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Neuroanesthesiology Case Companion



Shailendra Joshi

Foreword
William L Lanier

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Chapter 4

Spinal Cord Anatomy

INTRODUCTION

The spinal cord is the tubular extension of the central nervous system from the medulla oblongata to the conus medullaris. It is encased in the bony vertebral column. From the center outward, it consists of the central canal, gray matter, and white matter. Thus, spinal cord organization is reversed compared to the brain **(Fig. 1)**. Understanding the functional anatomy of the spinal cord is necessary for the anesthetic management of spine surgery cases and in the assessment of neuraxial blocks.

STRUCTURAL ORGANIZATION

- *Size and extent:*
  - The spinal cord is 40–50 cm long and 1–1.5 cm in diameter.
  - It constitutes 2% of the central nervous system (CNS) mass.
  - It extends throughout the length of the spine in embryonic life. However, the vertebral canal growth exceeds the development of the cord; therefore, in adults, the spinal cord ends at L1/2.
- *Segments:*
  - There are 31 spinal segments: *cervical:* 8; *thoracic:* 12; *lumbar:* 5; *sacral:* 5; *coccygeal:* 1.
  - Spinal nerves, except for the C1, exit below the corresponding vertebrae.
  - There are two regions of spinal cord enlargements: (1) Cervical C3-T1 and (2) Lumbar L1-S2.
- *Coverings and support:*
  - It is covered by dura, arachnoid, and pia matter. The cord is tethered to the dura by denticulate ligaments and by the dorsal and ventral roots.

FUNCTIONAL ORGANIZATION

- *Dermatome is an* area of the skin innervated by a single dorsal root.
- *Spinal nerve roots are dorsal* (sensory) and ventral (motor) roots.
- *Gray matter organization:* There are three broad layers **(Fig. 2)**:
  - *Dorsal horn:* Sensory

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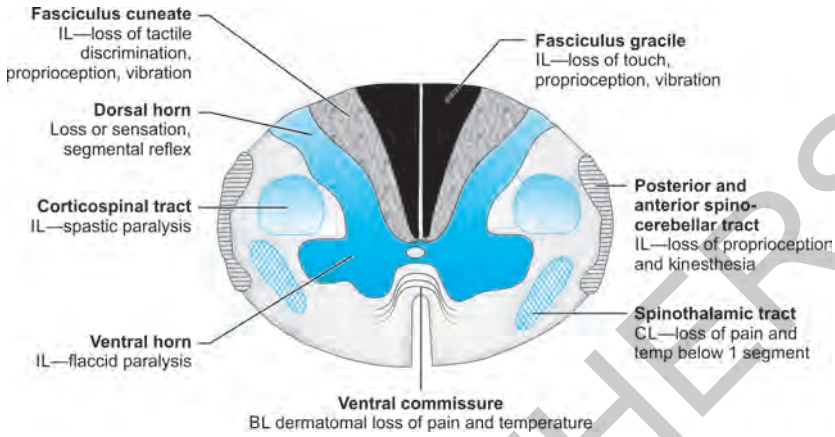

Fig. 1: Spinal tracts and consequences of injuries. (IL: ipsilateral; CL: contralateral; BL: bilateral)

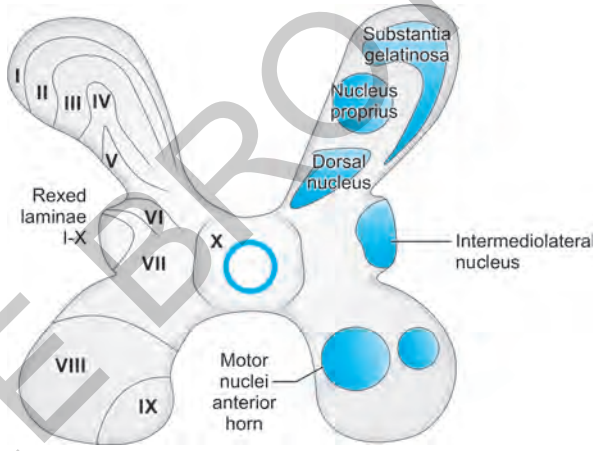

Fig. 2: Organization of the spinal gray matter.

- *Intermediolateral horn:* Visceral
- *Ventral horn:* Motor

Nuclei:

- *Dorsal group:*
  - *Marginal zone:* Axons to spinothalamic tracts: Pain and temperature
  - *Substantia gelatinosa:* Axons relay to ventral and lateral spinothalamic tracts: Transmit pain, temperature, and light touch impulses.
  - *The nucleus proprius, or* the chief sensory nucleus, contributes to ventral, and lateral spinothalamic tracts: Transmits light touch and pain impulses.
  - *Dorsal nucleus of Clarke (T1-L2):* Located in the lateral funiculus. The afferent dorsal spinocerebellar tracts relay unconscious proprioceptive information from muscle spindles to the cerebellum.

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- *Intermediolateral group (C8-L3):*
  - Preganglionic sympathetic fibers relay to the lateral horn to transmit visceral pain.
- *Ventral group:*
  - Lower motor neuron nuclei
  - Innervate the visceral and skeletal muscles.

Rexed laminae: The gray matter of the spinal cord is organized into *laminae* in the dorsal, lateral, and ventral horns. The dorsal horn: Receives sensory input through dorsal nerve roots (laminae I–VI), interoceptive sensations from within the body (I–IV), and proprioceptive sensations (V–VI). The intermediate horn (laminae VII) relays proprioceptive impulses from muscle spindles to the mid-brain and cerebellum. The ventral horn (laminae VIII and IX) relays between motor neurons. Rexed lamina X surrounds the central canal.

SPINAL CORD BLOOD FLOW

Organization of spinal cord blood flow:

- Three spinal arteries, one anterior (ASA) and two posterior spinal arteries (PSA) descend along the length of the spinal cord **(Fig. 3)**.
- The arteries form 6–8 arterial rings, from which branches arise to perfuse the cord radially.
- The ASA perfuses the anterior two-thirds of the gray matter.
- The PSA perfuses the posterior one-third of the gray matter.
- At each segmental level, the radicular arteries augment the anterior and the posterior arterial flow **(Fig. 4)**.

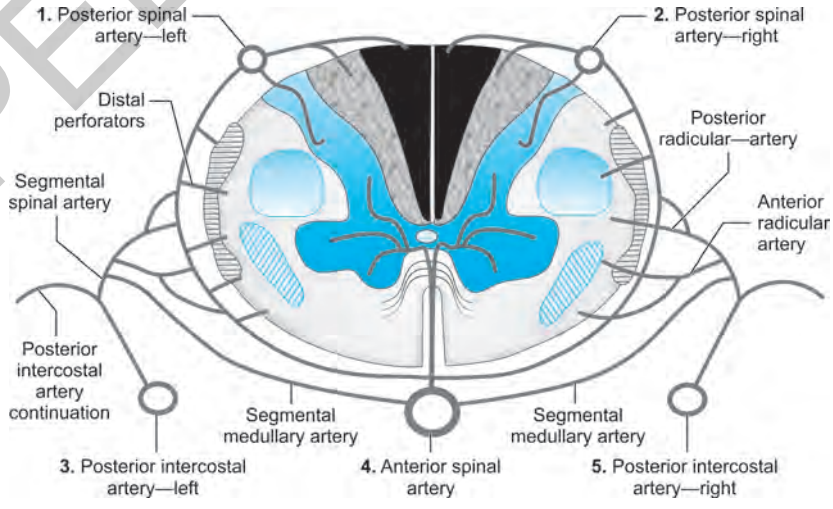

Fig. 3: Segmental spinal cord blood flow with collateral flow from five arteries shown as 1–5.

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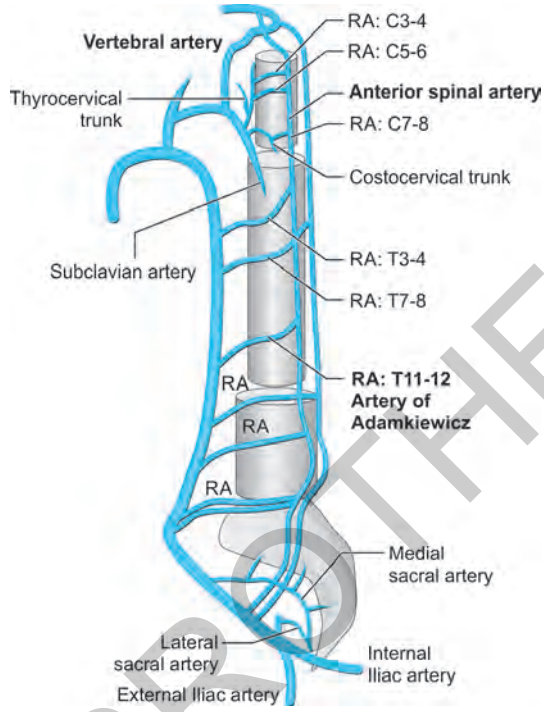

Fig. 4: Arterial supply to the spinal cord. (RA: radicular artery)

Anterior spinal artery:

- It is the dominant artery of the spinal cord.
- It is formed in the cervical region from branches of the vertebral artery that fuse into a single artery at the medulla.
- Descends in the anterior spinal groove, receiving supplementary branches from the segmental arteries.
- At the T10 level, the ASA receives the artery of Adamkiewicz.
- *The artery of Adamkiewicz:*
  - Usually arises from the left posterior intercostal artery at T9 to T 12 levels.
  - In the lower lumbar-sacral region, it is supplemented by several arteries from the pelvis.
  - It is 0.6–1.8 mm in diameter.
  - It provides significant blood supply to the lumbar and sacral cord.
  - Occlusion of the artery results in flaccid paralysis at the level of injury and spastic paralysis below the level; bilateral loss of pain and temperature below the lesion; urinary and fecal incontinence while proprioception, vibration, and touch are spared.
- Occlusion of the ASA can lead to infarction of the spinal cord, and the risk is most significant in the thoracic region.

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Posterior spinal arteries:

- They can originate from the vertebral artery, posterior inferior cerebellar, or posterior radicular artery at C-2.
- They descend along the posterior nerve roots.

Pial arterial plexus:

- It arises from the ASAs and the PSAs.
- It encircles the cord. It gives rise to penetrating arteries that supply the outer portions of the spinal cord.

Radicular arteries:

- A pair of radicular arteries at each segmental level, 31 pairs in all.
- They usually do not penetrate the spinal cord.
- They supply blood to the dura, nerve root, and spinal ganglia.

Regulation of Spinal Cord Blood Flow

- Spinal cord blood flow (SCBF) regulation is similar to cerebral blood flow (CBF).
- Of note is the reverse anatomy of the spinal cord compared to the brain, with the white matter outside and the gray matter inside.
- SCBF is higher than CBF.
- The values of SCBF vary between animal species, reflecting arterial supply, venous drainage, and intraspinal pressure differences.
- The spinal cord white matter blood flow is 15–25 mL/100 g/min, and the gray matter blood flow is 100–150 mL/100 g/min.
- SCBF is pressure autoregulated when mean arterial pressure (MAP) ranges between 50 and 135 mm Hg.
- The autonomic nervous system plays a more significant role.
- Like CBF, SCF increases linearly with $PaCO_2$ from 50 to 90 mm Hg.

Preventing Spinal Cord Ischemia

- The gray matter of the spinal cord has a much higher metabolic rate than the white matter, and it is perfused predominantly by the ASA.
- Hypotension, loss of autoregulation, and spinal shock can increase the vulnerability of the spinal cord to ischemic injury.
- Ischemia triggers secondary events such as excitotoxic damage, lipid peroxidation, free radical injury, and inflammation.
- The MAP should be maintained at ≥ 90 mm Hg.
- During aortic clamping, the cerebrospinal fluid (CSF) drain attenuates the rise in intraspinal pressure.
- The benefits of steroid treatment remain unproven and may have adverse effects.
- Hypothermia is beneficial after SCI after cardiac arrest and aortic clamping but is unproven for traumatic cord injuries.

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ORGANIZATION OF SENSORY SYSTEM (FIG. 5)

There are two main parts of the sensory system:

1. *Cranial nerves:* Transmit sensation from the head and the face.
2. *Spinal nerves:* Transmit sensation from the rest of the body.

The sensory pathways from the rest of the body also follow two courses:

1. The lateral spinothalamic tracts that cross over to the opposite side at the segmental level.
2. The dorsal column ascends on the same side to cross over at the mid-brain level.

Pain and Temperature

The pain and temperature sensations are transmitted via the dorsal root ganglion to the spinal cord via the Aδ and C fibers.

- *Aδ fibers:*
  - The first-order neurons are the Aδ fibers, whose cell bodies are in the dorsal root ganglion. They relay into the spinal cord's posterior

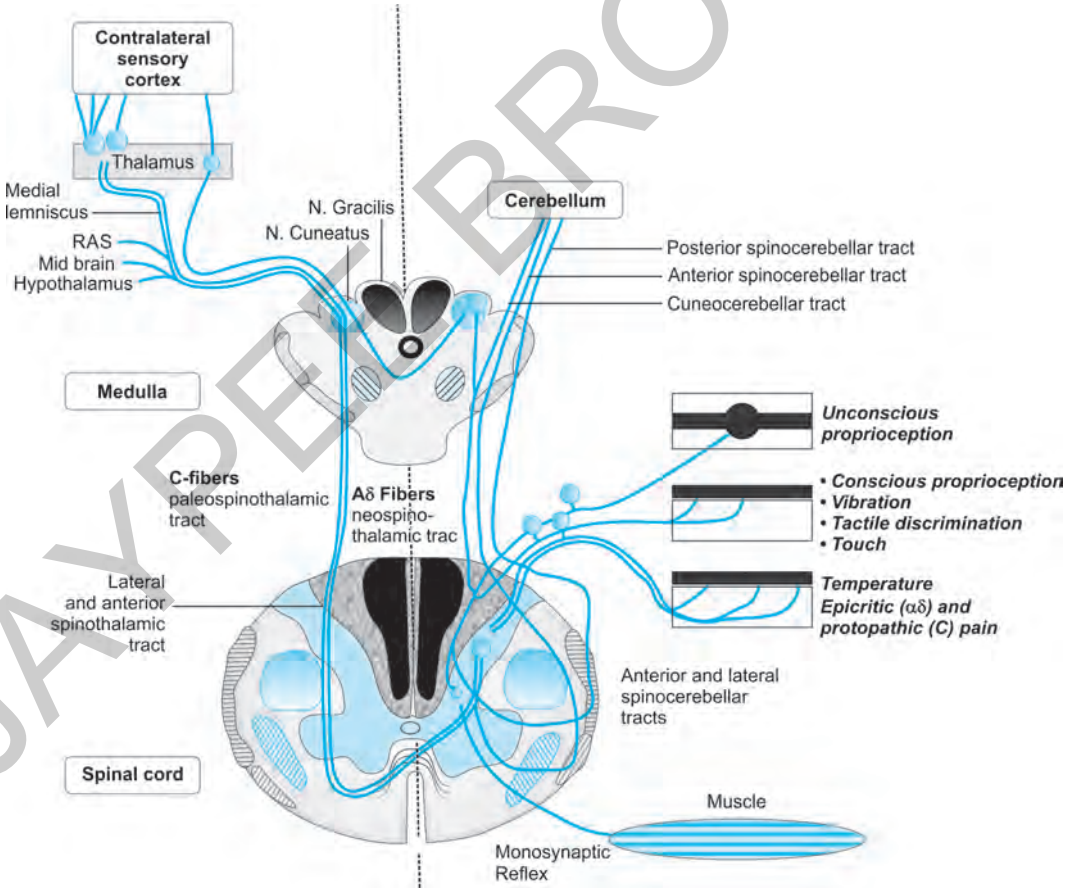

Fig. 5: Organization of sensory pathways.

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horn (laminae III and IV). They conduct the sharp/pricking pain sensation, which is well-localized.
  - The second-order neurons then cross the mid-line within a segment and relay from the lateral spinothalamic tract to the thalamus. At the pontine level, the tract lies close to the medial lemniscus.
  - The third-order neurons then project from the thalamus to the primary and the secondary cortex in areas 3, 1, and 2. A small number of fibers enter the brainstem reticular formation.
- *C fibers:*
  - C fibers are smaller fibers that conduct slow, poorly localized, burning pain.
  - Afferents from the dorsal root ganglia enter the spinal cord. They cross the midline to form the lateral spinothalamic tract. The tract relays to the reticular formation.
  - They project diffusely into the cortex. This pain is poorly localized and has an emotional component.

Touch, Pressure, and Kinesthesia

- The touch sensation can be fine or crude. The fine (epicritic) touch enables subtle discrimination of shapes and textures. The crude (protopathic) touch lacks such qualities.

Epicritic Touch

Mechanoreceptors (proprioceptive and vibratory) located throughout the body constantly report position- and movement-related information to the brain. The proprioceptive end organs are located in the joints and muscle spindles. Most of this information remains in the subconscious realm with minimal awareness.

- The primary fibers from mechanoreceptors ascend in the posterior column and at the mid-brain relay into the nucleus gracilis and cuneatus.
- The second-order neurons, the internal arcuate fibers, then ascend in the medial lemniscus to the thalamus.
- The third-order neurons then project into the sensory cortex.
- Collateral fibers project into the reticular formation and the cerebellum and are responsible for subconscious kinesthesia.

Subconscious proprioception: Proprioceptive information enters the dorsal horn and synapse in laminae V, VI, and VII (Clarke's column). They then ascend by two routes:

1. The second-order fibers cross over to the opposite side and ascend in the *anterior spinocerebellar tract* to the upper pons. They report to the contralateral cerebellum.
2. The second-order medial fibers ascend on the same side to the pons as the *posterior spinocerebellar tract* and project into the ipsilateral cerebellum.

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Protopathic Touch

- The primary fibers for protopathic touch relay to the dorsal root ganglia and enter the spinal cord. They cross over to the opposite side within one or two levels. In the spinal cord, they synapse in laminae VI–VIII.
- The second-order neurons then ascend to the thalamus.
- The third-order neurons then project into the sensory cortex.
- Collateral fibers project into the reticular formation, but their significance is relatively unknown.

MANIFESTATIONS OF INJURIES TO THE SENSORY PATHWAYS

- *Peripheral nerve injury (e.g., trauma):*
  - Flaccid paralysis
  - Loss of sensation
  - Loss of muscle tone
  - Loss of reflexes
  - Muscular atrophy
- *Posterior nerve root injury (e.g., disc herniation):*
  - Paresthesia
  - Paroxysmal pain
  - Decreased sensation.
  - Loss of reflexes
  - High stepping gait
  - *Positive Romberg's sign:* Loss of balance with eyes closed due to impaired proprioception.
- *Posterior and lateral funiculus injury (e.g., subacute combined degeneration of the cord).*
  - Loss of proprioception
  - Loss of vibratory sense
  - Muscle weakness
  - Spasticity
  - Hyperactive tendon reflexes
  - Positive Romberg test
  - Positive Babinski test is the dorsiflexion of the great toe with fanning of small ones on stimulation of the lateral aspect of the sole.
- *Gray commissure injury:* Gray matter around the central canal of the spinal cord, lamina X (e.g., syringomyelia)
  - Bilateral loss of pain and temperature at the level of injury
  - No loss of sensations below (sensory disassociation).

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Neuroanesthesiology Case Companion

This book reflects the author's experience in anesthesiology training at some of the best medical centers on three continents. Although this book is written for anesthesia residents, neurosurgery, neurology, and critical care trainees will find it helpful. This book provides a quick topical review for anesthesiologists in general practice. The text is bulleted and concise. Numerical data have been rounded. Simple line diagrams explain the key concepts and important table contents have been highlighted. All these measures are aimed at easy reading and assisting recall. The book's layout provides space for personal annotations to assist learning and to append information as it emerges. Thus, the book will remain a valuable companion well into the future.

"Neuroanesthesiology Case Companion has a unique approach to the subject. It is meant to be a practical manual, a teaching aid, and a source of case discussions. Its riveting vignettes about neurosciences will repeatedly draw in the reader."

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Emeritus Professor, Neurosurgery, AIIMS, New Delhi, India
Founder Department of Neurosurgery, AIIMS, and the
National Brain Research Center, Gurgram
Former President, Indian National Science Academy

Shailendra Joshi MBBS MD (Anesthesiology) FFARCS (I) is an Associate Professor of Anesthesiology at Columbia University in the city of New York, New York, USA. He has contributed to several anesthesia textbooks. He has authored over two hundred scientific papers and abstracts. He is a long-standing member of the Journal of Neurosurgical Anesthesiology editorial board. Dr Joshi's research has focused on the intraarterial delivery of drugs. He developed the first intraarterial drug formulations for glioma treatment, their novel delivery methods, and related devices. Dr Joshi has invented several medical and non-medical devices currently under patent review.

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