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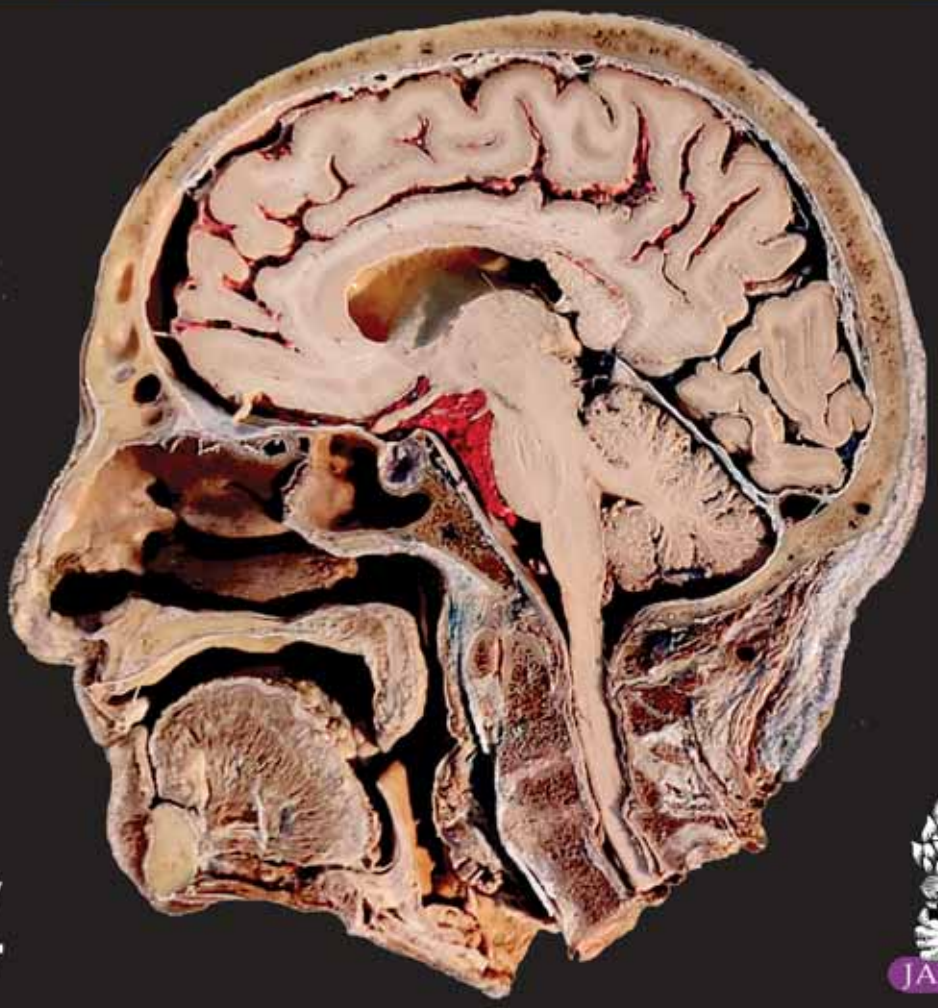
Inderbir Singh's Textbook of

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Previously known as Inderbir Singh's Textbook of
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Competency Table

Number	COMPETENCY The student should be able to	Domain K/S/A/C	Level K/ KH/SH/P	Core (Y/N)	Teaching-learning methods	Assessment methods	Chapter number	Page number
AN 7.1	Describe general plan of nervous system with components of central, peripheral and autonomic nervous systems	K	KH	Y	Lecture	Written	2 3 4 5	15–21 22–35 36–54 55–59
AN 7.2	List components of nervous tissue and their functions	K	KH	Y	Lecture	Written/viva voce	2	15–21
AN 7.3	Describe parts of a neuron and classify them based on number of neurites, size and function	K	KH	Y	Lecture	Written/viva voce	2	15–21
AN 7.4	Describe structure of a typical spinal nerve	K	KH	Y	Lecture	Written/viva voce	3	22–35
AN 7.5	Describe principles of sensory and motor innervation of muscles	K	KH	N	Lecture	Written	3	22–35
AN 7.6	Describe concept of loss of innervation of a muscle with its applied anatomy	K	KH	Y	Lecture	Written/viva voce	3	22–35
AN 7.7	Describe various type of synapse	K	KH	N	Lecture	Written	3	22–35
AN 7.8	Describe differences between sympathetic and spinal ganglia	K	KH	N	Lecture	Written	3	22–35
AN 41.1	Describe and demonstrate parts and layers of eyeball	K/S	SH	Y	Practical, lecture, small group discussion, DOAP session	Written/viva voce/skill assessment	20	255–269
AN 43.2	Identify, describe and draw the microanatomy of cornea, retina	K/S	SH	Y	Lecture, practical	Written/skill assessment	20	255–269
AN 43.3	Identify, describe and draw microanatomy of olfactory epithelium, optic nerve, cochlea-organ of Corti	K/S	SH	N	Lecture, practical	Written/skill assessment	20	255–269
AN 43.8	Describe the anatomical route used for carotid angiogram and vertebral angiogram	K/S	SH	N	Practical	Viva voce/skill assessment	21	270–274
AN 43.9	Identify anatomical structures in carotid angiogram and vertebral angiogram	K/S	SH	N	Practical	Viva voce/skill assessment	21	270–274
AN 56.1	Describe and identify various layers of meninges with its extent and modifications	K/S	SH	Y	Practical, lecture, small group discussion, DOAP session	Written/viva voce/skill assessment	18	229–239
AN 56.2	Describe circulation of CSF with its applied anatomy	K	Kh	Y	Lecture	Written/viva voce	18	229–239

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Number	*COMPETENCY The student should be able to*	*Domain K/S/A/C*	*Level K/ KH/SH/P*	*Core (Y/N)*	*Teaching-learning methods*	*Assessment methods*	*Chapter number*	*Page number*
AN 57.1	Identify external features of spinal cord	K/S	SH	Y	Practical, lecture, small group discussion, DOAP session	Written/viva voce/skill assessment	6	60–87
AN 57.2	Describe extent of spinal cord in child and adult with its clinical implication	K	KH	Y	Lecture	Written/viva voce	6	60–87
AN 57.3	Draw and label transverse section of spinal cord at mid-cervical and mid-thoracic level	K	KH	Y	Lecture	Written/viva voce	6	60–87
AN 57.4	Enumerate ascending and descending tracts at mid-thoracic level of spinal cord	K	KH	Y	Lecture	Written/viva voce	6	60–87
AN 57.5	Describe anatomical basis of syringomyelia	K	KH	N	Lecture	Written	6	60–87
AN 58.1	Identify external features of medulla oblongata	K/S	SH	Y	Lecture, DOAP session	Written/viva voce/skill assessment	7	88–98
AN 58.2	Describe transverse section of medulla oblongata at the level of—(1) pyramidal decussation, (2) sensory decussation and (3) open level of medulla	K	KH	Y	Lecture	Written/viva voce	7	88–98
AN 58.3	Enumerate cranial nerve nuclei in medulla oblongata with their functional group	K	KH	Y	Lecture	Written/viva voce	7	88–98
AN 58.4	Describe anatomical basis and effects of medial and lateral medullary syndrome	K	KH	N	Lecture	Written	7	88–98
AN 59.1	Identify external features of pons	K/S	SH	Y	Lecture, DOAP session	Written/viva voce/skill assessment	8	99–108
AN 59.2	Draw and label transverse section of pons at the upper and lower level	K	KH	Y	Lecture	Written/viva voce	8	99–108
AN 59.3	Enumerate cranial nerve nuclei in pons with their functional group	K	KH	Y	Lecture	Written/viva voce	8	99–108
AN 60.1	Describe and demonstrate external and internal features of cerebellum	KS	SH	Y	Practical, lecture, small group discussion, DOAP session	Written/viva voce/skill assessment	10	119–136
AN 60.2	Describe connections of cerebellar cortex and intracerebellar nuclei	K	KH	Y	Lecture	Written/viva voce	10	119–136
AN 60.3	Describe anatomical basis of cerebellar dysfunction	K	KH	N	Lecture	Written	10	119–136
AN 61.1	Identify external and internal features of midbrain	K/S	SH	Y	Practical, lecture, small group discussion, DOAP session	Written/viva voce/skill assessment	9	109–118
AN 61.2	Describe internal features of midbrain at the level of superior and inferior colliculus	K	KH	Y	Lecture	Written/viva voce	9	109–118
AN 61.3	Describe anatomical basis and effects of Benedikt's and Weber's syndrome	K	KH	N	Lecture	Written	9	109–118
AN 62.1	Enumerate cranial nerve nuclei with its functional component	K	KH	Y	Lecture	Written/viva voce	19	240–254

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Number	*COMPETENCY The student should be able to*	*Domain K/S/A/C*	*Level K/ KH/SH/P*	*Core (Y/N)*	*Teaching-learning methods*	*Assessment methods*	*Chapter number*	*Page number*
AN 62.2	Describe and demonstrate surfaces, sulci, gyri, poles, and functional areas of cerebral hemisphere	K/S	SH	Y	Practical, lecture, small group discussion, DOAP session	Written/viva voce/skill assessment	12	157–174
AN 62.3	Describe the white matter of cerebrum	K	KH	Y	Lecture	Written/viva voce	13	175–185
AN 62.4	Enumerate parts and major connections of basal ganglia and limbic lobe	K	KH	Y	Lecture	Written/viva voce	14 15	186–194 195–206
AN 62.5	Describe boundaries, parts, gross relations, major nuclei and connections of dorsal thalamus, hypothalamus, epithalamus, metathalamus and subthalamus	K	KH	Y	Lecture	Written/viva voce	11	137–156
AN 62.6	Describe and identify formation, branches and major areas of distribution of circle of Willis	K/S	SH	Y	Practical, lecture, small group discussion, DOAP session	Written/viva voce/skill assessment	17	217–228
AN 63.1	Describe and demonstrate parts, boundaries and features of IIIrd, IVth and lateral ventricle	K/S	SH	Y	Practical, lecture, small group discussion, DOAP session	Written/viva voce/skill assessment	16	207–216
AN 63.2	Describe anatomical basis of congenital hydrocephalus	K	KH	N	Lecture	Written	16	207–216
AN 64.1	Describe and identify the microanatomical features of spinal cord, cerebellum and cerebrum	K/S	SH	Y	Lecture, practical	Written/skill assessment	6 10 12	60–87 119–136 157–174
AN 64.2	Describe the development of neural tube, spinal cord, medulla oblongata, pons, midbrain, cerebral hemisphere and cerebellum	K	KH	Y	Lecture	Written/viva voce	1	1–14
AN 64.3	Describe various types of open neural tube defects with its embryological basis	K	KH	N	Lecture	Written/viva voce	1	1–14
AN 79.3	Describe the process of neurulation	K	KH	Y	Lecture	Written	1	1–14
AN 79.5	Explain embryological basis of congenital malformations, nucleus pulposus, sacrococcygeal teratomas, neural tube defects	K	KH	N	Lecture	Written	1	1–14

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CHAPTER 6

Spinal Cord

COMPETENCIES

AN 57.1: External features of spinal cord.
AN 57.2: Extent of spinal cord in child and adult.
AN 57.3: Transverse section of spinal cord at mid-thoracic and mid-cervical level.
AN 57.4: Ascending and descending tracts.
AN 57.5: Anatomical bases of syringomyelia and other applied anatomy of spinal cord.
AN 64.1: Describe and identify the microanatomical features of spinal cord.

◉ Specific Learning Objectives

At the end of learning, the student shall be able to:

- Describe the external features of spinal cord.
- Differentiate the internal structure of spinal cord and its variation at different levels.
- Define various nuclei in gray matter.
- Enumerate the ascending tracts in the white columns of spinal cord.
- Enumerate the descending tracts in the white columns of spinal cord.
- Discuss the blood supply of spinal cord.
- Specify anatomical basis of various lesions of spinal cord.
- Identify the microanatomical features of spinal cord.

INTRODUCTION

The spinal cord or the spinal medulla (medulla spinalis L.) is the most important content of the vertebral canal. In adults, it occupies only the upper two-thirds of the vertebral canal. Although the spinal cord constitutes only 2% of the central nervous system (CNS), its functions are vital. It contains:

- Afferent pathways which transmit sensory impulses from the body
- Efferent pathways to control voluntary motor function
- Autonomic component for the regulation of sympathetic innervation

It begins as a downward extension of the medulla oblongata at the level of the upper border of the first cervical vertebra (C1) and extends down to the level of the lower border of the first lumbar vertebra (L1) **(Figure 6.1A)**. The level varies with flexion or extension of the spine.

The lowest part of the spinal cord is conical and is called the **conus medullaris**. The conus is continuous, below, with a fibrous cord called the **filum terminale**, which is a prolongation of pia mater and is attached to the posterior surface of the first piece of coccyx **(Figures 6.1A to C)**.

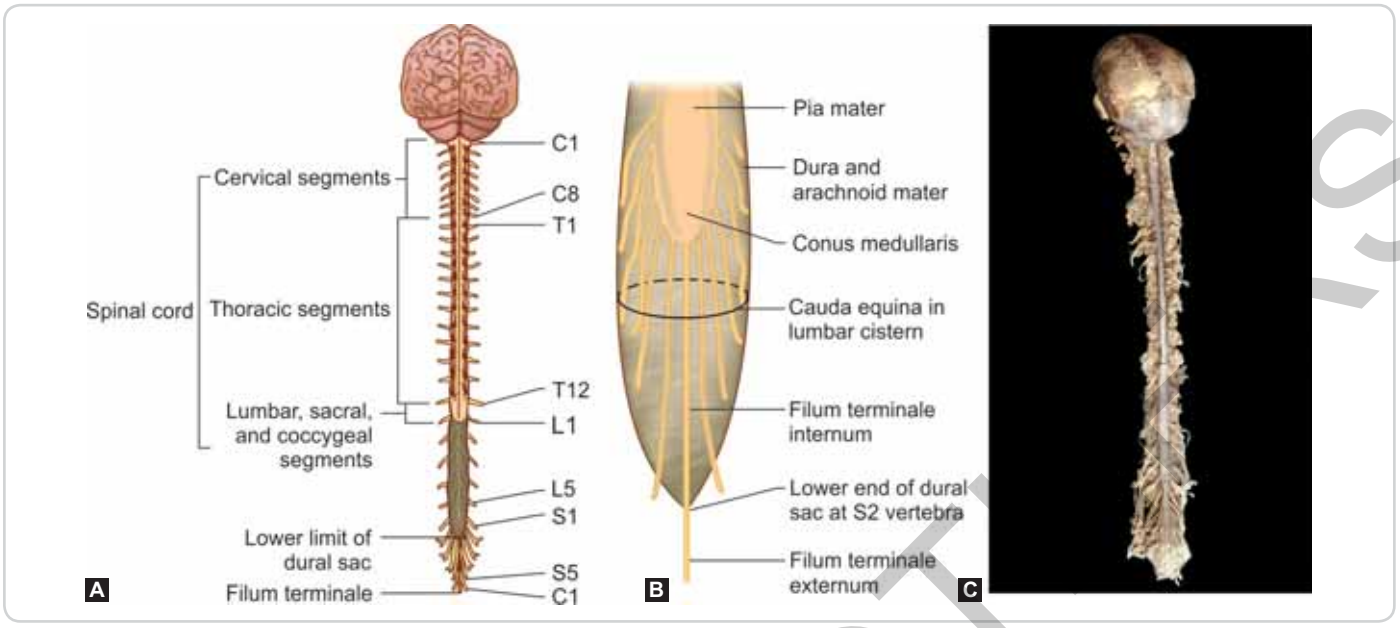
DIMENSIONS OF THE CORD (AN 57.1)

The length of the cord is about 45 cm. The spinal cord is not of uniform thickness. It resembles a flattened cylinder. The transverse diameter shows two enlargements at the cervical level and lumbar level. The spinal segments that contribute to the nerves of the upper limbs (from third cervical to second thoracic segments) are enlarged to form the **cervical enlargement** of the cord. Similarly, the segments innervating the lower limbs (first lumbar to third sacral segments) form the **lumbar enlargement (Figure 6.2)**.

AGE-WISE CHANGES IN THE CORD (AN 57.2)

In early fetal life (third month), the spinal cord is as long as the vertebral canal and each spinal nerve arises from the cord at the level of the corresponding intervertebral foramen.

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Figures 6.1A to C: (A) The spinal cord; (B) The lower end of the spinal cord magnified showing the conus medullaris, cauda equina, and filum terminale; (C) Specimen of brain and spinal cord—posterior view.

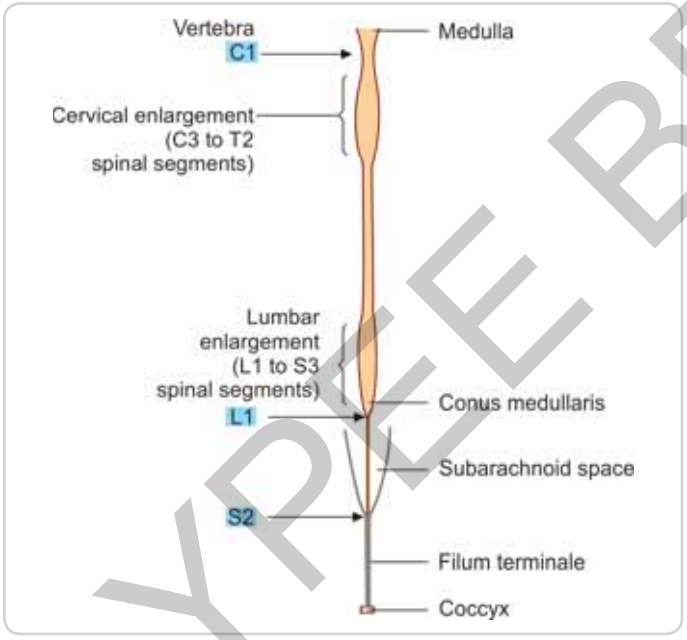


Figure 6.2: Important vertebral levels in relation to the spinal cord.

In subsequent development, the spinal cord does not grow as much as the vertebral column, and its lower end, therefore, gradually ascends to reach the level of the third lumbar vertebra at the time of birth and to the lower border of the first lumbar vertebra in the adult **(Figure 6.3)**.

As a result of this upward migration of the cord, the roots of spinal nerves have to follow an oblique downward course to reach the appropriate intervertebral foramen. This also makes the spinal nerve roots longer. The obliquity and length of the roots are most marked in the lower nerves and many of these roots occupy the vertebral canal below the level of the spinal cord. These roots constitute the **cauda equina (Figures 6.1A to C)**.

FUNCTIONS OF SPINAL CORD

The spinal cord has three major functions:

1. It acts as a pathway for motor information, which travels down the spinal cord.
2. It serves as a passage for sensory information in the reverse direction.
3. It is a center for coordinating simple reflexes.

SPINAL MENINGES (FIGURE 6.4)

Dura Mater

The spinal dura mater forms a loose tubular covering for the spinal cord. The spinal dura mater **does not fuse with the endosteum** of the vertebral canal. Hence, there is a well-developed **epidural space** surrounding the spinal cord. The spinal epidural space is filled with the internal vertebral venous plexus and fat.

Clinical Anatomy

Epidural anesthesia: As the spinal nerves pass through the spinal epidural space, they may be anesthetized by injecting a local anesthetic drug into the spinal epidural space. This type of epidural anesthesia is used in obstetric procedures during childbirth. One has to be careful about the venous plexus while introducing the needle for anesthesia as it may injure the veins and cause an epidural hematoma.

The dorsal and ventral roots of spinal nerves pass through the spinal dura mater separately. The dura and arachnoid partially enclose the dorsal nerve root ganglion. The dura and

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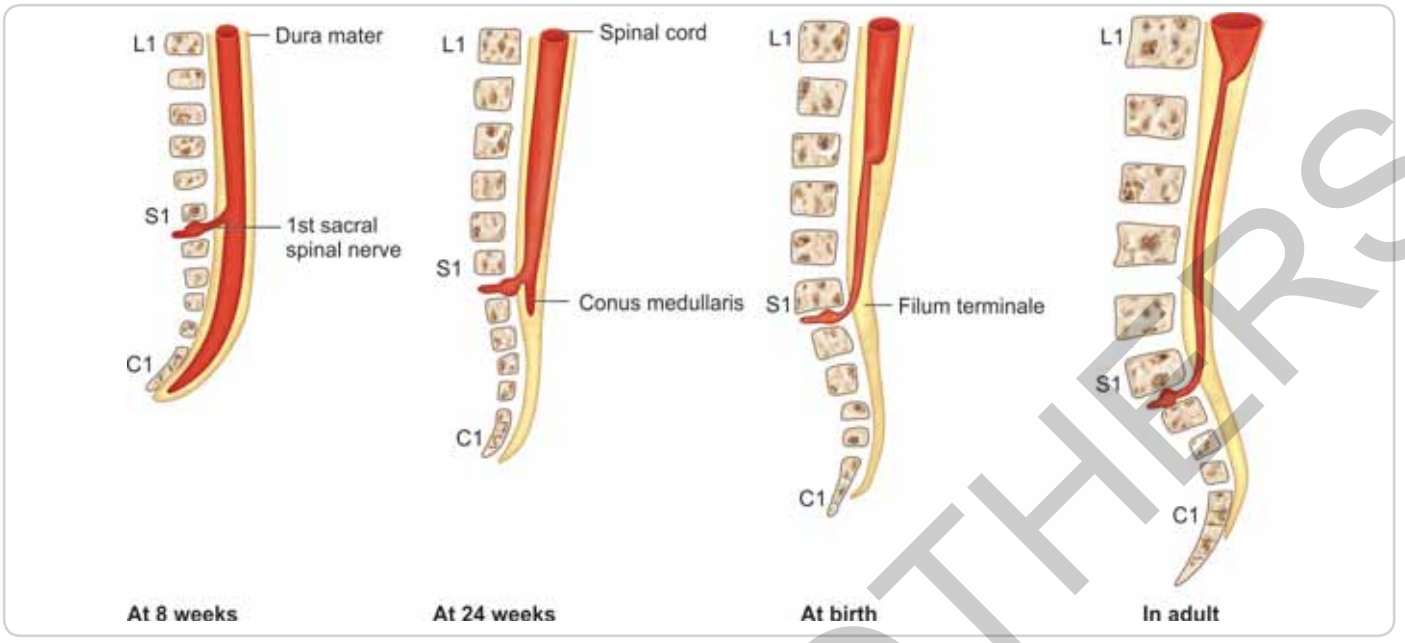


Figure 6.3: Scheme to show the effect of recession of the spinal cord (during development) on the course of the roots of spinal nerves.

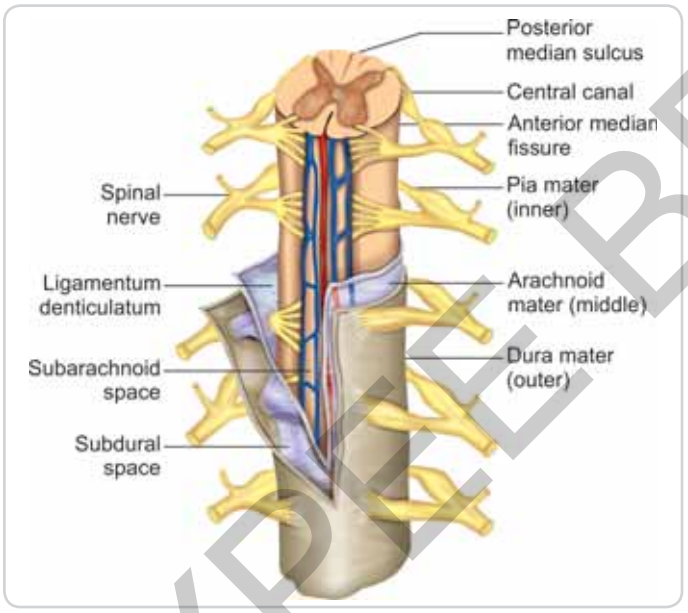


Figure 6.4: Spinal meninges.

arachnoid [along with the subarachnoid space containing cerebrospinal fluid (CSF)] extend up to the level of the second sacral vertebra. Beyond that level, the dura covers the filum terminale and distally gets attached to the dorsal surface of the first coccygeal vertebra.

Clinical Anatomy

Caudal anesthesia: For this procedure, the needle is introduced through the sacral hiatus and the anesthetic drug is injected. This will anesthetize the perineal area supplied by S4 and S5 nerves and may be useful in perineal surgeries.

Arachnoid Mater

The spinal arachnoid mater is present deep to the dura and extends up to the level of the second sacral vertebra. The subarachnoid space extends up to this level (**lumbar cistern**). The lumbar cistern is broadest between L2 and L4 levels. Lumbar puncture is, therefore, done at L3-L4 space or L2-L3 space.

Pia Mater

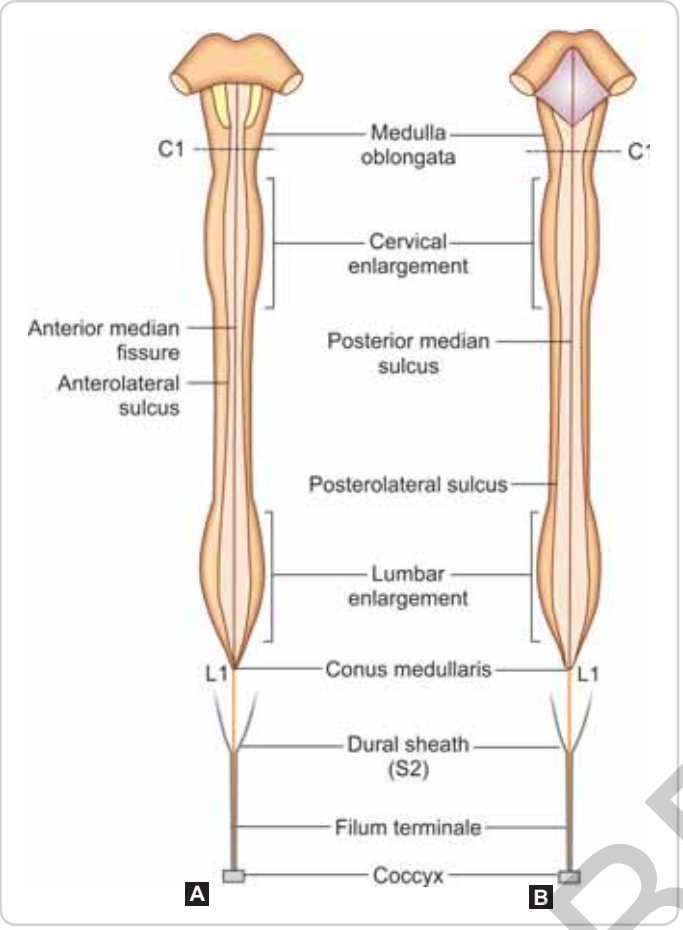
The spinal pia mater is a thin membrane closely applied to the spinal cord and specialized in some areas and continues above with the cranial pia mater. The modifications of pia mater are as follows:

- **Linea splendens:** Along the anteromedian fissure, the pia mater is thickened to form a glistening band called linea splendens. The branches from the anterior spinal artery pierce this to enter the spinal cord.
- **Ligamenta denticulata:** Along the lateral aspect of the spinal cord, between the dorsal and the ventral roots, the pia forms triangular thickenings, which pierce the arachnoid and are attached to the dura. These tooth-like thickenings are called ligamenta denticulata. There are 21 pairs of ligamenta denticulata.
- **Filum terminale:** At the lower end of the spinal cord, the pia mater extends as a thin filament called filum terminale surrounded by a leash of nerves, i.e., cauda equina. This filum terminale passes through the sacral hiatus and gets attached to the dorsal surface of the first coccygeal vertebra.

EXTERNAL FEATURES OF THE SPINAL CORD (FIGURES 6.5A AND B) (AN 57.1)

The external features of the spinal cord refer to its gross appearance to the naked eye. The anterior surface of the spinal cord is marked by a deep **anterior median fissure**, which contains the anterior spinal artery. The posterior surface is marked by a shallow **posterior median sulcus**. The anterior

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Figures 6.5A and B: External features of the spinal cord: (A) Anterior aspect; (B) Posterior aspect.

median fissure and posterior median sulcus divide the surface of the cord into two symmetrical halves.

Each half of the cord is further subdivided into posterior, lateral, and anterior regions by **anterolateral and posterolateral sulci**. The **rootlets of the dorsal or sensory roots** of the spinal nerves enter the cord at the posterolateral sulcus on either side.

The **rootlets of the ventral or motor roots** of spinal nerves emerge through the anterolateral sulcus on either side. The spinal cord gives attachment on either side to 31 pairs of spinal nerves: 8 cervical, 12 thoracic, 5 lumbar, 5 sacral, and 1 coccygeal.

The formation, course, and distribution of a typical spinal nerve are described in Chapter 3 (page 25).

Exit of Spinal Nerves

Each spinal nerve emerges through the intervertebral foramen. The cervical nerves leave the vertebral canal above the corresponding vertebrae with the exception of eighth, which emerges between the seventh cervical and first thoracic vertebrae. The remaining spinal nerves emerge below the pedicles of the corresponding vertebrae.

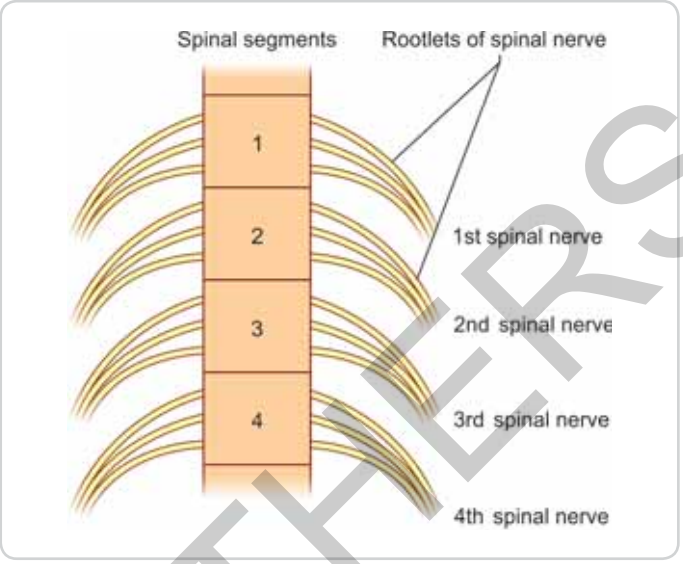


Figure 6.6: Scheme to show the concept of spinal segments.

As the spinal cord ends at the level of L1 vertebra, the lower spinal nerves below the L1 level descend down with the **filum terminale** as a leash, which resembles a horse's tail and hence called cauda equina.

SPINAL SEGMENTS

The part of the spinal cord giving origin to the rootlets for one pair of spinal nerves constitutes one **spinal segment (Figure 6.6)**. So, the spinal cord is made up of 31 such segments—8 cervical, 12 thoracic, 5 lumbar, 5 sacral, and 1 coccygeal.

Vertebral Levels of Spinal Segments

Since the length of the spinal cord (45 cm) is smaller than that of the vertebral column (65 cm), the spinal segments are thinner and crowded, more so in the lower part of the cord. Thus, the spinal and vertebral segments (vertebral bodies) do not lie at the same level. **The spinal segments as a rule always lie above their numerically corresponding vertebral bodies**. As a rough guide, it may be stated that in the cervical region, there is a difference of one segment (e.g., the fifth cervical spine overlies the sixth cervical segment); in the thoracic region, there is a difference of two to three segments (e.g., the fourth thoracic spine overlies the sixth thoracic segment; the ninth thoracic spine lies opposite the 12th thoracic segment). Approximate spinal segments and the corresponding vertebral level are given in **Table 6.1**.

Any condition that leads to pressure on the spinal cord, or on the spinal nerve roots, can give rise to symptoms in the region supplied by nerves. In such cases, it is important to be able to localize the particular spinal segments or roots involved. For this purpose, it is necessary to know which areas of skin and which muscles are innervated by each segment. Spinal segments responsible for muscle stretch reflexes also give an indication about the level of spinal cord involvement.

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TABLE 6.1: Relation between vertebral levels and spinal segments.

Vertebral level	*Formula (to get the number of spinal segments underlying, add the numeral to the number of vertebra)*	*Example*
Upper cervical C1–C4	Add 0 to the number of vertebrae to get the underlying spinal segment	Third cervical vertebra overlies the third cervical segment
Lower cervical C5–C7	Add 1 to the number of vertebrae to get the underlying spinal segment	Fifth cervical vertebra overlies the sixth cervical segment
Upper thoracic T1–T6	Add 2 to the number of vertebrae to get the underlying spinal segment	Fourth thoracic vertebra overlies the sixth thoracic segment
Lower thoracic T7–T9	Add 3 to the number of vertebrae to get the underlying spinal segment	Ninth thoracic vertebra overlies the 12th thoracic segment
T10	–	L1–L2 segments
T11	–	L3–L4 segments
T12	–	L5–S1 segments
L1	–	S2–Co segments

Clinical Anatomy

- **Prolapsed intervertebral disc** (herniated nucleus pulposus): 95% of all disc prolapses occur above or below the last lumbar vertebra. Typical herniation is posterolateral, with compression of nerve roots passing to the next intervertebral foramen. Backache occurs due to rupture of annulus fibrosus. Pain in the buttock/thigh/leg is caused by pressure on the posterior root fibers contributing to sciatic nerve leading to **sciatica**. An L4-L5 disc prolapse produces pain and paresthesia over the L5 dermatome.
- Prolapsed intervertebral disc between L5 and S1 spares the spinal nerve L5, since it is deeply snug in the groove below the pedicle of L5, significantly above the disc below the body of L5.

Transection of spinal cord at different vertebral segments

- **Hangman's fracture:** When a person is hanged, the second cervical vertebra is fractured. From **Table 6.1**, we can see that the spinal segment damaged is C2. This disconnects the respiratory centers of medulla oblongata from C3, C4, and C5 segments of phrenic nerves. This causes respiratory arrest and death.
- **Quadriplegia:** Damage to spinal segment C5 (due to disease **between vertebrae C4 and C5**) results in paralysis of both upper limbs and both lower limbs which is called quadriplegia.
- **Burst fracture of T3 vertebrae:** From **Table 6.1**, we find that this damages the spinal segment T5.
- **Deep traumatic injury at T6 spinous process:** The palpable tips of the spinous processes of middle four thoracic vertebrae (T5 to T8) reach the vertebral body, which is numerically two below, due to their long and down-sloping spinous processes. The T6 spinous process lies opposite the T8 vertebral body. From **Table 6.1**, the spinal segment that will be damaged is T11.
- **Spondylolisthesis (slipping of upper vertebral body over the lower one):** This is more common between L4 and L5. This will not damage any spinal segment as the spinal cord in adults ends at L1, but may compress the cauda equina.

INTERNAL FEATURES OF SPINAL CORD

A transverse section of the spinal cord shows gray matter surrounded by white matter. The gray matter is formed by neurons (dendrites, cell bodies, and unmyelinated axons) and glial cells. The white matter is composed of myelinated axons.

Gray Matter

The gray matter forms an H-shaped or a butterfly-shaped mass **(Figure 6.7)**. In a cross-section, the gray matter is called as **ventral horn, dorsal horn,** and central gray. Three-dimensionally, it forms **anterior (ventral) gray column and posterior (dorsal) gray column** and the **gray commissure**. In the thoracic and the sacral parts of the spinal cord, a small lateral projection of gray matter is seen between the ventral and the dorsal gray columns. This is the **lateral gray column**.

White Matter

The white matter of the spinal cord is divided into right and left halves, in front by the **anterior median fissure** and behind by the **posterior median septum**. In each half of the cord, the white matter between the dorsal gray column and the posteromedian septum forms the **posterior funiculus** (posterior white column). The white matter between the anterior gray column and the anteromedian fissure forms the **anterior funiculus** (anterior white column), while the white matter lateral to the anterior and posterior gray columns

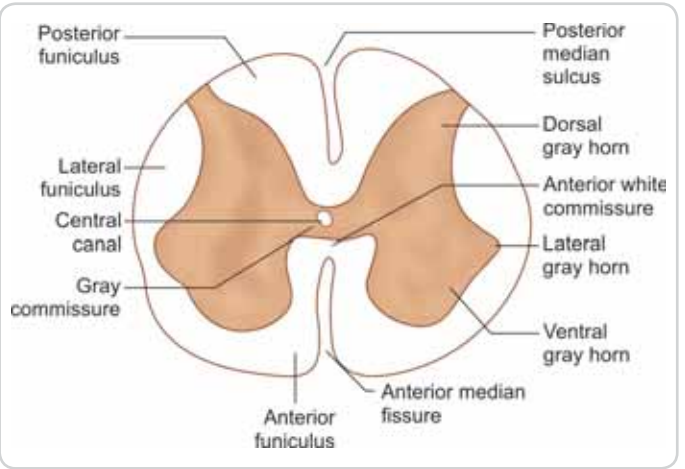
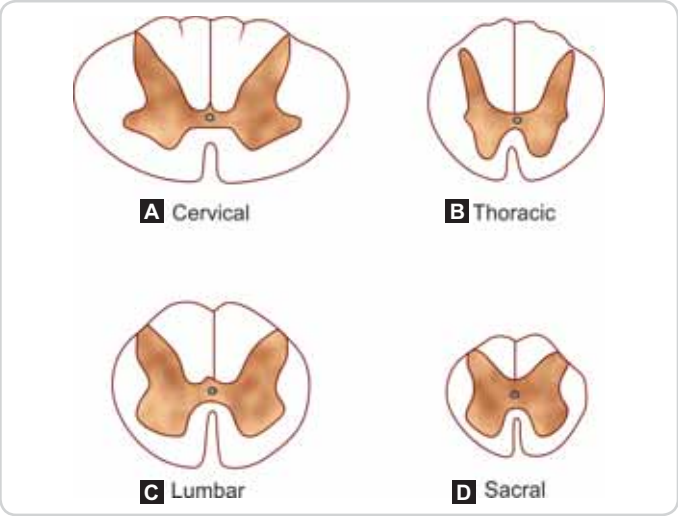


Figure 6.7: Transverse section through the spinal cord showing gray and white matter.

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Figures 6.8A to D: Differences in appearance of transverse sections through various levels of the spinal cord.

between the anterolateral sulcus and the posterolateral sulcus forms the **lateral funiculus** (lateral white column). (The anterior and lateral funiculi are sometimes collectively referred to as the **anterolateral funiculus**.) The white matter of the right and left halves of the spinal cord is continuous across the midline as the **anterior white commissure**, which lies anterior to the gray commissure.

Variation in the Internal Structure of Spinal Cord at Different Levels

- The shape of the transverse section of the spinal cord varies at different levels. It is transversely oval in the cervical region, round in the thoracic region, round to oval in the lumbar region, and round in sacral region.
- The relative amount of gray and white matter and the shape and size of the gray columns vary at different levels of the spinal cord **(Figures 6.8A to D)**.
- The amount of gray matter to be seen at a particular level can be correlated with the mass of tissue to be supplied. It is, therefore, greatest in the region of the cervical and lumbar enlargements, which supply the limbs.
- The amount of white matter undergoes a progressive increase from the lower part of the spinal cord to the upper part. This is because:
  - Progressively more and more ascending fibers are added as the upper levels of the cord are reached.
  - The number of descending fibers decrease as lower levels of the cord are reached as some of them terminate in each segment.

VARIATION IN THE INTERNAL STRUCTURE OF SPINAL CORD AT DIFFERENT LEVELS (FIGURE 6.9) (AN 57.3)

- Cervical segments are characterized by their relatively large size and oval shape. The transverse diameter is more than the anteroposterior diameter.
- The cervical spinal levels contain the largest number of fibers in the white matter because (i) it has all the descending fibers to be distributed at all lower levels and (ii) the ascending fiber tracts take contribution from all lower levels and attain maximum width.
- The gray matter is maximum at levels below C3 where it extends laterally into the white column. At C1 and C2, the posterior horn is enlarged but the anterior horn is relatively small.
- The cervical enlargement is associated with larger nerves that innervate muscles of upper limb. At C4, the neurons form the phrenic nerve which supplies the diaphragm.

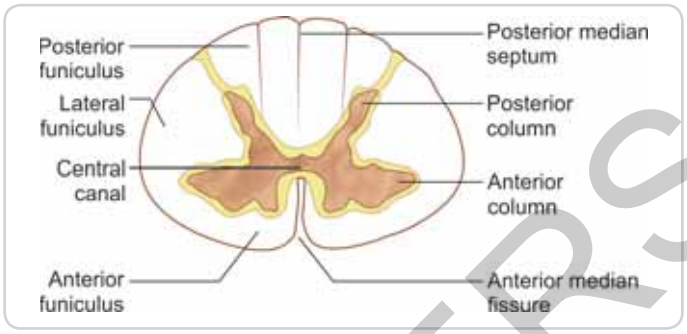


Figure 6.9: Schematic diagram of transverse section of the spinal cord at the midcervical level.

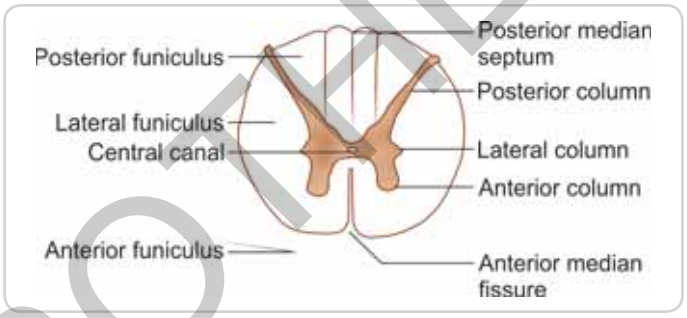


Figure 6.10: Schematic diagram of transverse section of spinal cord at the midthoracic level.

Transverse Section of Spinal Cord at Thoracic Level (Figure 6.10)

- The appearance of gray horns is typically H-shaped and somewhat tapered. A prominent but small lateral horn is present at all thoracic levels and contains the intermediolateral cell column which gives rise to preganglionic sympathetic efferent fibers. A collection of large nerve cells is visible in all thoracic segments which are known as the dorsal nucleus of Clarke. It is most prominent at T10–T12 Levels.
- In the posterior while columns, below the T6 Levels, only the fasciculus gracilis is visible. At the upper levels (T1–T6), both fasciculus gracilis and cuneatus are seen.

Transverse Section of Spinal Cord at Lumbar Level (Figure 6.11)

- Lumbar segments are nearly circular in transverse sections. The amount of gray matter in anterior and posterior horns is the maximum and appears very broad.

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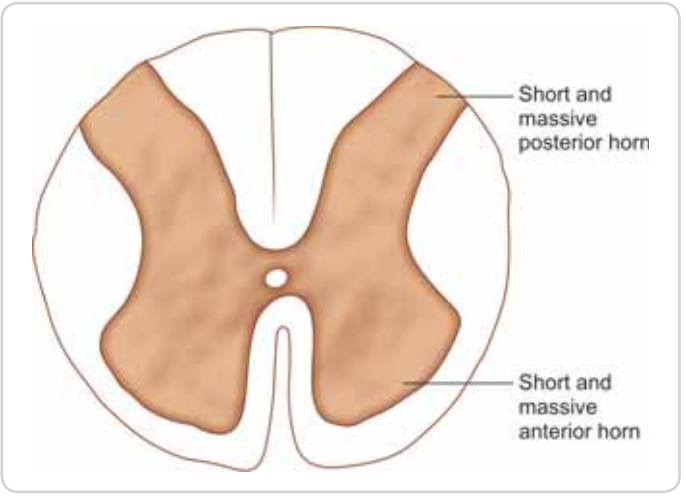


Figure 6.11: Schematic diagram of transverse section of spinal cord at the lumbar level.

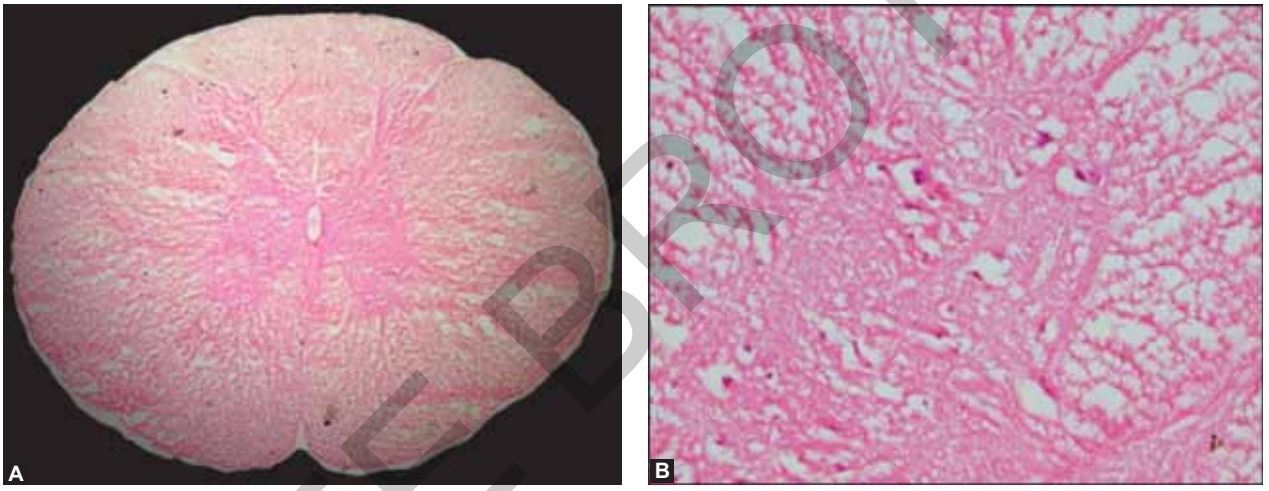
The enlargement of the anterior gray horn at these levels is because of the presence of large motor neurons to innervate large muscle groups in lower limbs.

- The white matter in the lumbar region is relatively less. The posterior white column contains a thin bundle of only fasciculus gracilis fibers.

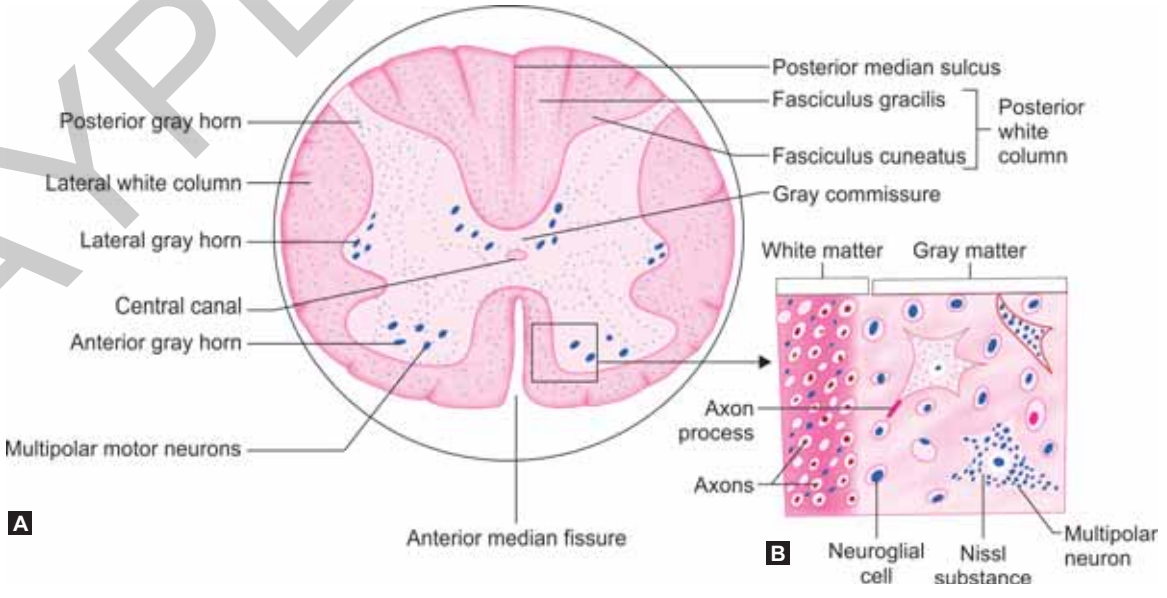
MICROSCOPIC STRUCTURE OF SPINAL CORD (FIGURES 6.12 AND 6.13) (AN 64.1)

The internal structure of the spinal cord is similar throughout its extent. However, there is variation in the diameter in different regions; it is surrounded by three meninges.

- The outer dura mater is thick and fibrous. The subdural space is narrow and contains serous fluid.
- The middle arachnoid mater is thin and encloses the subarachnoid space which is filled with CSF and may show nerve roots passing to the intervertebral foramina.



Figures 6.12A and B: Photographs of microanatomy of the transverse section of spinal cord: (A) 10X; (B) 40X.



Figures 6.13A and B: Microanatomy of the transverse section of the spinal cord: (A) Low magnification; (B) High magnification.

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- Anteriorly, there is a midline fissure visible which is anterior median fissure.
- Posteriorly, the shallow demarcation in the midline is posterior median septum.
- Centrally, the section of the spinal cord shows a central canal lined by a single layer of ciliated columnar epithelium. This is called ependyma.
- In the transverse sections, the central mass of gray matter appears like a butterfly or in the form of "H." The two anterior wings are called ventral (anterior) gray horns while the posterior ones are called dorsal gray horns.
- The ventral horns are prominent and contain cell bodies of large multipolar motor neurons. The cells have large nuclei, prominent nucleolus, and cytoplasmic process. Nissl granules are present in the soma and dendrites of the neurons.
- The dorsal gray horns contain the cell bodies of small second-order sensory neurons.
- In the thoracic and upper lumbar spinal regions, an additional lateral gray horn is present in between the anterior and the posterior horns. It contains cell bodies of sympathetic efferent neurons.
- The white matter consists of nerve fibers, neuroglia, and blood vessels. Each half of spinal cord is divided into anterior, lateral, and posterior funiculi.
- The white matter of the right and left halves of the spinal cord is continuous across the midline through the ventral white commissure.

NEURONS IN THE GRAY MATTER

- The largest neurons present in the spinal cord are **alpha motor** neurons with a cell size of 50–100 µm. These are located in the anterior horn and supply the skeletal muscles of the body.
- Medium-sized neurons with a diameter of 20–50 µm are found in all parts of gray matter except substantia gelatinosa. These are **projection** (sensory) cells which receive their inputs from the posterior root afferents and relay them to the brain.
- The smallest neurons with a diameter of 5–20 µm are **propriospinal** neurons. They act as internuncial neurons (intermediate cell stations) between the descending tracts and the motor neurons, between different levels of sensory transmission and also participating in spinal reflex action. In the anterior horn, there are small gamma motor neurons which supply muscle spindles.

NUCLEI IN GRAY MATTER

Discrete collections of neurons (or nuclei) occur in various regions of the spinal gray matter. The cell groups correspond with one or more of 10 cell layers, known as Rexed laminae.

- Lamina I to IV lie at the dorsal part of dorsal horn.
- Lamina V and VI lie at the base of dorsal horn.
- Lamina VII lies in the intermediate (lateral) gray column.

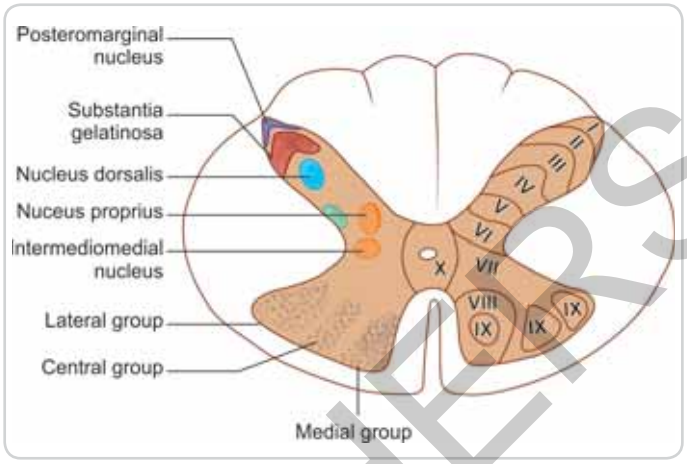


Figure 6.14: Nuclei and laminae of Rexed.

- Lamina VIII and IX lie in the ventral horn.
- Lamina X corresponds to the central gray.

The nuclei in gray matter are shown in **Figure 6.14** and listed in **Table 6.2**.

Nuclei in the Posterior Gray Column (Dorsal Horn)

This group consists of sensory and integrative nerve cells **(Figures 6.13A and B)**. It receives and processes the sensory input. It is present throughout the entire extent of spinal cord. It includes the following nuclei:

- **Posteromarginal nucleus (Rexed lamina I):** It is associated with the sensations of light touch, pain, and temperature.
- **Substantia gelatinosa (Rexed lamina II):** It is homologous to the spinal trigeminal nucleus. It is also associated with light touch, pain, and temperature sensations.
- **Nucleus proprius (Rexed laminae III and IV):** It carries the same sensations as above.
- **Posterior thoracic nucleus (nucleus dorsalis of Clarke; Rexed lamina VII):** It is located at the base of posterior horn. Its extent is limited to C8, T1–L2 segments of the spinal cord. It is homologous to the **accessory cuneate** nucleus of medulla oblongata. From this nucleus, the fibers of the posterior spinocerebellar tract originate. It carries the unconscious proprioception from muscle spindles and Golgi tendon organs.

Nuclei in the Lateral Gray Column (Rexed Lamina VII)

This group consists of proprioceptive and visceral nerve cells. It is located in between the anterior and posterior horns only at T1–L2 levels of the spinal cord. It contains preganglionic sympathetic neurons whose functional component is general visceral efferent.

Nuclei in the Anterior Gray Column (Rexed Laminae VII, VIII, IX)

This group contains predominantly motor nuclei which are found at all levels. The neurons of the anterior horn are arranged in three groups. These are medial, lateral, and central groups.

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TABLE 6.2: Nerve cell groups in the spinal gray columns.

Rexed lamina	*Nuclei in gray column*	*Extent in the spinal cord*	*Functions*
I	Posteromarginal nucleus	Entire cord	Relay station for "fast" pain
II	Substantia gelatinosa	Entire cord	Interneurons for modification of pain and other sensory inputs
III and IV	Nucleus proprius	Entire cord	Gives origin to ventral and lateral spinothalamic tracts
V	Diffuse spinal reticular nucleus	Entire cord	Integration of exteroceptive, nociceptive, proprioceptive and visceral senses
VI	Interneurons for spinal reflexes	Prominent in limb enlargements	Propriospinal polysynaptic reflexes like flexion or withdrawal reflex
VII	Central cervical nucleus	C1–C4	Tonic neck reflexes
	Posterior thoracic (Clarke's column)	C8–L3	Unconscious proprioception from lower limb; gives origin to posterior spinocerebellar tract
	Intermediomedial nucleus	T1–L2 and S2–S4	Visceral afferents
	Intermediolateral nucleus	T1–L2 and S2–S4	Visceromotor
VIII	Spinal border nucleus	Lateral border of L1–L5	Unconscious proprioception from lower limb
	Interneurons for motor neurons	Entire cord	Influence motor neurons
IX	Motor neurons (α and γ)	Entire cord	Innervates the striated muscles
X	Central gray	Entire cord	Diffuse and nondiscriminatory

- The **medial** group consists of **ventromedial** and **dorsomedial** nuclei. These supply the skeletal muscles of the trunk.
- The **lateral** group is present only in the cervical and lumbosacral regions of the spinal cord. It is divided into **ventrolateral**, **dorsolateral,** and **retrodorsal** nuclei. The ventrolateral nucleus supplies the muscles of the upper arm and thigh, the dorsolateral nucleus supplies the muscles of the forearm and leg, and the retrodorsolateral nucleus provides nerve supply to smaller muscles of hand and foot.
- The **central** group is mainly present in the cervical and lumbosacral regions of the spinal cord. It has the following main nuclei:
  - *Phrenic nucleus:* It supplies the diaphragm.
  - *Spinal accessory nucleus:* It supplies the sternocleidomastoid and trapezius muscles.
  - *Lumbosacral group of nuclei:* It supplies pelvic diaphragm, sphincters of urethra, and anal canal.

Lamina X

Lamina X is present around the central canal. It consists mainly of neuroglia cells.

WHITE MATTER

The white matter of the spinal cord is the collection of myelinated as well as nonmyelinated groups of nerve fibers which pass through the spinal cord at various levels. The nerve fibers can be of the following types depending upon their origin:

i. **Sensory fibers:** Fibers from the dorsal root ganglia and posterior horn of the spinal cord
ii. **Motor fibers:** Fibers from the motor neurons of the ventral horn of the spinal cord
iii. **Sympathetic fibers:** The preganglionic fibers from the lateral gray horn in the thoracic and upper lumbar levels of the spinal cord

The nerve fibers can also be divided according to their termination. These are:

- **Ascending fibers:** Fibers emerging from different levels of spinal cord and passing upward to different levels of brain.
- **Descending fibers:** Fibers arising from cerebral cortex and other higher centers and terminating at different levels of spinal cord.
- **Intersegmental fibers:** Short fibers connecting the adjacent segments of the spinal cord for integrated response. These can be ascending or descending.

The white matter of the spinal cord is divided into anterior, posterior, and lateral funiculi (or columns) as described earlier.

TRACTS IN THE SPINAL CORD (AN 57.4)

A collection of nerve fibers within the CNS, which connects two masses of gray matter, is called a tract (or fasciculus). This collection of nerve fibers has a similar origin, course, and termination. Tracts may be ascending, descending or intersegmental (which could include both ascending and descending). They are usually named after the masses of gray matter connected by them. Thus, a tract beginning in the cerebral cortex and descending to the spinal cord is called the **corticospinal tract**, while a tract ascending from the spinal cord to the thalamus is called the **spinothalamic tract**. Tracts are sometimes referred to as lemnisci (ribbons). The position

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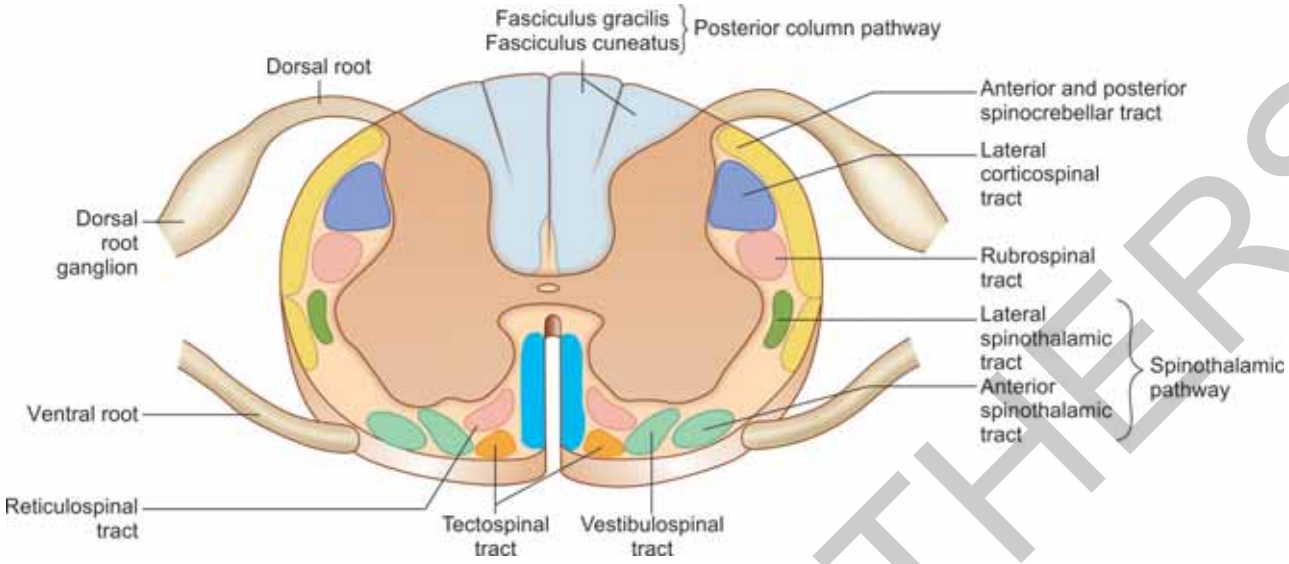


Figure 6.15: Positions of the main ascending and descending tracts present in a transverse section of the spinal cord.

TABLE 6.3: Important ascending and descending tracts in various funiculi.

Funiculus	*Ascending tracts*	*Descending tracts*
Posterior	• Fasciculus gracilis • Fasciculus cuneatus	• Septomarginal tract • Fasciculus interfascicularis (semilunar tract/comma tract of Schultze)
Lateral	• Posterior spinocerebellar • Anterior spinocerebellar • Lateral spinothalamic • Spinotectal • Spino-olivary • Dorsolateral (Lissauer's tract)	• Lateral corticospinal • Rubrospinal • Lateral reticulospinal • Olivospinal • Hypothalamospinal • Raphespinal
Anterior	• Anterior spinothalamic • Spinoreticular	• Anterior corticospinal (lateral) vestibulospinal • Medial vestibulospinal (medial longitudinal fasciculus) • Tectospinal • Medial reticulospinal

of the tracts in a transverse section of the spinal cord is shown in **Figure 6.15** and **Table 6.3**.

ASCENDING TRACTS

Sensory modalities are either special senses or general senses. The general senses are classified as follows:

- **Exteroception:** Sensations perceived by the body, arising from the external world and include touch, pressure, vibration, pain, thermal sensation, itch, tickle, etc.
- **Proprioception:** Sensations perceived by the body, generated by the own tissues and include perception of posture, joint position and movement, muscle contraction, and stretch
- **Interoception:** Sensations perceived by the body, arising from the internal world and include sensations from viscera such as hunger, thirst, bladder fullness, and defecation.

Ascending tracts related to the conscious general senses consist of a sequence of three neurons that extends from the peripheral receptor to the cerebral cortex. These are often referred to as primary, secondary, and tertiary neurons or first-order neurons, second-order neurons, and third-order neurons **(Figure 6.16)**. Unconscious proprioception and some exteroception going to the cerebellum consist of only two neurons, as also those terminating in brainstem.

Ascending Tracts Projecting to the Cerebral Cortex

The **first-order neurons** of these pathways are located in spinal (dorsal nerve root) ganglia. The neurons in these ganglia

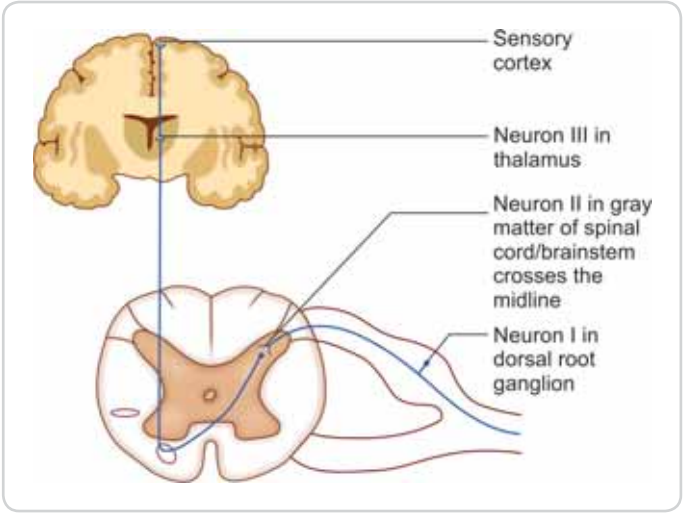


Figure 6.16: Levels of neurons in the ascending or sensory tract.

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- **Poliomyelitis (Figure 6.34):** Lesion of ventral or anterior gray column neurons as in poliomyelitis or as in progressive muscular atrophy results in lower LMN paralysis of the affected segments. It would be flaccid paralysis, with absent superficial and deep reflexes. If the virus affects the gray matter of the medulla (bulbar polio), it can result in respiratory arrest.
- **Sensory neuron disease:** Involvement of posterior columns, as in hereditary sensory neuropathy or tertiary syphilis, causes bilateral loss of fine touch, two-point discrimination, joint position, and vibration sense. However, crude sensations carried by spinothalamic tracts remain intact.
- **Tract of Lissauer:** A unilateral lesion of the spinothalamic tract will result in loss of crude touch, pressure, pain, and thermal sensation. The sensation will be lost on the opposite side below the level of lesion. The contralateral loss of pain and temperature sensations, however, occur **2–3 segments below the level of the lesion** because pain and thermal sense rise 2–3 levels up in the tract of Lissauer before they terminate.
- **Syringomyelia (Figure 6.35):** A destructive process around the central canal of the spinal cord results in increase in the size of the cavity and a cyst, called a syrinx, forms within the spinal cord and affects the crossing spinothalamic fibers in the anterior white commissure. So, there will be bilateral loss of pain and temperature sensations but the posterior column sensations (fine touch and proprioception) are retained as they do not get affected initially because the PC-ML pathway is preserved. This produces "dissociated sensory loss." The patient develops ulcers on the fingers arising from painless cuts and burns.
- A unilateral lesion of spinal cord will show **bilateral ataxia of lower limbs**, if the ventral spinocerebellar tract (carrying contralateral proprioceptive impulses) and dorsal spinocerebellar tract (carrying ipsilateral proprioceptive impulses) are affected.
- **Disorders of equilibrium:** Inability to maintain the equilibrium of the body, while standing or while walking, is referred to as **ataxia**. This may occur as a result of interruption of afferent proprioceptive pathways, i.e., tracts in the posterior column and the spinocerebellar pathways (sensory ataxia).
- Lack of proprioceptive information can be compensated to a considerable extent by information received through the eyes. The defects are, therefore, much more pronounced with the eyes closed **(Romberg's sign positive)**.
- A tumor in relation to the spinal cord can grow either from outside (meningioma) or from within (neuroglioma).
- If the meningioma is pressing the cervical part of spinal cord from the lateral aspect, it initially involves:
  - The sacral and lumbar fibers of the lateral corticospinal tract causing ipsilateral monoplegia of the lower limb
  - The sacral and lumbar fibers of the lateral spinothalamic tract causing contralateral loss of pain from the lower limb and perianal region
- If the neuroglioma is growing in the cervical part of the spinal cord laterally, it initially involves:
  - The cervical and thoracic fibers of the lateral corticospinal tract causing ipsilateral monoplegia of the upper limb
  - The cervical and thoracic fibers of the lateral spinothalamic tract causing contralateral loss of pain from the upper limb and trunk. The lower limb and perianal region are last to be involved. Some of the clinical conditions produced due to lesions of various funiculi of the spinal cord are shown in **Table 6.10**.
- **Transection of spinal cord (paraplegia in flexion or paraplegia in extension)::**
  - In a transection of the thoracic part of spinal cord, both lower limbs get paralyzed (paraplegia).
  - In an incomplete transection, fibers in the lateral funiculus get affected, i.e., lateral reticulospinal tract and rubrospinal tract (both facilitatory to flexors). The vestibulospinal tract and medial reticulospinal tract lying in the anterior funiculus (both facilitatory to extensors) are spared. This results in paraplegia in extension.
  - In a complete transection, all descending fibers are involved. Lower limbs go into flexor withdrawal reflex (spinal reflex). Hence, there is paraplegia in flexion.
- **Amyotrophic lateral sclerosis:** A combination of lesions of pyramidal tracts and anterior horn cells results in both UMN and LMN signs as in motor neuron disease (MND) or amyotrophic lateral sclerosis (ALS). This is a progressive degenerative disorder.
  In the earlier stages, depending of the site of involvement, there will be LMN signs at the level of lesion and UMN signs below the level of lesion. Plantar reflex will show a positive Babinski sign. As the disease progresses, death occurs due to paralysis of respiratory muscles. Death occurs much earlier in bulbar ALS **(Figures 6.36A and B)**.
- **Subacute combined degeneration:** Involvement of both posterior columns and pyramidal tracts is seen in subacute combined degeneration due to vitamin B12 deficiency.
  This causes bilateral loss of fine touch, two-point discrimination, joint position and vibration sense and bilateral spastic paralysis and a positive Babinski sign.

Summary

- The spinal cord, a two-way impulse conduction pathway and a reflex center, is located within the vertebral column and is protected by meninges and CSF. It extends from the foramen magnum to the end of the first lumbar vertebra.
- 31 pairs of spinal nerve roots issue from the cord. The cord is enlarged in the cervical and lumbar regions, where spinal nerves serving the limbs arise.
- The central gray matter of the cord is H shaped. Anterior horns contain somatic motor neurons. Lateral horns contain visceral (autonomic) motor neurons. Posterior horns contain sensory neurons.
- In thoracic and L1–L2 regions, a small lateral gray column is present which is meant for an autonomic efferent pathway.

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- Axons of neurons of the lateral and anterior horns emerge in common from the cord via the ventral roots. Axons of sensory neurons (with cell bodies located in the dorsal root ganglion) enter the posterior aspect of the cord and form the dorsal roots. The ventral and dorsal roots combine to form the spinal nerves.
- Each side of the white matter of the cord has posterior, lateral, and anterior columns (funiculi), and each funiculus contains a number of ascending and descending tracts. All tracts are paired and most decussate.
- Ascending (sensory) tracts include the fasciculi gracilis and cuneatus (touch and joint proprioception), spinothalamic tracts (pain, touch, temperature), and spinocerebellar tracts (muscle/tendon proprioception).
- Descending tracts include the pyramidal tracts (anterior and lateral corticospinal tracts that originate from the primary motor cortex) and the motor tracts originating from subcortical motor nuclei.
- Injury to the anterior horn neurons or the LMN results in flaccid paralysis (injury to the UMN in the brain results in spastic paralysis). If the dorsal roots or sensory tracts are damaged, paresthesias occur.
- The spinal cord is supplied by: (i) anterior spinal artery, (ii) posterior spinal arteries, and (iii) radicular arteries.
- The venous drainage of spinal cord is through six longitudinal channels which ultimately drain into the internal vertebral venous plexus located between the dura mater and the vertebral canal.

CLINICAL CASE

6.1: In a case of vehicular accident, a radiogram shows crush fracture of the body of the seventh thoracic vertebra.
A. Which spinal segment is affected in this person?
B. Below which part of the trunk would this person have loss of sensation?

6.2: In a person with anterior spinal artery syndrome at the spinal segment C8, what would be the effect on?
A. Biceps jerk; knee jerk
B. Plantar reflex; cremasteric reflex

6.3: Brown–Séquard syndrome
A person had a stab injury in the back of his neck between C7 and T1 vertebrae. Magnetic resonance imaging (MRI) scan showed that the left half of the spinal cord was damaged at the T1 spinal segment. Left-sided motor paralysis and left-sided fine touch sensations were lost from the T1 segment downward. Pain sensation was lost on the right side from the T4 segment.
A. Why was the pain sensation lost contralaterally from the T4 segment?
B. Which group of muscles will show LMN type of paralysis?

6.4: Poliomyelitis
A 4-year-old child suffered from fever and gastroenteritis. This was followed by acute flaccid paralysis with fasciculation of the quadriceps muscle and absence of knee jerk. Atrophy of the muscle soon ensued.
A. Specify the type of neurological lesion.
B. Which segment of the spinal cord is involved in this child?

Answer (Clinical cases):
6.1: A. Tenth thoracic spinal segment
B. From umbilicus downward
6.2: A. A biceps jerk will be normal; knee jerk will be exaggerated.
B. Plantar reflex will show positive Babinski sign; cremasteric reflex will be lost.
6.3: A. Pain sensations travel up ipsilaterally for two to three segments in the dorsolateral tract of Lissauer
B. Left sided (ipsilateral) intrinsic muscles of hand
6.4: A. Lower motor neuron
B. L3, L4

MULTIPLE CHOICE QUESTIONS

Q1. At birth, the lower end of spinal cord lies at the level of which vertebra?
A. L1 B. L3
C. S2 D. S4

Q2. In adults, the length of the spinal cord in centimeter is:
A. 25 B. 35
C. 45 D. 55

Q3. Inferior continuation of the pia mater of spinal cord is called:
A. Conus medullaris B. Cauda equina
C. Filum terminale D. Ganglion impar

Q4. Ligamentum denticulatum is an extension from the:
A. Posterior longitudinal ligament
B. Pia mater
C. Ligamentum flavum
D. Dura mater

Q5. Total number of spinal segments is:
A. 30 B. 31
C. 32 D. 33

Q6. Ninth thoracic spine corresponds to which spinal segment?
A. T9 B. T10
C. T11 D. T12

Q7. Cervical enlargement of the spinal cord extends between which of the following spinal segments?
A. C1 and C8 B. C1 and T2
C. C3 and C8 D. C3 and T2

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Q8. Which artery gives rise to arteria radicularis magna?
A. Vertebral B. Fifth intercostal
C. 11th intercostal D. First lumbar

Q9. Anterior spinal artery is a branch of which of the following arteries?
A. Internal carotid
B. Vertebral
C. Subclavian
D. Posteroinferior cerebellar

Q10. The somatic efferent cells of the ventral gray column of spinal cord are known as:
A. Alpha motor neurons
B. Ganglion cells
C. Gamma motor neurons
D. Renshaw cells

Q11. The fibers of the posterior spinocerebellar tract arise from:
A. Visceral afferent nucleus
B. Substantia gelatinosa
C. Nucleus dorsalis
D. Nucleus proprius

Q12. LMNs are located in the:
A. Dorsal root ganglion
B. Pontine nuclei
C. Sympathetic chain
D. Anterior gray column of the spinal cord

Q13. Which of the following is the most posterior in the dorsal gray column of the spinal cord?
A. Substantia gelatinosa (of Rolando)
B. Nucleus dorsalis (Clarke's column)
C. Nucleus proprius
D. Visceral afferent nucleus

Q14. Which of the following tracts is concerned with reflex head and neck movements in response to the stimulation of body parts?
A. Spino-olivary
B. Spinoreticular
C. Spinotectal
D. Spinovestibular

Q15. Which of the following columns of the spinal cord contains the fasciculus cuneatus?
A. Anterior B. Lateral, anterior half
C. Lateral, posterior half D. Posterior

Q16. The fibers of the medial reticulospinal tract begin from:
A. Medulla oblongata B. Pons
C. Midbrain D. Diencephalon

Answers

1. B	**2. C**	**3. C**	**4. B**	**5. B**
6. D	**7. D**	**8. C**	**9. B**	**10. A**
11. C	**12. D**	**13. A**	**14. C**	**15. D**
16. B				

SHORT NOTES

1. What are spinal segments? Describe their relation with vertebral levels.
2. Describe arterial supply of the spinal cord with a suitable diagram.
3. Draw and label the transverse section of the cervical part of spinal cord to depict various ascending and descending tracts.
4. What are the main differences in the internal structure of spinal cord between midcervical and midthoracic levels?
5. Enumerate all ascending and descending pathways.

LONG QUESTIONS

1. Describe the various nuclei in the anterior, posterior, and lateral gray columns of the spinal cord.
2. Describe various pathways which carry pain sensations to higher levels.
3. Explain corticospinal tract with a well-labeled diagram or flowchart.
4. Describe the dorsal column pathway in detail.

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Inderbir Singh's Textbook of
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The current edition of the *Inderbir Singh's Textbook of Clinical Neuroanatomy* (11th Edition) has been revised primarily to conform the guidelines of new competency-based curriculum of National Medical Council of India (NMC).

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- A brief 'Summary' has been added at the end of each chapter for a quick and easy revision.
- Flowcharts have been added to help in memorizing the various tracts, etc.
- Multiple choice questions (MCQs), clinical cases, short and long questions have been added at the end of the chapter along with the answers to MCQs and clinical cases.

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