Br 2010;92(1):98–102

21 Anterior Lumbar Interbody Fusion

Ankur S. Narain, Fady Y. Hijji, Philip K. Louie, Daniel D. Bohl, and Kern Singh

21.1 Case Presentation and Preoperative Imaging

A 35-year-old woman presents to the office with long-standing axial low back pain. The pain radiates to the bilateral lower extremities, including the right posterior thigh, right lateral calf, and left posterior thigh. Pain is persistent at baseline, but worsens with ambulation and changes in temperature. She denies any trauma or recent infections. Conservative therapy with physical therapy, narcotics, and muscle relaxants provided minimal pain relief. Lumbar magnetic resonance imaging (MRI) was obtained (**Fig. 21.1**).

Fig. 21.1 Sagittal T2-weighted MRI demonstrating L5–S1 retrolisthesis with disk space collapse, central disk protrusion, and a posterior annular tear.

21.2 Indications

• Spondylolisthesis (grade I or II).
• Degenerative disk disease.
• Postdiskectomy collapse with neuroforaminal stenosis.
• Revision of posterior pseudoarthrosis or postlaminectomy kyphosis.
• Coronal and/or sagittal imbalance.

21.3 Position

• Supine.
• Landmarks:
  – Umbilicus: opposite the L3–L4 disk space.
  – Pubic symphysis: pubic tubercle is located lateral to the midline.

21.4 Approach

• Superficial dissection:
  – Skin incision is midline, located between the umbilicus and pubic symphysis (**Fig. 21.2**):
    ◦ The internervous plane is in the midline, as the abdominal musculature is innervated segmentally by the 7th to 12th intercostal nerves.
  – Musculus rectus abdominis fascia incised and the muscle belly is mobilized.
  – The rectus sheath is then incised → exposes the retroperitoneum.
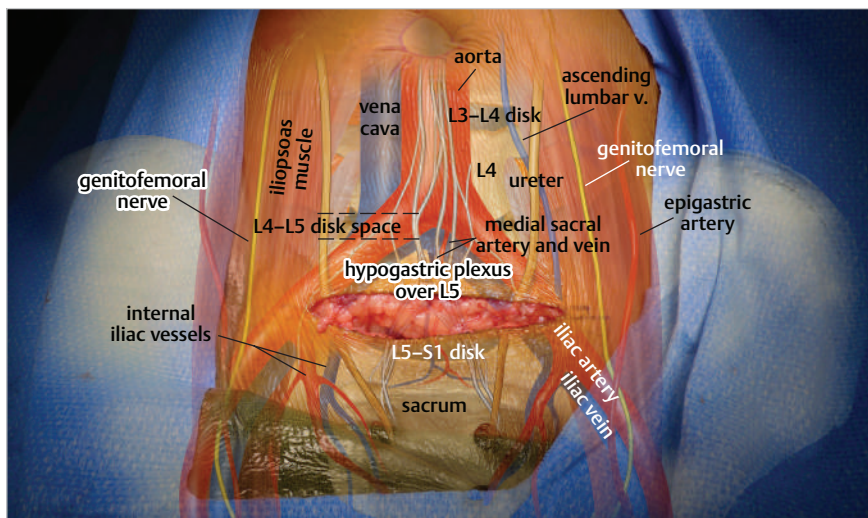
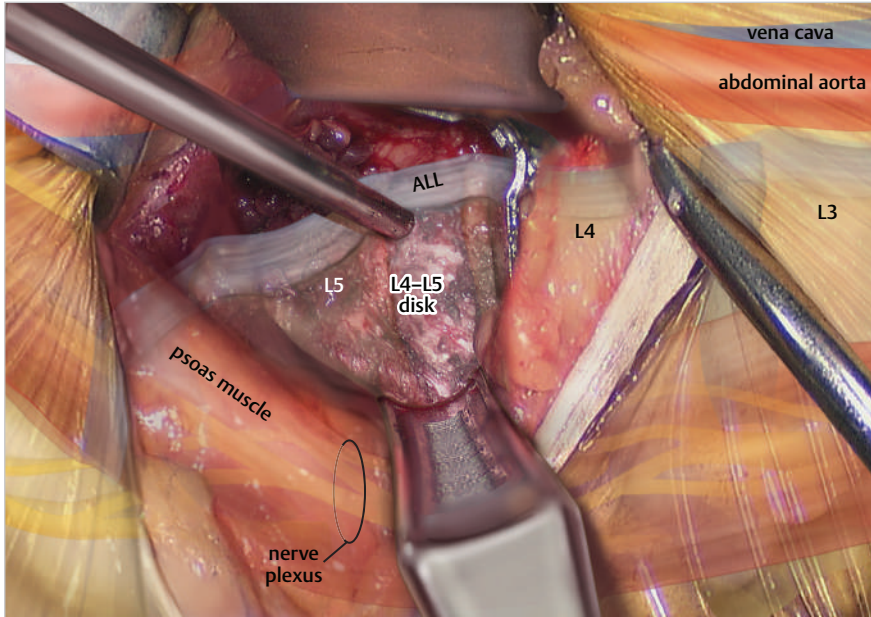**Fig. 21.2** Top-down view. Skin incision with depiction of underlying anatomic structures. (Reproduced with permission from Singh K, Vaccaro AR, eds. Pocket Atlas of Spine Surgery. 2nd ed. New York, NY: Thieme; 2018).
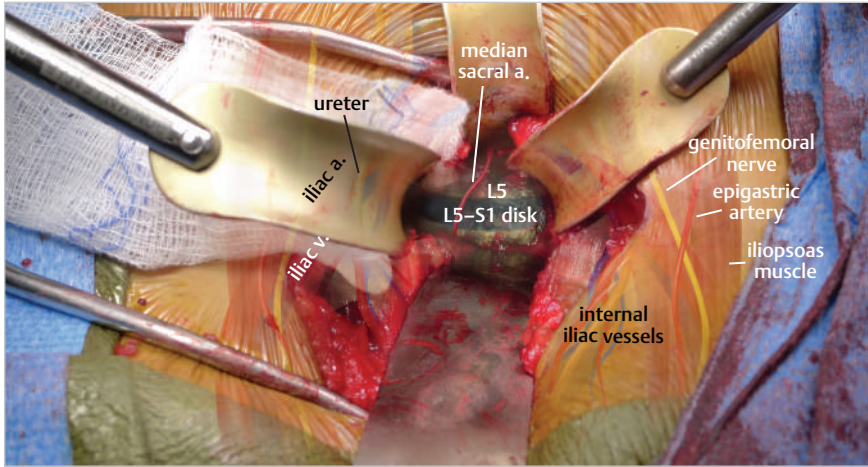
**Fig. 21.3** Top-down view. Deep dissection showing placement of retractors and exposure of the L5–S1 disk in relation to important anatomic landmarks. (Reproduced with permission from Singh K, Vaccaro AR, eds. Pocket Atlas of Spine Surgery. 2nd ed. New York, NY: Thieme; 2018.)

- Deep dissection:
  - Retroperitoneum is swept laterally and retractors are placed when the psoas is encountered (**Fig. 21.3**):
    - Care must be taken to avoid nerve injury to the adjacent presacral plexus or iliolumbar artery, depending on level of pathology.
    - Identify and ligate the middle sacral artery to prevent hemorrhage.
    - Visceral injury to the great vessels or ureters can occur. Identify and retract these structures out of the operative field.
  - Soft tissues in front of the disk space are retracted medially.
  - Bluntly dissect and clear off the disk space.
  - Perform annulotomy and remove disk fragments.
  - Prepare end plates.

21.5 Hardware and Implants

- After sequential distraction of the end plates, continue diskectomy posteriorly until the posterior annulus is visualized.
- Clear foramen laterally via microcurette.
- Interbody cages filled with autologous or allograft bone are placed with screw fixation into the cephalad and caudad vertebral bodies.

21.6 Case Presentation: Postoperative Imaging and Outcome

The patient underwent an anterior lumbar interbody fusion (ALIF) with placement of a stand-alone interbody cage. She experienced significant improvement in
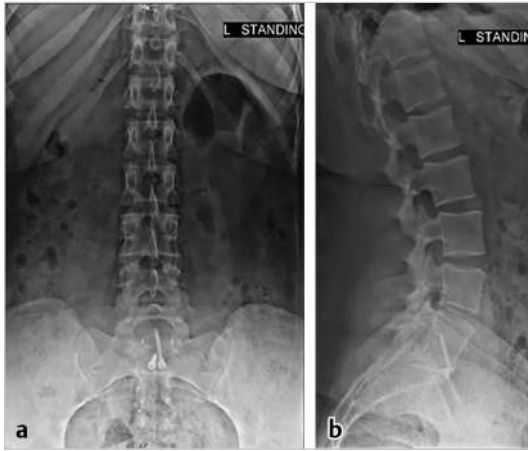
Fig. 21.4 Anteroposterior **(a)** and lateral **(b)** plain radiographs demonstrating adequate placement of the interbody cage with screw fixation. Good bony consolidation is seen.

pain at 6 months postoperatively. Good bony consolidation was demonstrated on postoperative imaging studies (**Fig. 21.4**).

21.7 Complications

• Presacral plexus injury:
  – Caused by manipulation of the plexus during dissection.
  – Presents with retrograde ejaculation ± impotence.
  – Prevention:
    ◦ Ensure midline incision is long enough for nerve mobilization.
    ◦ Avoid use of monopolar cautery.
• Great vessel injury:
  – Due to improper retraction during exposure.
  – Presents with hemorrhage; can be fatal.
  – Prevention:
    ◦ Ligation of penetrating lumbar vessels allows for more effective retraction of great vessels.
  – Treatment:
    ◦ Hemostasis, primary suture or double ligature repair.
    ◦ Vascular surgery consultation.
• Abdominal complications:
  – Ileus:
    ◦ Presents with abdominal distention, discomfort, decreased flatulence.
    ◦ Treatment:
      ▪ Place patient NPO (nil per os), administer intravenous (IV) fluids, and bowel rest.
      ▪ Laxatives and slow advancement of diet as symptoms resolve.
  – Ureteral injury:
    ◦ Occurs during deep dissection adjacent to the disk space.
    ◦ Prevention:
      ▪ Identification within the surgical field and lateral retraction.

- Subsidence, end plate fracture, graft dislodgement:
  - Caused by improper cage placement and sizing.
  - Presents with retropulsion or pseudoarthrosis on imaging, neuroforaminal impingement leading to focal neurologic deficits.
  - Prevention:
    - Optimizing surgical approach via adequate preoperative imaging.
    - Maintenance of correct surgical orientation via intraoperative fluoroscopy.
    - Testing implant sizes intraoperatively.

Suggested Readings

1. Sasso RC, Kenneth Burkus J, LeHuec JC. Retrograde ejaculation after anterior lumbar interbody fusion: transperitoneal versus retroperitoneal exposure. Spine 2003;28(10):1023–1026
2. Than KD, Wang AC, Rahman SU, et al. Complication avoidance and management in anterior lumbar interbody fusion. Neurosurg Focus 2011;31(4):E6
3. Tiusanen H, Seitsalo S, Osterman K, Soini J. Retrograde ejaculation after anterior interbody lumbar fusion. Eur Spine J 1995;4(6):339–342

22 Minimally Invasive Transforaminal Lumbar Interbody Fusion

Ankur S. Narain, Fady Y. Hijji, Philip K. Louie, Daniel D. Bohl, and Kern Singh

22.1 Case Presentation

A 52-year-old woman presents to the clinic with right leg pain of 6-month duration. The patient denies any benefit from nonoperative management prescribed by her primary care physician, which included nonsteroidal anti-inflammatory drugs (NSAIDs), epidural steroid injections, and physical therapy. On physical examination, the patient exhibits a positive straight leg test and sensory deficits along the lateral leg. The patient also demonstrates mild weakness on great toe dorsiflexion. There is no noted hypo- or hyperreflexia or Babinski's sign present. Lumbar radiographs are shown in **Figs. 22.1** and **22.2**. The patient's radiographs and magnetic resonance imaging (MRI) are presented. The patient is subsequently scheduled to receive a minimally invasive transforaminal lumbar interbody fusion (MIS TLIF) of the L5S1 disk space.

22.2 Indications

- Lumbar disk herniations.
- Compression of lumbar nerve roots.
- Lumbar instability.
- Access to the posterior lumbar spine with minimal blood loss and shortened patient recovery time.
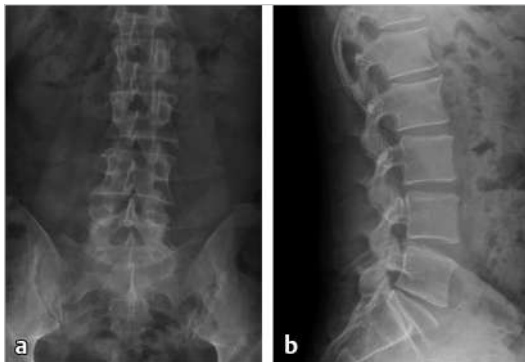
Fig. 22.1 Anteroposterior **(a)** and lateral **(b)** lumbar radiographs. There is moderate spondylosis of the L5–S1 disk space. Note the loss of disk height and narrowing of the neuroforamen.
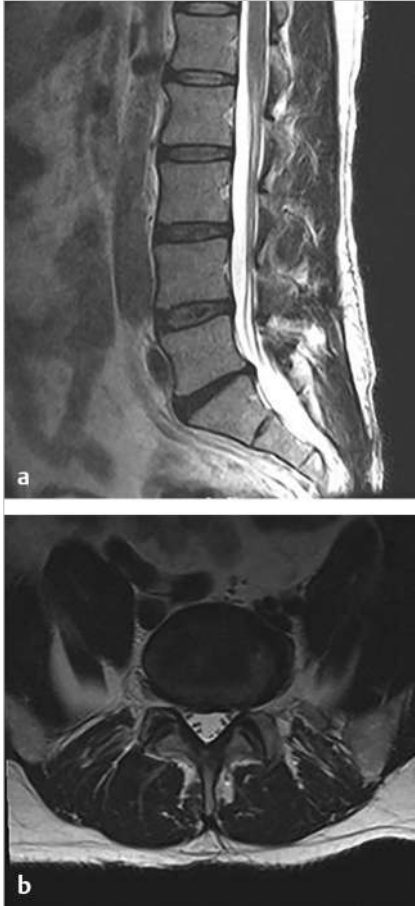
Fig. 22.2 Sagittal **(a)** and axial **(b)** T2-weighted MRI. There is significant foraminal and moderate central stenosis at the L5–S1 disk level.

22.3 Positioning

• Prone.
• Landmarks identified through fluoroscopic imaging:
  – Spinous processes.
  – Pedicular line (lateral edge of the pedicle).

22.4 Approach

• Superficial dissection:
  – The skin incision is made lateral to the midpedicular line (1.0 cm; **Fig. 22.3a**):
    ◦ Lateral fluoroscopy is utilized to confirm the location of the placed dilators at the correct level (**Fig. 22.3b**).
    ◦ There is no true internervous plane here, as the incision and entry point is made in between the paraspinal muscles, which are segmentally innervated.
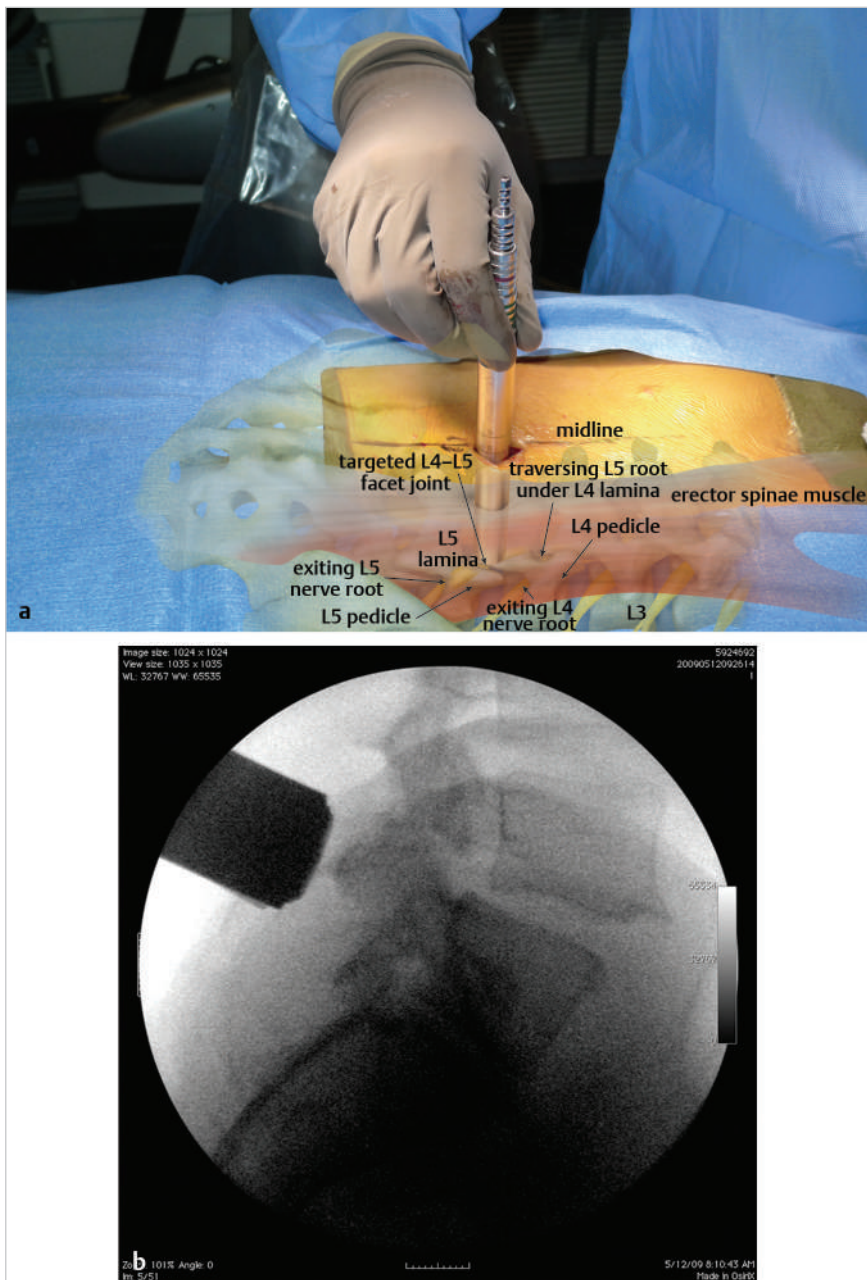
Fig. 22.3 Intraoperative fluoroscopy showing the placement of a dilator overlying the lamina of the targeted disk level **(a)** with corresponding lateral radiograph **(b)**. Note the off-midline approach. (Reproduced with permission from Singh K, Vaccaro AR, eds. Pocket Atlas of Spine Surgery. 2nd ed. New York, NY: Thieme; 2018.)
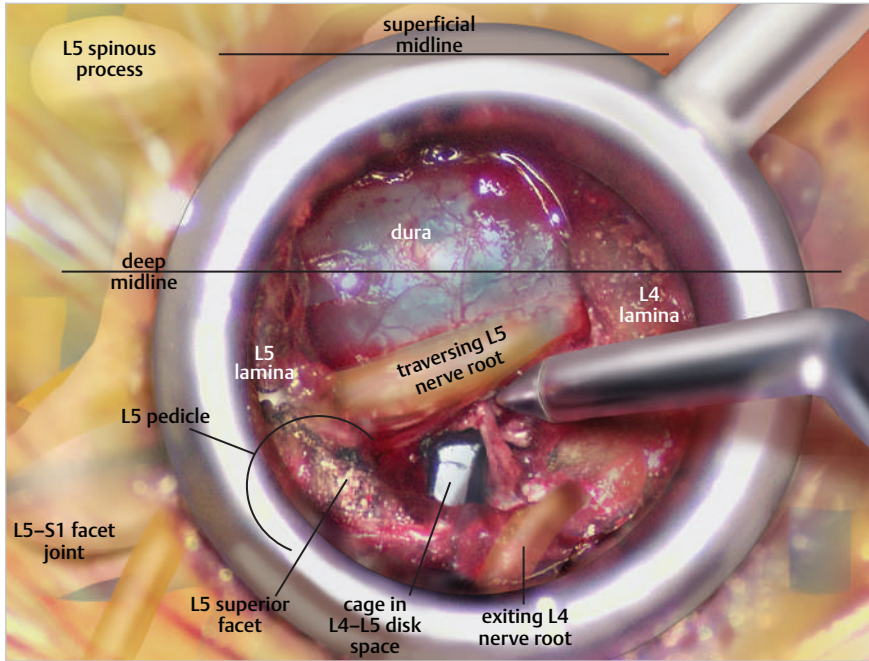
Fig. 22.4 Top-down view. The lamina, superior and inferior articular facets, and ligamentum flavum have been resected, exposing the dura and nerve root. (Reproduced with permission from Singh K, Vaccaro AR, eds. Pocket Atlas of Spine Surgery. 2nd ed. New York, NY: Thieme; 2018.)

- – Dilators are docked over the lamina at the level of pathology with removal of residual paraspinal musculature.
- • Deep dissection:
  - – The lamina and facet joint are resected:
    - ◦ The superior articular process of the caudal vertebrae is removed first during the facetectomy:
      - ▪ Inadequate facet removal can result in a narrowed working space, increasing the risk for excessive nerve root retraction and interbody cage misplacement/migration.
  - – Once laminectomy and facetectomy are completed, the ligamentum flavum is removed:
    - ◦ The disk space, dura, and nerve root are exposed (**Fig. 22.4**).
    - ◦ Veins overlying the disk space and dura can cause profuse bleeding.

22.5 Implants and Hardware

- • The disk space is prepared and cage is impacted into place (**Fig. 22.5**):
  - – Complete intervertebral disk removal and appropriate end plate preparation reduces the risk of pseudarthrosis or nonunion.
- • Fixation using posterior pedicle screws can be performed from a posterior approach.

Fig. 22.5 Intraoperative fluoroscopy shooing the impaction of the interbody device into disk space following complete disk removal and end plate preparation.

22.6 Case Presentation: Postoperative Outcome and Imaging

The patient underwent an L5–S1 MIS TLIF with placement of an interbody cage with supplemental fixation using bilateral pedicle screws. At 3-month follow-up, the patient reports resolution of her radiculopathy with improved strength and sensation. The patient also notes minimal low back pain. Postoperative imaging demonstrates stable posterior instrumentation with no evidence of cage migration or pseudoarthrosis (**Figs. 22.6, 22.7**).

22.7 Complications

- Nerve root injury:
  - Direct damage of nerve root during or following procedure.
  - Caused by:
    - Intraoperative manipulation or cage misplacement.
    - Compression from potential epidural hematoma:
      - Most commonly affects the inferior nerve root.
  - Prevention:
    - Identify nerve roots located in the working zone prior to diskectomy.
- Durotomy:
  - Tear of the dura with subsequent cerebrospinal fluid (CSF) leak:
    - Often occurs during decompression or ligamentum flavum resection:
      - Rare due to the minimal dural exposure in this approach.
    - Can present with headaches worsened with head elevation or photophobia.

Fig. 22.6 Anteroposterior **(a)** and lateral **(b)** lumbar radiographs. A 3-month postoperative radiograph following minimally invasive transforaminal lumbar interbody fusion (MIS TLIF) exhibiting placement of an interbody cage with supplemental bilateral fixation.

Fig. 22.7 Postoperative coronal **(a)** and sagittal **(b)** CT scans. Twelve-month postoperative CT scans demonstrating bony bridging at L5–S1 with no evidence of pseudarthrosis.

- Prevention:
  - Refrain from flavum removal until completion of ipsilateral and contralateral neural decompression:
    - Thecal sac protected by dura and pushed ventrally during contralateral decompression.
- Treatment:
  - Primary repair with nonabsorbable sutures.
  - Head elevation during bed rest to reduce pressure on the repair.
- Cage misplacement:
  - Cage migration causing compression of neural structures.
  - Inadequate removal of disk, preparation of vertebral end plates, or damage to anterior longitudinal ligament increase the risk of misplacement.

Suggested Readings

1. Wong AP, Smith ZA, Nixon AT, et al. Intraoperative and perioperative complications in minimally invasive transforaminal lumbar interbody fusion: a review of 513 patients. J Neurosurg Spine 2015;22(5):487–495
2. Knox JB, Dai JM III, Orchowski J. Osteolysis in transforaminal lumbar interbody fusion with bone morphogenetic protein-2. Spine 2011;36(8):672–676

23 Lateral Lumbar Interbody Fusion

Ankur S. Narain, Fady Y. Hijji, Philip K. Louie, Daniel D. Bohl, and Kern Singh

23.1 Case Presentation

A 55-year-old man presents to the clinic complaining of an 8-month history of gradually worsening low back pain. The patient notes bilateral lower extremity radiculopathy radiating to the anteromedial thigh. He has failed multiple trials of physical therapy and steroidal injections. On physical examination, the patient is noted to exhibit a sensory loss on the right anterior thigh. The patient's radiographs and magnetic resonance imaging (MRI) findings are shown in **Figs. 23.1** and **23.2**. The surgeon schedules the patient for a lateral lumbar interbody fusion (LLIF).

23.2 Indications

- Lumbar nerve root compression above the level of the iliac crest.
- Lumbar instability.
- Tumors.
- Infection or anterior lumbar abscess.

23.3 Positioning

- Lateral decubitus position.
- Superficial landmarks include:
  - Ribs and associated intercostal spaces.
  - Pubic symphysis.
  - Lateral border of rectus abdominis muscle:
    - 5 cm lateral to midline.
  - Spinous processes of desired levels.
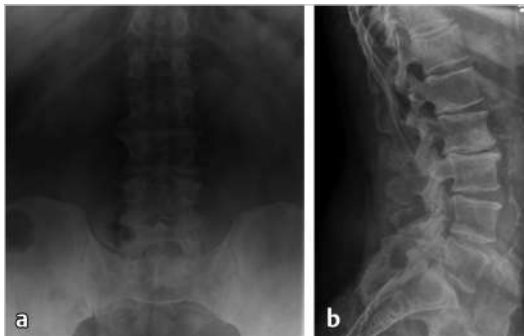
Fig. 23.1 Anteroposterior **(a)** and lateral **(b)** lumbar radiographs. Significant spondylosis is apparent at the L2–L3 disk level with radial and anterior osteophyte formation. Note the concurrent retrolisthesis of L2 over L3.

Fig. 23.2 Sagittal **(a)** and axial **(b)** cuts of a T2-weighted lumbar MRI. There is significant degeneration of the L2–L3 disk with moderate bilateral foraminal stenosis.

23.4 Approach

• Superficial dissection:
  – Skin incision made at the lateral aspect of the desired level:
    ◦ Fluoroscopy used to determine appropriate level.
  – External oblique, internal oblique, and transversalis fascia are dissected (**Fig. 23.3**):
    ◦ No true internervous plane exists in this approach; the muscles of the abdominal wall being divided are segmentally innervated.
• Deep dissection:
  – Transversalis fascia is opened and retroperitoneal fat is exposed and removed.
  – The psoas muscle is then identified and retracted posteriorly or traversed with careful ongoing neuromonitoring (**Fig. 23.4**):
    ◦ The lumbar plexus lies within the psoas muscle and can be injured with excessive manipulation.
  – The disk space is identified and prepared.

23.5 Implants and Hardware

• The intervertebral disk is completely removed and the end plates are prepared.
• The interbody cage is impacted into the prepared disk space.
• Supplemental percutaneous posterior fixation can be performed using a posterior lumbar approach.

23.6 Case Presentation: Postoperative Outcomes and Imaging

The patient underwent an L2–L3 LLIF procedure with placement of an interbody cage and supplemental fixation using unilateral pedicle screws. Postoperatively, the patient complained of new-onset hip flexion weakness with continuing sensory loss of the anterior thigh. However, at his 3-month visit, the patient noted complete resolution of his motor weakness and sensory loss. At his 9-month follow-up, the patient notes
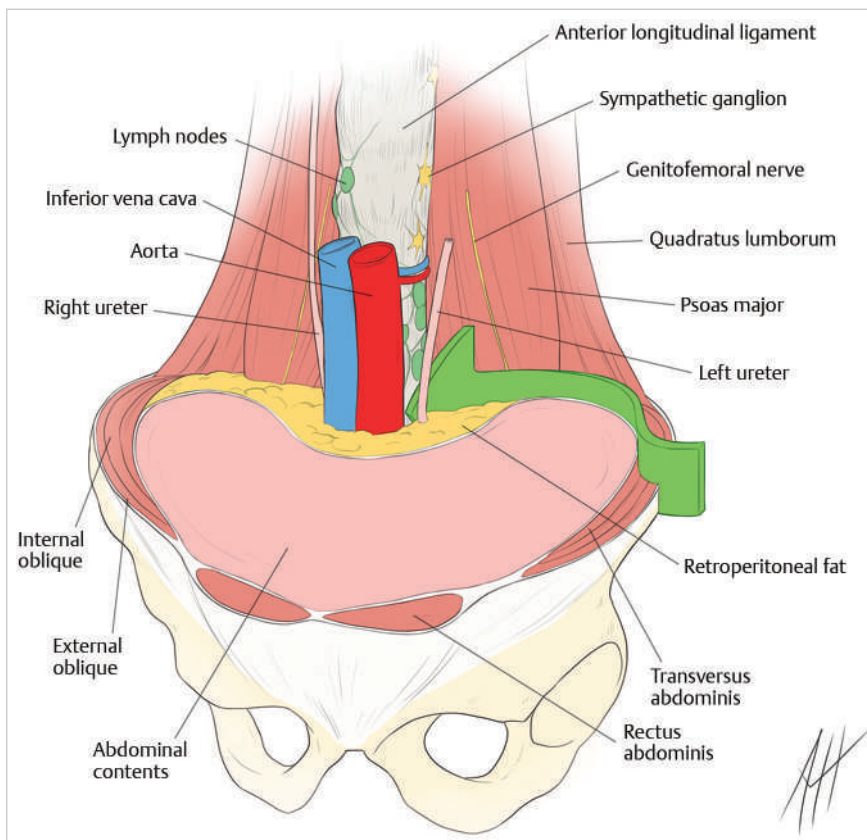
Fig. 23.3 Lateral view of approach. (Reproduced with permission from Singh K, Vaccaro AR, eds. Pocket Atlas of Spine Surgery. 2nd ed. New York, NY: Thieme; 2018.)

improved lower back pain and no new onset of neurologic symptoms. Postoperative radiographs are presented in **Fig. 23.5**.

23.7 Complications

• Visceral or vascular injury:
  – Injury to the bowels, great vessels, and ureters can occur during exposure and retraction of abdominal contents:
    ◦ Visceral injury can present with peritonitis and abdominal pain.
    ◦ Vascular injury can present with hemorrhage, hypotension, and/or progressive neurologic deficit from expanding hematoma.

Fig. 23.4 Top-down view. The psoas muscle and abdominal contents are retracted, exposing the targeted disk space. Note the location of the lumbar plexus within the psoas muscle. (Reproduced with permission from Singh K, Vaccaro AR, eds. Pocket Atlas of Spine Surgery. 2nd ed. New York, NY: Thieme; 2018.)
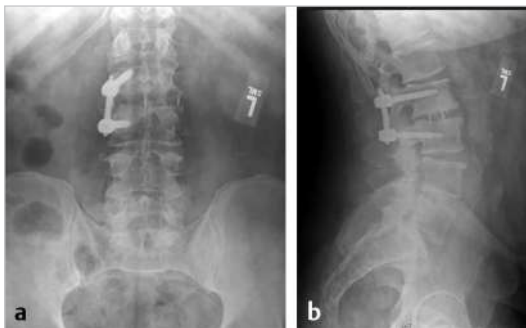
Fig. 23.5 Anteroposterior **(a)** and lateral **(b)** views. A 9-month postoperative radiograph following lateral lumbar interbody fusion (LLIF) showing placement of an interbody cage at L2–L3 with supplemental unilateral pedicle screw fixation.

- Prevention:
  - Meticulous finger dissection to palpate visceral structures prior to retractor placement.
  - Sweep all structures posteriorly, protected by the dilators or retractors.
- Neural injury:
  - Injury to the lumbosacral plexus or sympathetic ganglion during exposure and psoas retraction:

- Thigh weakness, pain, and sensory loss.
- Transient sensory loss and hip flexion weakness are extremely common following LLIF and usually resolve within 4 to 6 weeks:
  - Attributed to psoas trauma rather than true neurologic injury.
- Prevention:
  - Neuromonitoring to identify potential injury to lumbar plexus.
  - Intermittent relaxation of muscle retraction, especially during multilevel or prolonged cases.

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24 Surgical Complications

Ikechukwu Achebe, Ankur S. Narain, Fady Y. Hijji, Philip K. Louie, Daniel D. Bohl, and Kern Singh

24.1 Introduction

Surgery is inherently associated with risk. Surgeries involving the spine and spinal cord are subject to various severe complications, and thus warrant additional intervention. An understanding of these complications, along with appropriate prevention and treatment strategies, is essential to patient safety. Therefore, it is important to recognize the etiology, presentation, and management strategies for common surgical complications including postoperative fever, surgical site infection, durotomy, and spinal epidural hematoma (**Table 24.1**).

Table 24.1 Common etiologies of postoperative fever

Etiology	Approximate day of onset	Clinical evaluation	Imaging	Primary treatment
Surgical trauma and tissue manipulation	POD 0	–	–	Self-limited
Atelectasis	POD 1–2	Incentive spirometry	CXR	Oxygen therapy Pulmonary rehabilitation
Pneumonia	POD 3	WBC, sputum culture	CXR	Antibiotics Pulmonary therapy
UTI	POD 2–3	Urinalysis, urine culture	–	Antibiotics Catheter removal or replacement
DVT/PE	POD 3–7	D-dimer	CT angiogram, duplex ultrasonography	Anticoagulation
Wound infection or bacteremia	POD 3–7	WBC, ESR, CRP, blood culture, wound culture	MRI	Antibiotics Wound care Debridement and removal of hardware
Implant infection	Delayed (weeks to months)	ESR, CRP, WBC, wound culture	MRI	Antibiotics Debridement Hardware removal

Abbreviations: CRP, C-reactive protein; CT, computed tomography; CXR, chest X-ray; DVT, deep vein thrombosis; ESR, erythrocyte sedimentation rate; MRI, magnetic resonance imaging; PE, pulmonary embolism; POD, postoperative day; UTI, urinary tract infection; WBC, white blood cell.

24.2 Postoperative Fever

• Background:
  – Body temperature greater than 38.6°C (101.5°F).
  – Incidence rate of 14 to 91%.
• Etiology:
  – Immediate onset:
    ◦ Majority are noninfectious (>50% of cases).
  – Acute, subacute, and delayed onset:
    ◦ Strongly consider infectious etiology.
• Risk factors:
  – Immunosuppression, prolonged operative time, nosocomial infections.
  – Urinary catheterization, respiratory ventilation.
• Presentation:
  – Diaphoresis, chills, headache.

24.3 Surgical Site Infections

• Background:
  – Postoperative infection localized to surgical site; occurs within 30 days.
  – Incidence following spine surgery is 1 to 12%.
  – Surgical site infection (SSI) types and associated tissues **(Fig. 24.1).**
• Etiology:
  – Routes of infection:
    ◦ Direct Inoculation of skin flora.
    ◦ Wound contamination.
  – SSI pathogens association:
    ◦ Gram (+): *Staphylococcus. aureus* (50% of SSIs), *S. epidermidis,* and *Streptococcus.*
    ◦ Gram (−): *Pseudomonas. aeruginosa, Escherichia coli,* and *Proteus.*
• Risk factors:
  – Preoperative: diabetes, smoking history, body mass index (BMI), corticosteroid use, age.
  – Intraoperative: sterile technique, invasiveness, operative duration.
  – SSI risk by procedure: trauma > diskitis > tumor resection > minimally invasive.
  – SSI risk by location: thoracic (2.1%) > lumbar (1.6%) > cervical (0.8%) vertebrae.
• Presentation:
  – Clinical symptoms:
    ◦ Back pain, wound drainage, erythema, palpable fluctuance.
    ◦ Fever, fatigue (deep SSI [DSSI] > SSSI).
• Clinical evaluation:
  – Laboratory tests:
    ◦ Erythrocyte sedimentation rate (ESR), C-reactive protein (CRP) elevation (high sensitivity 94–100%).
    ◦ White blood cell (WBC) elevation (poor sensitivity 44–58%).
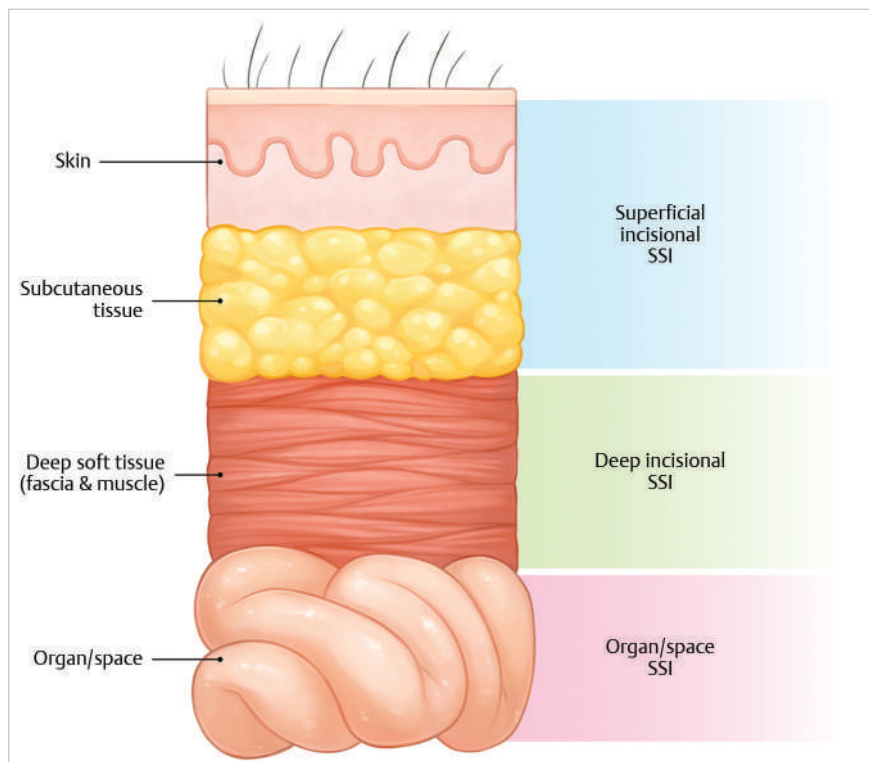
Fig. 24.1 Centers for Disease Control and Prevention (CDC) surgical site infection classification.

- Bacterial cultures:
  - Positive in 51 and 78% of SSSI and DSSI cases, respectively.
  - Intraoperative and deep cultures preferred.
- Radiographic evaluation:
  - Magnetic resonance imaging (MRI) at 3 to 5 days postoperatively (sensitivity 93%):
    - T2: edema appears as hyperintense signal.
    - Decreased height of vertebral disk/body seen with late stage infection.
  - Radionucleotide imaging: increased uptake of 67Ga at sites of infection.
  - X-ray: decreased intervertebral height discernable 4 to 6 weeks postoperatively.
  - Computed tomography (CT): bony destruction, soft-tissue abscesses.
- Treatment:
  - Antibiotics, wound care:
    - Start antibiotics with broad coverage and narrow upon determination of causative organism.
  - If conservative treatment fails or symptoms progress: debridement, removal of hardware.

24.4 Durotomy

- Background:
  - Incidental tear of dura mater.
  - Severity determines need for corrective surgery (1–17% of tears).
  - Cerebrospinal fluid (CSF) leak may create fistulas and pseudomeningoceles.
- Etiology:
  - Direct injury from instrumentation or injection **(Fig. 24.2)**.
  - Failed dural repair (i.e., tumor/cyst resection, shunt placement).
- Risk factors:
  - Preoperative: diabetes, smoking, age, BMI, radiation, or steroid therapy.
  - Intraoperative: procedure invasiveness, revision surgery.
  - Risk by primary diagnosis: spinal trauma (20%) > degenerative stenosis (11.2%) > tumors (10.5%) > lumbar disk herniations (8%).
  - Risk by surgery location: thoracic (2.2%) > lumbar (2.1%) > cervical (1%) spine.
- Cutaneous CSF fistula:
  - Etiology:
    - Residual opening permits leak **(Fig. 24.3)**.
    - CSF drains along surgical tract.
    - Infection can occur (meningitis).
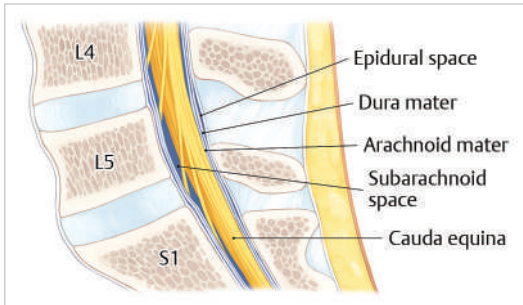
Fig. 24.2 Vertebrae and their association with the meningeal layers.
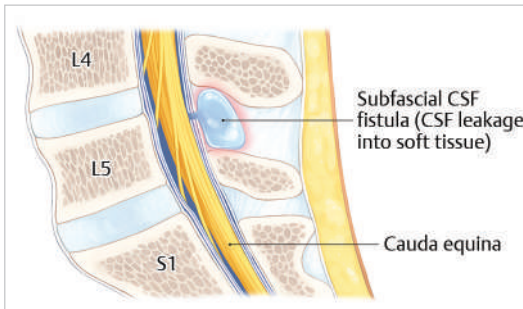
Fig. 24.3 Cutaneous cerebrospinal fluid (CSF) fistula with leakage into the adjacent soft-tissue space.

- Presentation:
  - Postural headache, CSF discharge, fever, neck stiffness, pain.
- Clinical evaluation:
  - Clear drainage (CSF) at incision site..
  - Valsalva maneuver aggravates CSF leak and headache.
  - Lab tests:
    - Drainage fluids are Beta-2 transferrin positive.
- Imaging:
  - MRI shows T2-hyperintense extra-arachnoid fluid.
- Treatment:
  - Wound suture with optional hemostatic agents.
  - Drainage, epidural blood patch, bed rest.
  - Dural repair surgery:
    - Indications: severe CSF leak.
    - Contraindications: poor CSF absorption, high intradural pressure.

• Pseudomeningocele:
  - Etiology:
    - Arachnoid herniation through dural opening leading to nerve compression.
    - CSF leakage into paraspinal or local tissues contributes to nerve compression (**Fig. 24.4**).
  - Presentation:
    - Postural headache, swelling, back pain, delayed-onset radiculopathy.
  - Clinical evaluation:
    - Valsalva maneuver leads to aggravation of headache.
  - Imaging:
    - MRI:
      - T1-hypointense mass in the posterior spine.
      - T2-hyperintense cystic CSF-filled mass.

L4

L5

S1

Nerve root
Pseudomeningocele

Cauda equina
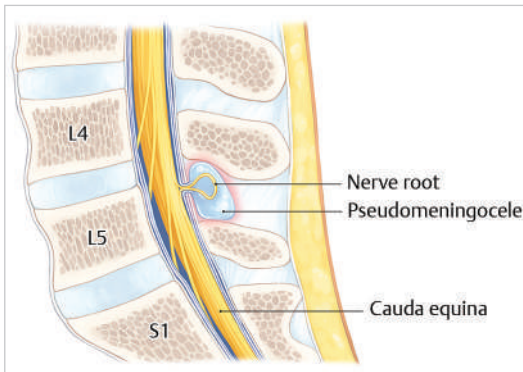
Fig. 24.4 Pseudomeningocele depicted by an arachnoid herniation leading to nerve root entrapment.

- Treatment:
  - ◦ Drainage (3–5 days).
  - ◦ Epidural blood patch.
  - ◦ Dural repair surgery (nonurgent):
    - ▪ Indications and contraindications similar to that for cutaneous CSF fistula.

24.5 Spinal Epidural Hematoma

- Background:
  - Bleeding into the potential space between bone and dura mater **(Fig. 24.5)**:
    - ◦ Symptoms range from asymptomatic to severe neurologic complications due to cord compression.
  - Incidence: 0.1 to 1%.
- Etiology:
  - Spine surgery (iatrogenic).
  - Spinal tap or anesthesia.
- Risk factors:
  - Preoperative: coagulopathy, antithrombotics, higher in females than in males, age older than 60 years.
  - Intraoperative: multilevel procedures, prior surgeries.
- Presentation:
  - Rapid onset and symptom progression:
    - ◦ Bilateral motor and sensory deficits (68% of patients).
    - ◦ Gastrointestinal (GI)/genitourinary (GU) dysfunction (8%).
    - ◦ Severe back pain ± radicular symptoms.
- Radiographic evaluation:
  - MRI: First line:
    - ◦ T1 hypointense and T2 hyperintense in the acute stage.
    - ◦ T1 and T2 hyperintense in the subacute stage.
  - CT ± myelography.
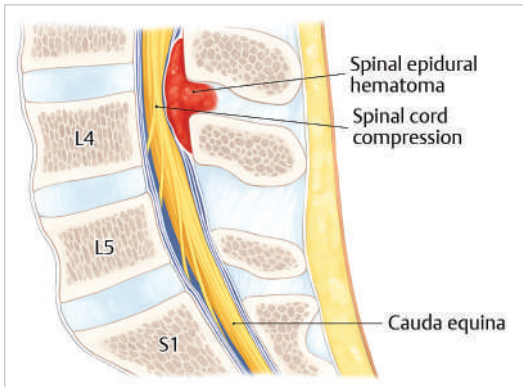
Fig. 24.5 Spinal epidural hematoma with resultant cord compression.

• Treatment:
  – Surgical decompression with evacuation.
  – Conservative therapy involves use of intravenous (IV) steroids:
    ◦ Indicated when symptomatology improves prior to potential operative therapy.

24.6 Pedicle Screw Misplacement

• Background:
  – Occurs in 7.8% of cases involving pedicle instrumentation.
  – Greater than 4 mm displacement is associated with a high risk of injury to adjacent structures.
• Etiology:
  – Malpositioning of the pedicle secondary to:
    ◦ Guide wire pullout.
    ◦ Improper targeting of pedicular structures.
    ◦ Erosion of metal–bone interface leading to screw displacement.
• Presentation:
  – Varies based on anatomical direction of misplacement:
    ◦ Medial or inferior violation: nerve root or spinal cord injury (0.6–11%).
    ◦ Lateral violation: injuries to aorta, segmental vessels, lung parenchyma, pneumothorax.
    ◦ Anterior violation: injuries to aorta, vena cava, esophagus.
  – Pedicle fracture (1.1%).
  – Screw breakage (3.0–5.7%).
• Radiographic evaluation:
  – Postoperative CT:
    ◦ Axial sections best demonstrate screw position **(Fig. 24.6)**:
      ▪ Adjacent areas of radiolucency may indicate improper placement.
    ◦ Can demonstrate pedicle or vertebral body fractures.
• Management:
  – Prevention:
    ◦ Ensure proper guide wire targeting.
    ◦ Ensure adequate preoperative characterization of anatomy and screw sizing via imaging.
    ◦ Screw augmentation via polymethylmethacrylate, hydroxyapatite, calcium phosphate, or carbonated apatite.
    ◦ Use of surgical assistance techniques (intraoperative fluoroscopy, robotic assisted).
  – Treatment:
    ◦ Repair of damaged vasculature or visceral structures.
    ◦ Revision with alternate screw trajectory or extension of fusion.

Fig. 24.6 Axial computed tomography image demonstrating medial pedicle violation into the thecal sac.

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25 Common Medical Complications Following Routine Spinal Surgery

Ankur S. Narain, Fady Y. Hijji, Benjamin Khechen, Brittany E. Haws, Philip K. Louie, Daniel D. Bohl, and Kern Singh

25.1 Gastrointestinal Complications

25.1.1 Postoperative Nausea and Vomiting

- Background and etiology:
  - Incidence rates approach 20 to 30% of patients undergoing spinal procedures.
  - Risk factors include the following:
    - Patient factors: female gender, history of motion sickness or postoperative nausea and vomiting (PONV), nonsmokers, younger age.
    - Surgical factors: extended duration of anesthesia.
    - Pharmacologic factors: postoperative opioids.
- Management:
  - Prevention:
    - Avoid general anesthesia and volatile anesthetics if possible.
    - Limit opioid use.
    - Promote adequate hydration.
  - Treatment:
    - Antiemetics.
      - 5-HT3 receptor antagonists, neurokinin 1 (Nk-1) receptor antagonists, corticosteroids, butyrophenones, antihistamines, anticholinergics, phenothiazines.
      - Use of dopamine and serotonin antagonist medication is associated with QT prolongation; monitoring of echocardiogram (ECG) for QT interval and presence of arrhythmias is recommended.

25.1.2 Dysphagia

- Background and etiology:
  - Incidence rate approaching 71% following cervical procedures; most common in the first postoperative week.
  - Risk factors include the following:
    - Patient factors: female gender, older age.
    - Surgical factors: multilevel procedures, revision procedures, procedures involving lower cervical levels (C4–C6).
  - Etiology is multifactorial and may involve manipulation of esophageal tissue during surgery, hardware displacement, esophageal perforation, retropharyngeal abscesses, or neural injury.

- Presentation:
  - Reflexive coughing.
  - Difficulty swallowing food or drink with leakage.
  - Risk for aspiration and possible pneumonia.
- Clinical evaluation:
  - Bedside swallowing test.
  - Speech/language pathology consultation.

- Radiographic evaluation:
  - Cervical radiographs: to evaluate for structural etiologies.
  - Videofluoroscopic/modified barium swallow study: allows for evaluation of the pharynx and esophagus:
    - Soft-tissue swelling with displacement of the esophagus is the most common finding.
    - Can additionally evaluate for hardware failure.

- Management:
  - Prevention:
    - Avoidance of prolonged operative time.
    - Intermittent relaxation of self-retaining retractors and partial deflation of the endotracheal cuff once retractors are in place.
    - Instrumentation modifications (anchored spacer, smaller cervical plates).
  - Treatment:
    - Nothing by mouth (NPO) or restricted dietary status:
      - Consider nasogastric (NG) or percutaneous endoscopic gastrostomy (PEG) tube placement if severe dysfunction with aspiration risk and nutritional deficits is present.
    - Behavioral modifications: postural changes, swallowing maneuvers.

25.1.3 Postoperative Ileus

- Background and etiology:
  - Incidence rate of 3.5% after elective spinal procedures (most common after anterior lumbar and lateral retroperitoneal procedures).
  - Risk factors include the following:
    - Patient factors: older age, male gender, previous opioid use, history of gastroesophageal reflux disease (GERD), history of abdominal surgery.
    - Surgical factors: anterior or lateral surgical approaches.
  - Etiology involves failure of peristalsis due to a pathologic response by the gastrointestinal (GI) tract to surgical manipulation and tissue trauma:
    - Underlying sepsis and electrolyte abnormalities (hypokalemia, hyponatremia, and hypomagnesemia) may worsen ileus.
- Presentation:
  - Pain, nausea, vomiting, abdominal distention, inability to pass flatus or stool.
- Radiographic evaluation:
  - Abdominal radiographs:
    - Identify possible bowel distention or transition points indicative of mechanical obstruction.

- Computed tomography (CT) scan:
  - Evaluate for mechanical obstruction or bowel injury.
- Management:
  - Prevention:
    - Limit bowel manipulation.
    - Minimize narcotic consumption.
  - Treatment:
    - Place patient NPO for bowel rest.
    - Administer intravenous (IV) fluids for electrolyte correction.
    - Laxatives and slow diet advancement as tolerated.
    - For patients with vomiting and distention, a nasogastric tube may provide symptomatic relief; however, there is no conclusive evidence that nasogastric tubes facilitate resolution of ileus.

25.2 Pulmonary and Respiratory Complications

25.2.1 Airway Compromise and Reintubation

- Background and etiology:
  - Incidence approaching 6.1% of patients undergoing cervical spine surgery.
  - Risk factors include the following:
    - Patient factors: morbid obesity, obstructive sleep apnea, history of pulmonary disease, low preoperative hematocrit, high serum creatinine.
    - Surgical factors: exposures involving more than three vertebral bodies, blood loss greater than 300 mL, exposures of C2–C4, operative time greater than 5 hours, anteroposterior approach.
  - Etiologies include laryngopharynx and prevertebral soft-tissue edema, hematoma, cerebrospinal fluid (CSF) leaks, or hardware dislodgement.
    - Presentation after 12 hours postoperatively is associated with airway edema.
    - Delayed presentation after 72 hours postoperatively is associated with hematoma, CSF leaks, hardware failure.
- Presentation:
  - Dyspnea, dysphonia.
  - Can progress to stridor, cyanosis.
  - Increased risk of aspiration.
- Clinical evaluation:
  - Arterial blood gases demonstrate hypercarbia and hypoxia.
- Radiographic evaluation:
  - Plain radiographs and CT scan:
    - Lateral views often demonstrate prevertebral soft-tissue swelling.
- Management:
  - Prevention:
    - In high-risk patients, consider delayed extubation with postoperative intensive care unit (ICU) admission.

- Treatment:
  - Emergent intubation is required if there is evidence of airway compromise.

25.2.2 Pneumonia

- Background and etiology:
  - Incidence ranges from 0.45 to 1.05% depending on surgical location.
  - Risk factors include the following:
    - Cervical procedures: Older age, chronic obstructive pulmonary disease (COPD), increased operative time, dependent functional status.
    - Lumbar procedures: COPD, diabetes, increased number of operative levels, steroid use.
  - Etiology is multifactorial:
    - Endotracheal intubation can lead to mini-aspirations.
    - Postoperative atelectasis reduces air movement.
    - Postoperative dysphagia poses an additional aspiration risk.
- Presentation:
  - Fever, dyspnea, productive cough often presenting postoperative day 3 (POD3) or later.
  - Associated with higher rates of sepsis, mortality, and readmission.
- Clinical evaluation:
  - White blood cells (WBCs).
  - Sputum culture.
- Radiographic evaluation:
  - Chest radiography: pattern of infiltrate can help determine etiology:
    - Lobar infiltrates are associated with bacterial sources.
    - Diffuse, interstitial infiltrates are associated with viral sources.
    - Infiltrates in dependent areas are associated with aspiration:
      - If patients are upright: inferior lung segments.
      - If patients are supine: posterior lung segments.
  - CT scan: allows for detailed evaluation:
    - Detection of complications such as pleural effusions or abscess formation.
- Management:
  - Prevention:
    - Elevation of head of bed to 30 degrees and sitting up for all meals to prevent aspiration.
    - Oral hygiene.
    - Pulmonary rehabilitation with incentive spirometry to prevent atelectasis.
    - Adequate analgesia.
    - Supervised ambulation.
  - Treatment:
    - Antibiotics.
    - Pulmonary rehabilitation.

25.3 Cardiac Complications

25.3.1 Myocardial Infarction

• Background and etiology:
  – Incidence ranges from 1 to 2% after spinal procedures.
  – Risk factors include the following:
    ◦ Patient factors: older age (>65 years), atrial fibrillation, hypertension, prior MI, current anticoagulation requirement.
    ◦ Abnormal lab values: low albumin, creatinine greater than 1 mg/dL.
    ◦ Surgical factors: traumatic indication, two-level fusion, intraoperative transfusion requirement, length of stay greater than 7 days.
  – Etiology:
    ◦ Associated with decreased coronary perfusion secondary to operative blood loss.
    ◦ Hypotension and hemodynamic instability are also more frequent in the prone position due to decreases in blood pressure and cardiac function.
• Presentation:
  – Crushing chest pain with radiation to the shoulder, arm, and jaw.
  – Dyspnea, diaphoresis.
• Clinical evaluation:
  – ECG changes differ by type and location of MI:
    ◦ Non-ST–segment elevation MI (NSTEMI): ST-segment flattening, T-wave flattening or inversion.
    ◦ ST-segment elevation MI (STEMI): ST elevation in ischemic areas, ST depression in reciprocal areas, Q-wave formation.
    ◦ Troponin and creatine kinase-MB (CK-MB) levels:
      ▪ Elevated in both STEMI and NSTEMI.
  – Radiographic evaluation:
    ◦ ECG can be used to detect wall motion abnormalities:
      ▪ Do not delay treatment for radiographic examinations if there is significant clinical suspicion for MI.
  – Management:
    ◦ All patients receive morphine for pain control, supplemental oxygen, nitrates, aspirin, beta-blockers, and statins.
    ◦ STEMI: emergent percutaneous revascularization or fibrinolytic therapy.
    ◦ NSTEMI: anticoagulation, possible escalation to revascularization therapy based on cardiac catheterization findings.

25.3.2 Stroke and Cerebrovascular Accident

• Background and etiology:
  – Incidence rates approximately 0.22% after spine surgery.
  – Risk factors include the following:

  ◦ Patient factors: older age, greater comorbidity burden.
  ◦ Surgical factors: cervical procedures, spinal cord tumor resection, increased length of stay.
  – Etiology:
    ◦ Can be either ischemic (most common) or hemorrhagic:
      ▪ Hypothesized to involve increasing rates of intracranial hemorrhage secondary to postoperative CSF leak.

• Presentation:
  – Most common symptoms include dysarthria, hemiparesis.
  – Other symptoms include weakness, numbness, headache, nonorthostatic dizziness.

• Clinical evaluation:
  – Neurology consultation.
  – Imperative to determine time of symptom onset.
  – National Institutes of Health (NIH) stroke scale:
    ◦ 42-point scale, higher scores indicate increased likelihood for stroke.

• Radiographic evaluation:
  – CT without contrast:
    ◦ Evaluates for presence of hemorrhage.
    ◦ Can be performed quickly and is sufficient in most emergency cases.
  – Magnetic resonance imaging (MRI): more sensitive than CT.
    ◦ Significant time requirement compared to CT.
    ◦ Contraindicated in those with contrast allergy, presence of instrumentation.
  – Computed tomography angiography (CTA) or magnetic resonance angiography (MRA):
    ◦ Indicated when possible endovascular procedures are planned.

• Management:
  – Ischemic stroke:
    ◦ Recombinant tissue plasminogen activator (rTPA) if presenting within 3 to 4.5 hours of symptom onset.
    ◦ Can also consider intra-arterial thrombolysis or endovascular techniques up to 6 hours from symptom onset.
    ◦ After therapy: patients are placed on antiplatelet medications, anticoagulants, and blood pressure control.
  – Hemorrhagic stroke
    ◦ Blood pressure and intracranial pressure monitoring.
    ◦ Discontinuing anticoagulant medications.
    ◦ Consult neurosurgery for possible surgical decompression:
      ▪ Indicated if the following sources of bleeding are identified:
        ❖ Aneurysm.
        ❖ Arteriovenous malformation.
        ❖ High intracranial pressure.

25.4 Urinary Complications

25.4.1 Postoperative Urinary Retention

• Background and etiology:
  – Reported incidence of 5.6 to 38% following spine procedures.
  – Risk factors:
    ◦ Patient factors: older age, male gender, history of benign prostatic hypertrophy, diabetes, depression, myelopathy.
    ◦ Surgical factors: intraoperative Foley catheterization.
    ◦ Pharmacological factors: administration of phenylephrine or neostigmine.
• Presentation:
  – Bladder or abdominal distention.
  – Suprapubic tenderness.
  – Inability to void despite sensation of a full bladder.
• Evaluation:
  – Necessity for catheterization indicates increased likelihood of retention.
  – Blood urea nitrogen (BUN), creatinine levels.
  – Urinalysis.
  – Consider digital rectal examination if concerned for cauda equina syndrome.

• Radiographic evaluation:
  – Bladder ultrasonography can determine postvoid residuals.

• Management:
  – Prevention:
    ◦ Avoid excessive opioid use:
      ▪ Multimodal analgesia has been associated with decreased rates of postoperative urinary retention (POUR).
    ◦ Limiting postoperative indwelling catheter time.
  – Treatment:
    ◦ Intermittent catheterization: majority of patients have self-limited symptomatology after evacuation of residual urine:
      ▪ Urethral catheterization.
      ▪ Suprapubic catheterization.
    ◦ Alpha-adrenergic medications.
    ◦ Cholinergic medications.

25.4.2 Urinary Tract Infection

• Background and etiology:
  – 2-3% incidence after spinal procedures.
  – Risk factors include the following:
    ◦ Patient factors: increased comorbidity burden, elevated postoperative C-reactive protein (CRP), older age, female gender, creatinine greater than 1.5 mg/dL.
    ◦ Surgical factors: increased operative time.

- Etiology:
  - ○ Interference of normal voiding, presence of indwelling catheters, introduction of bacteria in a nosocomial setting.
- Presentation:
  - Dysuria, urgency, frequency, suprapubic pain, hematuria.
  - Assess for flank pain and costovertebral angle (CVA) tenderness.

- Clinical evaluation
  - Urinalysis.
  - Urine culture with susceptibilities.

- Radiographic evaluation:
  - CT scan: used to identify pyelonephritis or abscesses.
    - ○ Indicated if there is evidence of pyelonephritis such as fever, flank pain, CVA tenderness.
- Treatment:
  - Antibiotics: fluoroquinolones with renal clearance:
    - ○ Narrow spectrum upon identification of organism and susceptibilities.
  - Removal possible sources of infection:
    - ○ IV catheters, indwelling urinary catheters.

25.5 Vascular and Hematologic Complications

25.5.1 Deep Vein Thrombosis, Venous Thromboembolism, and Pulmonary Embolism

- Background and etiology:
  - Reported incidences following spine procedures.
  - Venous thromboembolism (VTE): 0.3 to 31%:
    - ○ Pulmonary embolism (PE): 0.3 to 0.4%.
    - ○ Most cases are diagnosed during the first 2 postoperative weeks.
  - Risk factors include the following:
    - ○ Patient factors: body mass index (BMI) > 40 kg/m2, older age (>80 years), increased comorbidity burden (American Society of Anesthesiologists [ASA] score > 3), history of VTE, history of factor V Leiden, male sex (PE only).
    - ○ Surgical factors: prolonged operative time, use of general anesthesia.
  - Etiology:
    - ○ Combination of postoperative recumbency, venous stasis due to impaired mobility, and hypercoagulable state due to surgical tissue manipulation and local inflammatory response.
- Presentation:
  - Deep vein thrombosis (DVT):
    - ○ Leg swelling, unilateral leg tenderness.
  - PE:
    - ○ Dyspnea, tachypnea, pleuritic chest pain, cough, hemoptysis, fever.

- Clinical and radiographic evaluation:
  - DVT:
    - Dependent on risk stratification:
      - Intermediate to high risk:
        - Compression ultrasonography.
      - Low risk:
        - D-dimer: if positive, compression ultrasonography is performed for confirmation.
  - PE:
    - Dependent on risk stratification:
      - High risk:
        - CT pulmonary angiography to detect location of thrombus.
        - Ventilation/perfusion (V/Q) scan to detect areas of mismatch if CT is contraindicated.
      - Low to intermediate risk:
        - D-dimer: if elevated consider further investigation with CT pulmonary angiography or venous duplex ultrasonography for confirmation.
- Management:
  - DVT:
    - Anticoagulation with early ambulation:
      - Must consider postoperative status and invasiveness of recent spine procedure.
    - Consider thrombolytic therapy if the presentation is consistent with impending gangrene.
  - PE:
    - Suspected or confirmed PE with no evidence of shock: anticoagulation.
    - Suspected or confirmed PE with evidence of shock: thrombolysis and anticoagulation.
    - Consider inferior vena cava (IVC) filter if patient has a contraindication to anticoagulation or has recurrent PE on anticoagulation therapy.

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Questions & Answers

1 Neuroanatomy and Physiology

Jacob V. DiBattista, Ankur S. Narain, Fady Y. Hijji, Philip K. Louie, Daniel D. Bohl, and Kern Singh

Clinical Questions

1. A 50-year-old man presents to your office with complaints of arm pain. On examination, he has loss of sensation over the lateral aspect of the arm, and weakness with shoulder abduction. What is the expected deep tendon reflex deficit expected in this patient?

   a. Biceps reflex.
   b. Triceps reflex.
   c. Brachioradialis reflex.
   d. Hoffman's sign/reflex.

2. Which of the following is true?

   a. The myelin sheath is a fatty insulating layer around the cell body that facilitates saltatory conduction.
   b. The nodes of Ranvier are interruptions in the myelin sheath that contain a large number of voltage-gated sodium and potassium channels.
   c. The dendrites receive signals from the cell body and transfer those signals to other neurons.
   d. Schwann's cells myelinate neurons of the central nervous system.

3. Which of the following is *not* a presentation of a UMN lesion?

   a. Increased reflexes.
   b. Spasticity.
   c. Fasciculations.
   d. Babinski's sign.

Answers

1. a is correct. This patient's presentation is consistent with C5 radiculopathy, which is associated with deficiencies in the biceps reflex. The C5–C6 nerve roots comprise the neural pathway for the biceps reflex.

2. b is correct. The myelin sheath is a fatty insulating layer around the axon. Dendrites receive signals from other neurons and transmit them to the cell body. Oligodendrocytes myelinate neurons of the central nervous system.

3. c is correct. Fasciculations are an LMN sign. The other findings are consistent with UMN pathology.

2 General Spine Anatomy and Long Tract Pathways

Jacob V. DiBattista, Ankur S. Narain, Fady Y. Hijji, Philip K. Louie, Daniel D. Bohl, and Kern Singh

Clinical Questions

1. Which of the following is *not* true regarding spinal nerve roots?

   a. C1–C7 spinal nerves exit below the corresponding vertebrae.
   b. Spinal nerves exit the spinal canal via the intervertebral foramina.
   c. There a total of 31 spinal nerves.
   d. The spinal cord terminates at the conus medullaris (L2).

2. Which of the following is the correct pairing of spinal tract and site of decussation?

   a. Anterior corticospinal: anterior white commissure.
   b. Rubrospinal: none (ipsilateral innervation).
   c. Tectospinal: none (ipsilateral innervation).
   d. Medial vestibulospinal: midbrain.

3. Which of the following is *not* true regarding intervertebral disks?

   a. The intervertebral joint space is not a synovial joint.

   b. The most cephalad disk is located between C2 and C3.
   c. The nucleus pulposus surrounds the annulus fibrosis.
   d. They are composed of primarily type I and II collagens.

Answers

1. **a** is correct. C1–C7 vertebrae exit *above* their corresponding vertebrae.

2. **a** is correct. Nerve fibers of the anterior corticospinal tract decussate at the anterior white commissure, which is located in the anterior portion of the midline of the spinal cord. The rubrospinal and tectospinal tracts decussate at the midbrain. The medial vestibulospinal tract decussates at the caudal medulla.

3. **c** is correct. The annulus fibrosis is surrounded by the nucleus pulposus. All the other choices are true statements.

3 Atlanto-Occipital Anatomy

Suzanne Labelle, Fady Y. Hijji, Ankur S. Narain, Philip K. Louie, Daniel D. Bohl, and Kern Singh

Clinical Questions

1. Which of the following branches of the vertebral artery supplies the odontoid process of C2?

    a. Anterior spinal artery.
    b. Posterior spinal artery.
    c. Posterior ascending artery.
    d. Anterior segmental medullary artery.

2. A 55-year-old man comes into the office complaining of axial neck pain of 6 months' duration. On physical examination, decreased sensation of the upper occiput and scalp is noted. Pathology of which joint space is most likely to be demonstrated on radiographic examination?

    a. Atlanto-occipital junction.
    b. C1–C2 disk space.
    c. C2–C3 disk space.
    d. Both atlanto-occipital junction and the C1–C2 disk space.

3. A 50-year-old woman presents to the emergency room following a motor vehicle accident. On radiographic examination, instability is noted between the atlantoaxial joint with increased space between the anterior arch of the atlas and the dens. Which ligament is most likely injured?

    a. Alar ligament.
    b. Barkow's ligament.
    c. Nuchal ligament.
    d. Tectorial membrane.
    e. Cruciate ligament.

Answers

1. **c** is correct. The posterior ascending arteries connect to form the apical arcade at the top of the odontoid process and aid in collateral circulation of the dens with the anterior ascending arteries.

2. **b** is correct. The C2 nerve root is likely affected in this individual, resulting in decreased sensation of the scalp. In the cervical vertebrae above C7, all nerve roots exit above the respective vertebrae. As such, the C2 nerve root will be exiting between the C1–C2 disk space, and significant pathology here will result in impingement of this nerve root.

3. **e** is correct. The cruciate ligament maintains the stability of craniocervical junction by locking the odontoid process against the anterior arch of C1. This middle pivot joint provides the axis for rotation at the atlantoaxial joint.

4 Cervical Spine Anatomy

Fady Y. Hijji, Ankur S. Narain, Phillip K. Louie, Daniel D. Bohl, and Kern Singh

Clinical Questions

1. A 30-year-old motorcyclist is involved in an accident on the highway. Following evaluation, he is diagnosed with superior brachial plexus injury. Which of the following would likely be normal on his physical examination?

   a. Shoulder abduction.
   b. Flexion of the elbow.
   c. Sensation over the radial aspect of the forearm.
   d. Sensation of the third digit of the hand.
   e. Sensation over the lateral aspect of the shoulder.

2. Which of the following statements is true?

   a. All subaxial cervical vertebrae have transverse foramens in a majority of patients.
   b. Range of rotation is least at more cranial levels.
   c. As one moves cranially, superior articular facets transition toward posterolateral orientation.
   d. The vertebral artery can be found in the transverse foramen of all cervical vertebrae.

3. A 50-year-old man presents with left arm pain lasting 4 weeks. The pain is distributed over the anterior surface of his upper arm and forearm. What would be the likely motor deficit and level of nerve root compression on this patient?

   a. Flexion of forearm with nerve root compression at the C5–C6 disk level.
   b. Abduction of arm with nerve root compression at the C5–C6 disk level.
   c. Extension of forearm with nerve root compression at the C6–C7 disk level.
   d. Abduction of arm with nerve root compression at the C4–C5 disk level.
   e. Flexion of the wrist with nerve root compression at the C6–C7 disk level.

Answers

1. **d** is correct. The patient has experienced a C5–C6 root avulsion. They will experience loss of shoulder abduction and sensation of the lateral shoulder (axillary nerve), biceps weakness, and decreased sensation over the radial aspect of the forearm (musculoskeletal nerve–lateral antebrachial cutaneous nerve).

2. **a** is correct. The vertebral artery enters the transverse foramen at C6; however, in most patients' vertebrae, C3–C7 exhibit a transverse foramen.

3. d is correct. Based on dermatomal distribution, this patient is exhibiting C5 sensory deficit, which corresponds with a weakness in arm abduction (C5 primary motor innervation is the deltoid). In the cervical vertebrae, each nerve root exits above its corresponding level (C5 nerve root exits above C6 vertebrae at the C5–C6 disk level).

5 Thoracic Spine

Catherine Maloney, Fady Y. Hijji, Ankur S. Narain, Philip K. Louie, Daniel D. Bohl, and Kern Singh

Clinical Questions

1. Which of the following thoracic vertebrae exhibits the narrowest pedicle diameter?

   a. T1.
   b. T3.
   c. T6.
   d. T7.
   e. T12.

2. At which level does the artery of Adamkiewicz typically arise?

   a. T1.
   b. T3.
   c. T6.
   d. T7.
   e. T9.

3. In order to prevent early instrumentation failure, spinal fusion constructs should not end at which level?

   a. T4–T5.
   b. T5–T6.
   c. T6–T7.
   d. T7–T8.
   e. T9–T10.

Answers

1. c is correct. The thoracic pedicles are widest at T1 and T12, and gradually become narrower as one progresses toward the middle of the spinal column (T6).

2. e is correct. The artery of Adamkiewicz typically arises from left posterior intercostal artery between T9 and T12 in 85% of individuals.

3. d is correct. The apex of thoracic kyphosis exists at T7–T8. Instrumentation ending at the thoracic kyphotic apex can lead to early instrumentation failure.

6 Lumbar Spine Anatomy

Melissa G. Goczalk, Ankur S. Narain, Fady Y. Hijji, Philip K. Louie, Daniel D. Bohl, and Kern Singh

Clinical Questions

1. A patient presents to your clinic with weakness in knee extension, decreased patellar reflex, and cutaneous sensory loss along the lower anterior thigh, knee, anterior lower leg, and medial ankle. Which nerve root is likely affected?

   a. L2.
   b. L3.
   c. L4.
   d. L5.

2. Which of the following statements is true?

   a. The psoas muscles lie lateral to the lumbar vertebrae.
   b. The genitofemoral nerve courses along the iliacus muscle.
   c. The abdominal aorta bifurcates at the L5 vertebral level.
   d. The obturator nerve arises from the L2–L3 levels.

3. Which of the following is *not* true regarding lumbar ligamentous anatomy?

   a. The ligamentum flavum spans from the posterior aspect of the inferior lamina to the anterior aspect of the superior lamina.

   b. The posterior longitudinal ligament limits spine extension and secures intervertebral disks.
   c. The supraspinous ligament terminates at L3.
   d. The interspinous ligament connects the spinous processes and is oriented obliquely.

Answers

1. **c** is correct. L4 provides motor innervation to the anterior thigh and along the dermatome described. The disk herniation at the L3–L4 level would compress L4.

2. **a** is correct. The genitofemoral nerve courses along the psoas major muscles, the abdominal aorta bifurcates at L4, and the obturator nerve arises from L2 to L4.

3. **b** is correct. The posterior longitudinal ligament limits spine *flexion* and secures the intervertebral disks.

7 Sacral Spine

Antonios Varelas, Fady Y. Hijji, Ankur S. Narain, Philip K. Louie, Daniel D. Bohl, and Kern Singh

Clinical Questions

1. A 25-year-old female gymnast sustains an injury during a fall from the uneven bars. Following evaluation, she is diagnosed with an S3 and S4 nerve lesion. Which of the following would likely be limited for the patient?

   a. External rotation of the femur, extension, and lateral stabilization of the left hip.
   b. Voluntary control over the anal sphincter.
   c. External rotation, abduction, and extension of the left hip joint.

2. Which of the following statements is true?

   a. The dural sac ends at S2 and continues to the coccyx as the sacrospinous ligament.
   b. The nerve to the obturator internus supplies motor innervation to both the obturator internus and the inferior gemellus.
   c. The sacral plexus is located between the pelvic (Waldeyer's) fascia and piriformis.
   d. The apex of the sacrum articulates with the final lumbar vertebrae.

3. A 40-year-old man presents with diminished ankle plantar flexion and sensation over the posterior surface of his right thigh. Impingement of which of the following nerve roots could result in this presentation?

   a. L5.
   b. S1.
   c. S2.
   d. a and b.
   e. b and c.
   f. All of the above.

Answers

1. **b** is correct. The pudendal nerve, which provides motor innervation to the external anal sphincter, receives contributions from S2, S3, and S4. a is incorrect because the function described can be attributed to the gluteus maximus, which is innervated by the inferior gluteal nerve (L5, S1, S2). c is incorrect because this is the function of the piriformis, which is innervated by the nerve to the piriformis (L5, S1, S2).

2. **c** is correct. The sacral plexus lies deep to the pelvic fascia and superior to the piriformis. a is incorrect because the dural sac continues as the coccygeal ligament. b is incorrect because the nerve to the obturator internus supplies the superior gemellus. d is incorrect because the superior articular process, located at the base of the sacrum, articulates with the final lumbar vertebrae.

3. **e** is correct. The posterior cutaneous femoral nerve, responsible for sensation to the posterior surface of the thigh and leg, receives contributions from S1, S2, and S3. While S2 is the predominant nerve root in this dermatome, injury to any of these sacral roots can affect the posterior cutaneous nerve's function. Active ankle plantar flexion is predominantly innervated by the S1 nerve root.

8 Spinal History and Physical Examination

Fady Y. Hijji, Ankur S. Narain, Junyoung Ahn, Philip K. Louie, Daniel D. Bohl, and Kern Singh

Clinical Questions

1. Which of the following examination findings would most likely be present in a patient with myelopathic symptoms?

   a. Reproduction of a patient's radicular pain when rotating and laterally flexing head to one side and then providing an axial load.
   b. Absent sphincter reflex when squeezing patient's glans penis or clitoris or tugging on indwelling Foley catheter, monitoring for anal external sphincter contraction.
   c. Patient unable to perform at least 20 cycles of grip/release within 10 seconds when patient asked to rapidly make a fist and release with both hands.
   d. Negative sitting root test with positive straight leg raise.
   e. Patient is unable to maintain balance when asked to stand up with their feet together and eyes closed for 10 seconds.

2. Which of the following is an incorrect pairing of nerve root and examination?

   a. C5 – lateral shoulder sensation – deltoid muscle – biceps reflex.

   b. C6 – lateral arm/forearm sensation – biceps muscle – triceps reflex.
   c. L4 – lower anterior thigh sensation – tibialis anterior muscle – patellar tendon reflex.
   d. L5 – posterolateral thigh and lateral leg sensation – extensor hallucis longus muscle – medial hamstring reflex (rare).
   e. S1 – lateral foot, lateral posterior thigh, and leg sensation – gastrocnemius muscle – Achilles' reflex.

3. Patients with spinal stenosis often present with what type of gait:

   a. Forward leaning.
   b. Trendelenburg gait.
   c. Antalgic gait.
   d. Circumduction gait.
   e. High-steppage gait.

Answers

1. **c** is correct. The grip and release test is an appropriate test for the assessment of cervical myelopathy. Reproduction of radicular pain with rotation and flexion of the head is the Spurling's test, which is an assessment for cervical radiculopathy. Absent sphincter reflexes when squeezing the glans penis is indicative of damage to the conus medullaris or sacral nerve roots.

Negative sitting root test implies a nonorganic pathology of a patient's lumbar symptoms. Inability to maintain balance when standing with eyes closed indicates injury to the dorsal column of the spinal cord.

2. **b** is correct. C6 provides lateral forearm to thumb sensation, motor innervation to the biceps, and the brachioradialis reflex.

3. **a** is correct. Forward leaning helps increase the space within the spinal canal, diminishing symptoms for patients experiencing spinal stenosis. Trendelenburg gait is exhibited by patients with gluteus medius weakness. Antalgic gait is predominant in patients experiencing pain with weight bearing, such as those with hip arthritis. Circumduction gait indicates upper motor neuron pathology, such as a previous stroke. High-steppage gait indicates L4 nerve root or deep peroneal nerve palsy.

9 Common Radiographic Measurements

Dustin H. Massel, Benjamin C. Mayo, William W. Long, Krishna D. Modi, and Kern Singh

Clinical Questions

1. Which of the following is not true regarding radiographic arthrodesis?

   a. Refers to fusion of two or more vertebral bodies.
   b. Plain radiographs are the gold standard for determining the presence of arthrodesis.
   c. Defined by bony bridging on three sequential cuts in the sagittal and coronal planes.
   d. The presence of subchondral cysts may be a sign of a failed arthrodesis.

2. Which of the following is true regarding measurements of cervical lordosis?

   a. Cervical lordosis is measured via lateral radiographs.
   b. Hypolordosis is defined as a measurement less than 15 degrees.
   c. Normal lordosis is defined as a measurement between 20 and 40 degrees.
   d. Hyperlordosis is defined as a measurement greater than 50 degrees.

3. Which of the following is not true regarding spondylolisthesis?

   a. Anterolisthesis refers to anterior displacement of the vertebral body.
   b. The Meyerding classification is the most widely used classification system.
   c. The slip angle quantifies the degree of lumbosacral kyphosis.
   d. The Wiltse classification system is based on percent slip.

Answers

1. **b** is correct. Computed tomography (CT) scan is the gold standard for determination of arthrodesis.

2. **c** is correct. Cervical lordosis is measured via lateral radiographs. Hypolordosis is defined as a measurement less than 10 degrees and hyperlordosis is defined as a measurement greater than 40 degrees.

3. **d** is correct. The Wiltse classification is based on etiology. The Meyerding classification is based on percent slip.

10 Cervical Disk Disease

Fady Y. Hijji, Ankur S. Narain, Philip K. Louie, Daniel D. Bohl, and Kern Singh

Clinical Questions

1. An 82-year-old woman presents to clinic with progressive gait instability and difficulty with fine motor tasks. Which of the following does an MRI of the cervical spine most likely reveal?

   a. No obvious pathology; well-maintained disk height and lordosis.
   b. Herniated disk at C4–C5 with bilateral foraminal stenosis; Torg–Pavlov ratio 1.1.
   c. Loss of cervical lordosis with no obvious central canal stenosis.
   d. Decreased disk space throughout, herniated disk at C6–C7 with central stenosis; Torg–Pavlov ratio 0.7.
   e. Complete transection injury to the spinal cord at C4–C5.

2. A 67-year-old man with a long history of chronic kidney disease on hemodialysis and a pacemaker in place presents with worsening numbness, paresthesias, and weakness down his left arm to the ring and small fingers. A plain radiograph of the cervical spine shows mild spondylotic changes. What would be the next step in imaging?

   a. MRI.
   b. MR neurography.
   c. CT myelogram.
   d. CT.
   e. Bone scan.

3. A 54-year-old man presents with chronic axial neck pain for the past 6 months. MRI shows a protruding central disk herniation at C5–C6 with a Torg–Pavlov ratio of 0.7. Which of the following physical exam findings would you also expect to find?

   a. Radiating pain on extension, rotation, lateral bend, and vertical compression of the neck.
   b. Numbness along the lateral arm and shoulder.
   c. Spontaneous flexion of other fingers on snapping of the patient's distal phalanx of middle finger.
   d. Decreased biceps reflex.

Answers

1. **d** is correct. The patient is exhibiting symptoms consistent with myelopathy. MRI findings revealing pathology causing central stenosis with a Torg–Pavlov ratio below 0.8 would confirm a diagnosis of myelopathy.

2. **d** is correct. The patient has symptoms consistent with radiculopathy. However, because of medical history, the patient is contraindicated for MRI or CT myelogram. Thus, the next best choice for

imaging would be CT scan to assess for spondylosis.

3. **c** is correct. The patient's MRI reveals findings consistent with myelopathy. Answer choice c describes Hoffman's sign, a physical examination finding often found with myelopathic patients.

11 Lumbar Disk Disease

Fady Y. Hijji, Ankur S. Narain, Philip K. Louie, Daniel D. Bohl, and Kern Singh

Clinical Questions

1. A 59-year-old man comes into the office complaining of progressively worsening low back pain for the past 2 weeks. Your patient works at Home Depot and reports decreased ability to perform his work functions which include moving large pieces of equipment and inventory. Upon examination, he has pain on lumbar extension and paresthesias in the L5 dermatome. Imaging reveals a herniated disk at L4/L5. What treatment would you recommend?

   a. Microdiskectomy.
   b. Rest, PT, and NSAIDs.
   c. Corticosteroid injection.
   d. Laminotomy.

2. A 25-year-old woman reports to your clinic with low back pain. She has a history of playing competitive soccer. She currently complains of pain with lumbar extension, and lower extremity pain while walking. What type of pathology might you find in this patient?

   a. Spondylosis.
   b. Far lateral disk herniation.
   c. Isthmic spondylolisthesis.
   d. Degenerative spondylolisthesis.

3. A 52-year-old man presents with low back pain radiating into the left thigh and anterior leg for 6 months' duration. On physical examination, the patient exhibits weakness on left leg extension and absent left quadriceps reflex. Which of the following would be most likely present on MRI?

   a. Left L2–L3 far-lateral (foraminal) HNP.
   b. Left L4–L5 paracentral HNP.
   c. Left L4–L5 far-lateral HNP.
   d. Left L4–L5 central HNP.

Answers

1. **b** is correct. The patient has radiculopathy with imaging findings consistent with L5 nerve root compression. As the patient has not gone through a minimum of 6 to 12 weeks of conservative therapy, the patient should utilize these methods prior to undergoing more invasive treatment options.

2. **c** is correct. Based on the patient's age and history, the patient is most likely suffering from isthmic spondylolisthesis. Disk herniation is also possible; however, symptoms caused by disk herniations are typically worsened with lumbar flexion, not extension.

3. **d** is correct. The patient is presenting with L4 radiculopathy. Lumbar nerve roots typically exit under the pedicle of the superior lumbar vertebrae of any given disk level. Therefore, the L4 nerve root exits

at the L4–L5 disk space and would be compressed in neuroforaminal stenosis caused by a far-lateral disk herniation. Central and paracentral herniations of the L4–L5 disk would likely affect the traversing nerve root of the next level (L5).

12 Scoliosis

Lauren M. Sadowsky, Ankur S. Narain, Fady Y. Hijji, Philip K. Louie, Daniel D. Bohl, and Kern Singh

Clinical Questions

1. A 14-year-old adolescent girl is routinely screened for scoliosis because her mother has severe scoliosis. She is found to have a 12-degree right-sided thoracic scoliosis. On the Adams forward bend test, she has left-sided protrusion of her ribcage. Which of the following is *true* regarding the treatment of this patient?

   a. TLSO bracing is indicated to prevent progression of her curvature.
   b. Nighttime bracing is indicated to prevent progression of her curvature.
   c. Serial casting is indicated to prevent progression of her curvature.
   d. No treatment is indicated for this patient.

2. A 5-year-old boy has a severe scoliosis curve identified as 3AN by the Lenke classification system. Which of the following is the correct description of his curve?

   a. Double major (DM).
   b. Triple major (TM).
   c. Double thoracic (DT).
   d. Main thoracic (MT).
   e. Thoracolumbar/lumbar (TL/L).

3. A 6-month-old infant presents to the office because his mother noticed his legs always twist to the right on the changing table. Upon physical examination, it is noted that the infant has significant axillary freckling in addition to a diagnosis of scoliosis. Which of the following is the *most* likely etiology for this child's presentation?

   a. Idiopathic.
   b. Congenital.
   c. Neuromuscular.
   d. Syndromic.

Answers

1. **d** is correct. No corrective treatment is indicated for patients with spinal curves with Cobb's angles less than 20 degrees. Rather, this patient should be monitored through adolescence for progression of the curve via external inspection and X-rays.

2. **a** is correct. Type 3 scoliosis curves on the Lenke classification system are described as DM curves.

3. **d** is correct. This child's freckling pattern is suggestive of neurofibromatosis, which is a syndromic etiology of scoliosis. Even if the scoliosis was present at birth, the etiology appears to not be one of malformation but rather associated with a syndromic disease process.

13 Spinal Trauma and Fractures

Ankur S. Narain, Fady Y. Hijji, Philip K. Louie, Daniel D. Bohl, and Kern Singh

Clinical Questions

1. Which of the following is not a component of the initial management of ALL suspected spinal fractures?

   a. Primary survey (ABCDE).
   b. Evaluation of spinal shock via assessment of bulbocavernosus reflex.
   c. Determination of the neurologic level of injury.
   d. MRI scan.

2. In which of the scenarios would surgical management be indicated?

   a. Jefferson's fracture with an intact TAL.
   b. Unilateral facet dislocation with no focal neurologic deficits.
   c. Thoracolumbar burst fracture with greater than 30 degree kyphosis.
   d. Sacral fracture with less than 1 cm displacement.

3. Which of the following is the most common type of injury associated with sacral fractures?

   a. Pelvic injuries.
   b. Thigh injuries.
   c. Knee injuries.
   d. Foot injuries.

Answers

1. **d** is correct. MRI is necessary only in cases where neurologic deficit is present. All other interventions are required in ALL cases of suspected spinal fracture.

2. **c** is correct. Thoracolumbar with greater than 30 degree kyphosis signifies instability and is a surgical indication. The other scenarios do not present with instability and thus are not immediate surgical candidates.

3. **c** is correct. Pelvic injuries are associated with 30 to 45% of sacral fractures. While thigh, knee, and foot injuries may occur concomitantly with a sacral fracture, they are not as common as pelvic injuries.

14 Primary and Metastatic Spinal Tumors

Ankur S. Narain, Fady Y. Hijji, Philip K. Louie, Daniel D. Bohl, and Kern Singh

Clinical Questions

1. An 18-year-old man presents to your office with chronic back pain that is relieved by the use of non-steroidal anti-inflammatory drugs (NSAIDs). CT scan demonstrates a 15-mm circular radiolucency surrounded by sclerotic bone changes. What is the most likely diagnosis?

   a. Osteoid osteoma.
   b. Osteoblastoma.
   c. Osteosarcoma.
   d. Giant cell tumor.

2. Which of the following is *not* a common primary tumor leading to spinal metastatic disease?

   a. RCC.
   b. Invasive lobular carcinoma of the breast.
   c. Papillary thyroid cancer.
   d. Gastric adenocarcinoma.

3. A 15-year-old adolescent boy presents to your office with low back pain of 6 months' duration. Upon examination, there is a palpable soft-tissue mass in the midline of the lower back. Radiographs demonstrated an irregular appearance of the L3 vertebral body, with an extensive periosteal reaction leading to the appearance of multiple layers. What is the most likely diagnosis?

   a. Chondrosarcoma.
   b. Ewing's sarcoma.
   c. Chordoma.
   d. Osteosarcoma.

Answers

1. **a** is correct. Osteoid osteoma is indicated by a 15- to 20-mm circular radiolucency surrounded by sclerotic bone changes. Relief of pain with NSAIDs is also a characteristic feature of osteoid osteoma.

2. **d** is correct. Gastric adenocarcinoma is not one of the most common primary etiologies of metastatic spinal disease. The most common primary sources include breast cancer, lung cancer, thyroid cancer, RCC, and prostate cancer.

3. **b** is correct. Ewing's sarcoma is characterized by an irregular, "moth-eaten" bone appearance with extensive periosteal reaction that forms layers like an "onion skin." Ewing's sarcoma is also often associated with soft-tissue extension, in this case presenting as a palpable soft-tissue mass in the lower back.

15 Spinal Infections

Ankur S. Narain, Fady Y. Hijji, Philip K. Louie, Daniel D. Bohl, and Kern Singh

Clinical Questions

1. Which imaging modality is the most informative for the diagnosis of osteomyelitis?

    a. Plain radiography.
    b. CT.
    c. MRI.
    d. Bone scintigraphy.

2. Which of the following is *false* regarding the treatment of a spinal epidural abscess?

    a. Surgery is indicated if neurologic deficits are present.
    b. Abscess location in the posterior spine requires decompression via laminectomy.
    c. Arthrodesis is necessary if spinal instability is present or suspected.
    d. Antibiotic administration is not required postoperatively upon successful irrigation and debridement.

3. Which of the following is *true* regarding postoperative spinal infection?

    a. Infection is caused by hematogenous inoculation of the wound by skin flora.
    b. Intraoperative deep wound cultures are preferred for pathogen identification.
    c. Prophylactic antibiotic dosing should occur within 90 minutes prior to the procedure start time.
    d. Postoperative antibiotics should be continued for a 4-week course.

Answers

1. c is correct. MRI, specifically T2-weighted images, provides excellent resolution of edema and inflammation within the intervertebral disk space and vertebral bodies. Plain radiography findings can be delayed for weeks to months after infection. Bone scintigraphy has low sensitivity compared to MRI. CT is indicated only in patients who have contraindications to MRI and contrast administration.

2. d is correct. Antibiotic administration is required for 4 to 6 weeks after irrigation and debridement. The other answer choices are true statements.

3. b is correct. Intraoperative deep wound cultures are preferred for pathogen identification, as they are not contaminated with skin flora and thus provide more accurate pathogen identification. Infection is caused by direct inoculation of the wound by skin flora. Prophylactic antibiotic dosing should occur within 60 minutes prior to the procedure start time. Postoperative antibiotics should be continued for a course of at least 6 weeks.

16 Pediatrics

Jonathan Markowitz, Ankur S. Narain, Fady Y. Hijji, Philip K. Louie, Daniel D. Bohl, and Kern Singh

Clinical Questions

1. In order to reduce the risk of NTDs, maternal supplementation should include which of the following?

   a. Ibuprofen 400 mg.
   b. Omega-3 1,200 mg.
   c. Folic acid 4 mg.
   d. Folic acid 0.4 mg.
   e. Calcium 600 mg.

2. Myelodysplasia at which of the following lumbar levels would present with a hip adduction, knee extension, and cavovarus foot deformity?

   a. L1.
   b. L2.
   c. L3.
   d. L4.
   e. L5.

Answers

1. **d** is correct. Maternal deficiency in folic acid is a major cause of NTDs. Maternal supplementation with 0.4 mg of folic acid decreases the risk of NTDs by 70 to 80%.

2. **d** is correct. Myelodysplasia involving the L4 nerve root level would present with an adducted hip, extended knee, and cavovarus foot deformity.

17 Anterior Cervical Diskectomy and Fusion

Ankur S. Narain, Fady Y. Hijji, Philip K. Louie, Daniel D. Bohl, and Kern Singh

Clinical Questions

1. A 45-year-old man undergoes an ACDF procedure due to C4–C5 herniation with radiculopathic symptoms. After he is transferred to the floor, the patient has significant hoarseness with difficulty speaking. What structure was likely injured during the procedure?

   a. Recurrent laryngeal nerve.
   b. Vocal folds.
   c. Epiglottis.
   d. Esophagus.

2. Which of the following is *not* true of patient positioning during an ACDF?

   a. The patient is placed in a supine position.
   b. The head is rotated ipsilaterally toward the side of surgical access.
   c. The hyoid bone serves as a landmark for the C3 level.
   d. The cricoid cartilage serves as a landmark for the C6 level.

3. Which of the following is not an indication for ACDF?

   a. Symptomatic cervical disk herniation.
   b. Cervical spondylosis.
   c. Occipitocervical dislocation.
   d. Unstable cervical fractures.

Answers

1. **a** is correct. Injury to the recurrent laryngeal nerve presents with postoperative hoarseness and possible aphonia. This can be avoided by placing retractors under the medial edge of the longus colli muscles.

2. **b** is correct. The head is not rotated ipsilaterally, but rather contralaterally to the side of surgical access. All other statements are true.

3. **c** is correct. Occipitocervical dislocation is typically treated with posterior fusion of the occiput to at least C2. Anterior approaches are not appropriate in this context.

18 Posterior Cervical Laminoplasty with Instrumentation

Ankur S. Narain, Fady Y. Hijji, Philip K. Louie, Daniel D. Bohl, and Kern Singh

Clinical Questions

1. Which of the following is a contraindication to cervical laminoplasty?

   a. Cervical spondylosis.
   b. Severe spinal stenosis.
   c. Grade 2 spondylolisthesis.
   d. Kyphotic deformity.
   e. Previous cervical diskectomy.

2. Two days following a cervical C3 to C7 laminoplasty with instrumentation, a patient begins complaining of new-onset weakness of his right arm. He notes he has difficulty raising his arm overhead to reach objects. Which of the following would be the best treatment options for this patient?

   a. Nonsteroidal anti-inflammatory drugs (NSAIDs).
   b. Repositioning of posterior instrumentation.
   c. Rotator cuff cortisone injection.
   d. Extension of the laminoplasty to include C4.
   e. MRI of the cervical spine.

Answers

1. **d** is correct. Kyphotic deformity is a contraindication for cervical laminoplasty as this procedure does not address the anterior cord compression in the kyphotic spine. Additionally, laminoplasty can potentially lead to worsening kyphosis in these situations.

2. **e** is correct. The patient is presenting with C5 nerve root palsy, as evidenced by weakness in his right deltoid. These symptoms are a known complication following cervical laminoplasty and are often self-limited. However, an MRI of the cervical spine should be obtained in order to rule out an epidural hematoma or residual severe foraminal stenosis that may be resulting in C5 nerve root compression.

19 Posterior Cervical Laminectomy and Fusion

Ankur S. Narain, Fady Y. Hijji, Philip K. Louie, Daniel D. Bohl, and Kern Sing

Clinical Questions

1. A 47-year-old man is postoperative day 1 after a PCLF for C2–C4 spondylosis with central spinal stenosis. He is experiencing nausea, vomiting, and headaches that are worsened in the upright position. What is the etiology of the patient's postoperative symptoms?

    a. Expected postoperative findings, no mechanism.
    b. Surgical site infection caused by introduction of skin flora into the surgical wound.
    c. Durotomy secondary to disruption of the thecal sac.
    d. Symptoms are secondary to effects of the medications given by anesthesia.

2. Which of the following is *not* a part of the management strategy for vertebral artery injury after PCLF?

    a. Aggressive IV fluid resuscitation.
    b. Hemostasis via digital pressure and Gelfoam.
    c. Placement of the head in a neutral position.
    d. Sacrifice of the dominant vertebral artery.

3. Which of the following is true regarding patient positioning and the initial surgical incision during a PCLF?

    a. The patient is placed in a lateral decubitus position.
    b. Placement of the patient in a Mayfield or other skull clamp is not required.
    c. The internervous plane for the paracervical muscles is in the midline.
    d. There are no sources of significant bleeding during the superficial approach.

Answers

1. c is correct. While nausea and vomiting can signal a large number of presentations, positional/orthostatic headaches are most consistent with durotomy leading to a cerebrospinal fluid (CSF) leak. Durotomy during PCLF most commonly occurs during the laminectomy.

2. d is correct. Sacrifice of the dominant vertebral artery is not recommended. Nondominant vertebral arteries can, however, be sacrificed. All the other presented statements are accepted management strategies in the case of vertebral artery injury.

3. **c** is correct. The patient is placed in the prone position. The patient is placed in a Mayfield or other skull clamp for stabilization. The adjacent venous plexuses may cause significant bleeding during the initial superficial dissection.

20 Open Posterolateral Lumbar Fusion

Ankur S. Narain, Fady Y. Hijji, Philip K. Louie, Daniel D. Bohl, and Kern Singh

Clinical Questions

1. A patient begins experiencing new-onset big toe extension weakness following an L5–S1 open PLF. Which of the following would be a likely cause of this patient's neurologic deficit?

  a. S1 pedicle screw cutout.
  b. S1 pedicle screw misplacement laterally.
  c. S1 pedicle screw misplacement medially.
  d. Direct nerve root injury during laminectomy.

2. Which of the following is a risk factor for an intraoperative pedicle fracture during open PLF?

  a. Screw misplacement.
  b. Intraoperative steroids.
  c. Diabetes.
  d. Osteoporosis.
  e. Male sex.

Clinical Answers

1. b is correct. The L5 nerve root, responsible for big toe extension, traverses laterally as one moves inferiorly and posteriorly. Lateral displacement of the S1 pedicle screw with perforation of the anterior alar cortex can injure the L5 nerve root. Extreme medial displacement of the pedicle screw would put the sympathetic chain or iliac vessels at risk.

2. d is correct. Osteoporosis is a significant risk factor for pedicle fracture during the placement of pedicle screws.

21 Anterior Lumbar Interbody Fusion

Ankur S. Narain, Fady Y. Hijji, Philip K. Louie, Daniel D. Bohl, and Kern Singh

Clinical Questions

1. Which of the following is *not* true regarding presacral plexus injury during ALIF procedures?

   a. Caused by manipulation of the plexus during dissection.
   b. Can be prevented by ensuring the initial incision is long enough to allow for nerve mobilization.
   c. Can be prevented by avoiding use of bipolar cautery during the procedure.
   d. Presents with postoperative retrograde ejaculation and possible impotence.

2. Which of the following is *not* a typical precaution taken to avoid visceral and vascular complications during an ALIF procedure?

   a. Identification and retraction of the genitofemoral nerve.
   b. Ligation of the middle sacral artery to prevent hemorrhage.
   c. Identification and retraction of the ureters.
   d. Retraction of the great vessels.

3. Which of the following is correct regarding patient positioning for ALIF procedures?

   a. The patient should be placed in the lateral decubitus position.
   b. The umbilicus corresponds to the L3–L4 vertebral level.
   c. The pubic tubercle lies superior and medial to the pubic symphysis.
   d. The patient is positioned with their arms at their sides in a slightly flexed position.

Answers

1. **c** is correct. In the prevention of presacral plexus injury, bipolar cautery usage is preferred. Monopolar cautery usage is not recommended for fear of nerve injury.

2. **a** is correct. The genitofemoral nerve is not typically encountered during ALIF procedures. It usually lies outside the surgical field lateral to the incision.

3. **b** is correct. The patient should be placed in a supine position ± reverse Trendelenburg. The pubic tubercle lies lateral to the pubic symphysis. The patient is positioned with their arms across their chest to allow for C-arm fluoroscopic access.

22 Minimally Invasive Transforaminal Interbody Fusion

Ankur S. Narain, Fady Y. Hijji, Philip K. Louie, Daniel D. Bohl, and Kern Singh

Clinical Questions

1. Which of the following is not a direct benefit of minimally invasive transforaminal lumbar interbody fusion?

   a. Decreased soft-tissue damage.
   b. Higher fusion rates.
   c. Decreased blood loss.
   d. Decreased inpatient length of stay.

2. Which of the following techniques can reduce the risk of neural injury?

   a. Use of intraoperative steroids.
   b. Increased number of interbody cages.
   c. Increasing exposure with extra facet removal.
   d. Repair of dural tears.

3. A patient begins complaining of progressively worsening back pain and new-onset weakness of left leg plantar flexion 2 days postoperatively following an L5–S1 MIS TLIF. Which of the following is most likely the cause of this patient's neurologic decline?

   a. Deep vein thrombosis.
   b. Stroke.
   c. Dural tear and CSF leak.
   d. Epidural hematoma.

Answers

1. **b** is correct. Minimally invasive spine surgical procedures have been demonstrated to reduce tissue damage, decrease blood loss, and decrease hospital length of stay postoperatively.

2. **c** is correct. By maximizing exposure through complete facet removal, the need for nerve root retraction is reduced.

3. **d** is correct. Progressive decline of neurologic function following surgery may cause suspicion for a hematoma formation. While surgical drains are not necessary postoperatively, epidural hematomas are a known complication following MIS TLIF and should always be considered in these cases.

23 Lateral Lumbar Interbody Fusion

Ankur S. Narain, Fady Y. Hijji, Philip K. Louie, Daniel D. Bohl, and Kern Singh

Clinical Questions

1. Which of the following would be a contraindication for LLIF at L4–L5?

   a. Degenerative spondylolisthesis.
   b. Lumbar plexus located in the anterior one-third of the L4 vertebral body.
   c. Bifurcation of the aorta at L3–L4.
   d. Previous abdominal surgery.

2. All of the following methods help reduce postoperative hip flexion weakness following LLIF, except:

   a. Reducing retraction time.
   b. Lengthening the incision to maximize exposure.
   c. Utilization of neuromonitoring.
   d. Preoperative imaging to identify location of the lumbar plexus.

Answers

1. c is correct. Following bifurcation of the aorta, the iliac vessels begin to traverse laterally. This may place the vessels at risk when performing an LLIF procedure.

2. b is correct. Hip flexion weakness is attributed to damage of the psoas muscle and irritation or damage to nerves within the muscle. Reducing traction time along with utilizing neuromonitoring and preoperative imaging to help localize the lumbar plexus will be beneficial in avoiding nerve damage or excessive muscle or nerve irritation.

24 Surgical Complications

Ikechukwu Achebe, Ankur S. Narain, Fady Y. Hijji, Philip K. Louie, Daniel D. Bohl, and Kern Singh

Clinical Questions

1. A 53-year-old man is postoperative day 3 (POD3) after a transforaminal lumbar interbody fusion (TLIF) procedure for degenerative L4–L5 spondylolisthesis. He complains of difficulty voiding and pain upon micturition. He also has a fever of 101.7°F. Which of the following is a risk factor for his current postoperative presentation?

   a. Prolonged IV catheterization.
   b. Urinary catheterization.
   c. Wound contamination by skin flora.
   d. Incidental durotomy during the procedure.

2. Which of the following is *not* true of a postoperative cutaneous CSF fistula?

   a. Fluids obtained via drainage are negative for beta-2-transferrin.
   b. Progression to meningitis can occur.
   c. MRI shows hyperintense, extra-arachnoid fluid on T2 sequences.
   d. Presents with postural headache, fever, neck stiffness, and pain.

3. Which of the following is true regarding spinal epidural hematomas?

   a. Symptoms usually follow an indolent course, and include back pain and neurologic deficits.
   b. MRI is the imaging modality of choice for diagnosis.
   c. Most cases can be treated nonoperatively with steroids.
   d. Single-level procedures are a risk factor for spinal epidural hematoma.

Answers

1. **b** is correct. The patient is presenting with symptoms typical of a urinary tract infection (UTI). UTIs commonly present around POD3 with fever, difficulty voiding, dysuria, and atypical discharge. A risk factor for postoperative UTI is urinary catheterization.

2. **a** is correct. Fluids obtained via drainage would be beta-2-tranferrin positive in a case of cutaneous CSF fistula.

3. **b** is correct. Symptoms usually follow a rapidly progressive course. Most cases require urgent operative decompression. Multilevel procedures are a risk factor for spinal epidural hematoma.

25 Common Medical Complications Following Routine Spinal Surgery

Ankur S. Narain, Fady Y. Hijji, Benjamin Khechen, Brittany E. Haws, Philip K. Louie, Daniel D. Bohl, and Kern Singh

Clinical Questions

1. Which of the following is *not* true regarding postoperative nausea and vomiting (PONV) after spinal procedures?

   a. Limiting postoperative opioid use can be an effective preventative measure.
   b. Female gender and extended duration of anesthesia are risk factors for development of PONV.
   c. Incidence rates approach 20 to 30% among all spinal procedures.
   d. Dopamine and serotonin receptor antagonist medications do not require ECG monitoring for QT prolongation.

2. Which of the following is *not* associated with either the clinical workup or management of postoperative urinary tract infections?

   a. Use of antibiotics, such as fluoroquinolones, with renal clearance.
   b. Indwelling lines and catheters are not removed.
   c. Assessment for flank pain and CVA tenderness is required to evaluate for possible pyelonephritis.
   d. CT scan can be used to detect possible abscesses.

3. A 55-year-old man is POD3 after undergoing a transforaminal lumbar interbody fusion (TLIF) procedure for lumbar spondylosis. His BMI is 42 kg/m², and he has a history of a lower extremity thrombus after a prior surgical procedure. He presents with dyspnea, pleuritic chest pain, cough, hemoptysis, and fever. A chest radiograph demonstrates no infiltrates. He has no history of contrast allergy. What is the most appropriate next step in the workup of this patient?

   a. Emergent CT pulmonary angiography.
   b. Ventilation/perfusion scan.
   c. D-dimer.
   d. Sputum culture.

Answers

1. **d** is correct. Dopamine and serotonin receptor antagonists are associated with QT prolongation and require serial ECG monitoring.

2. **b** is correct. Indwelling lines and catheters should be removed, as they can serve as the source of infection for UTIs.

3. **a** is correct. This patient is presenting with the classic symptomatology indicative of a PE. The patient's BMI, gender, and prior

medical history make him a high-risk candidate for PE. As such, emergent CT pulmonary angiography is required for diagnosis. V/Q scan is not preferred when there are no contraindications to CT scan.

D-dimer is not utilized in patients at high risk for PE. This patient had a chest radiograph with no associated infiltrates. As such, pneumonia is unlikely. Therefore, sputum culture is not required.

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