

## **Spinal Column**

The spinal cord is a vital structure between the body and the brain. It is the main connection that gathers information from different parts of our body and sends signals to the brain. The spinal cord is a cylindrical structure of nervous tissue made up of white and gray matter.<sup>1</sup> The spinal column extends from the skull to the pelvis and is made up of 33 individual bones called vertebrae.<sup>2</sup> The vertebrae are small bones that protect the spinal cord.<sup>3</sup>

The anatomy of the spine is divided into four regions: cervical (C), thoracic (T), lumbar (L), and sacral (S). The vertebrae are named according to their particular section of the spine and are assigned a specific number based on their position and order. The cervical vertebrae (cervical spine) are comprised of seven segments, C1 to C7 from top to bottom. The thoracic vertebrae (thoracic spine) have twelve segments, T1 to T12. The lumbar vertebrae (lumbar spine) have five segments, L1 to L5. The sacral vertebrae have five segments, S1 to S5.<sup>4</sup>

The cervical spine is divided into two parts: the upper cervical region (C1 and C2), and the lower cervical region (C3 to C7). C1 is referred to as the Atlas and C2 the Axis. The Atlas is the first cervical vertebra, hence referred to as C1. This bone supports the skull. The Axis is the second cervical vertebra, hence C2. The Axis is also referred to as the dens, which is Latin for tooth. The 'dens' provides a type of pivot and collar allowing the head and atlas to rotate around the dens.<sup>5</sup>

The thoracic vertebrae (T1 to T12) increase in size each segment. The rib cage connects to the thoracic vertebrae. The ribs at T11 and T12 are not attached; hence, the "floating ribs."<sup>6</sup>

The lumbar vertebrae (L1 to L5) also increase gradually in size each segment. The lumbar vertebrae carry the weight of the body and all related biomechanical stress, which is why they are longer and wider than the thoracic vertebrae.<sup>7</sup>

The sacral vertebrae (sacrum) are located behind the pelvis. The sacrum (S1 to S5) consists of five bones fused into a triangular or shield-like shape. It is located at the base of the lumbar vertebrae and connected to the pelvis. Joined at the very end of the sacrum are five additional bones, fused together to form the Coccyx, also known as the tailbone.

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<sup>1</sup> Nachum Dafny, Ph.D., *Anatomy of the Spinal Cord* sec. 2 ch.3 (Department of Neurobiology and Anatomy, University of Texas Medical School at Houston) (available at <http://neuroscience.uth.tmc.edu/s2/chapter03.html>).

<sup>2</sup> Keith Bridwell, M.D., *Vertebral Column* (SpineUniverse) (available at <http://www.spineuniverse.com/anatomy/vertebral-column>).

<sup>3</sup> American Academy of Orthopaedic Surgeons (AAOS) (available at <http://orthoinfo.aaos.org/topic.cfm?topic=A00575>).

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<sup>4</sup> Bridwell, *supra*.

<sup>5</sup> *Id.*

<sup>6</sup> *Id.*

<sup>7</sup> *Id.*



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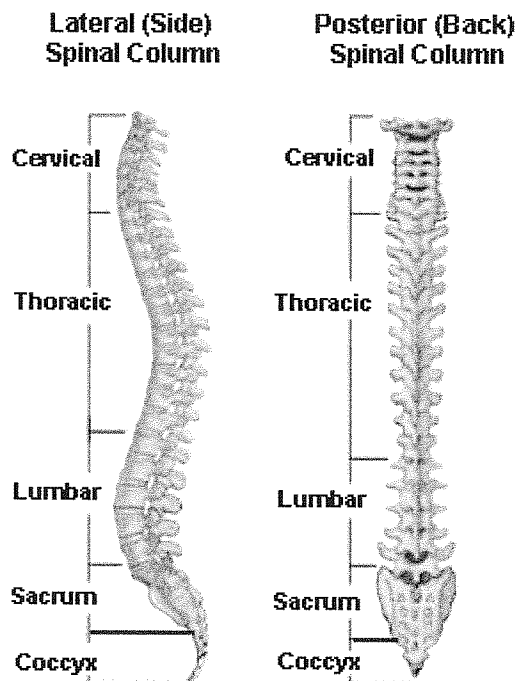
## Vertebral Column



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The spinal column (or vertebral column) extends from the skull to the pelvis and is made up of 33 individual bones termed vertebrae. The vertebrae are stacked on top of each other group into four regions:



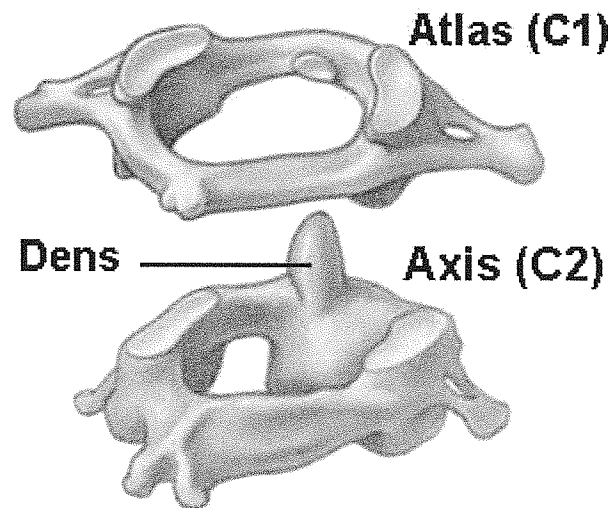
Term	# of Vertebrae	Body Area	Abbreviation
<u>Cervical</u> [2]	7	Neck	C1 – C7
<u>Thoracic</u> [3]	12	Chest	T1 – T12
<u>Lumbar</u> [4]	5 or 6	Low Back	L1 – L5
<u>Sacrum</u> [5]	5 (fused)	Pelvis	S1 – S5
<u>Coccyx</u> [5]	3	Tailbone	None

### Cervical Vertebrae (C1 – C7)

The cervical spine is further divided into two parts; the upper cervical region (C1 and C2), and the lower cervical region (C3 through C7). C1 is termed the Atlas and C2 the Axis. The **Occiput** (CO), also known as the Occipital Bone, is a flat bone that forms the back of the head.

**Atlas (C1)**

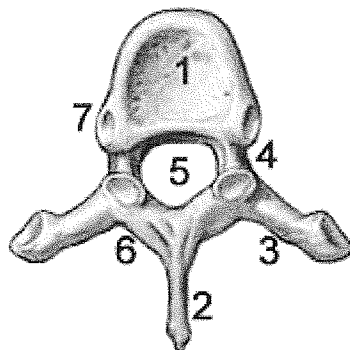
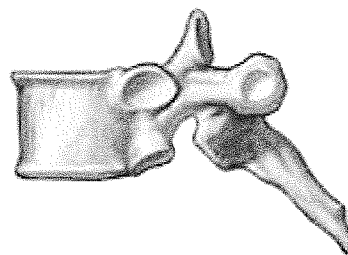
The Atlas is the first cervical vertebra and therefore abbreviated C1. This vertebra supports the skull. Its appearance is different from the other spinal vertebrae. The atlas is a ring of bone made up of two lateral masses joined at the front and back by the anterior arch and the posterior arch.

**Axis (C2)**

The Axis is the second cervical vertebra or C2. It is a blunt tooth-like process that projects upward. It is also referred to as the 'dens' (Latin for 'tooth') or odontoid process. The dens provides a type of pivot and collar allowing the head and atlas to rotate around the dens.

**Thoracic Vertebrae (T1 – T12)**

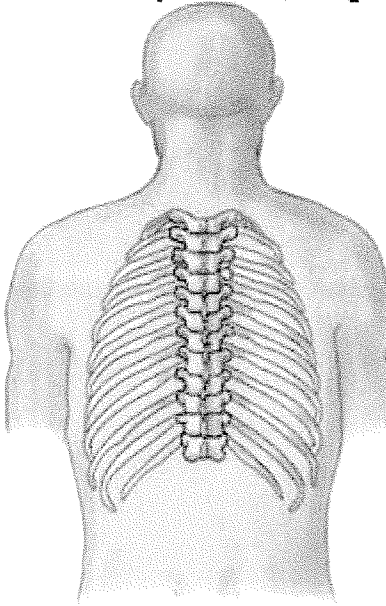
The thoracic vertebrae increase in size from T1 through T12. They are characterized by small pedicles, long spinous processes, and relatively large intervertebral foramen (neural passageways), which result in less incidence of nerve compression.

**Thoracic Vertebrae****Axial (Overhead) View****Lateral (Side) View**

- 1-Vertebral Body 2-Spinous Process 3-Transverse Facet  
4-Pedicle 5-Foramen 6-Lamina 7-Superior Facet

The rib cage is joined to the thoracic vertebrae. At T11 and T12, the ribs do not attach and are so are called "floating ribs." The thoracic spine's range of motion is limited due to the many rib/vertebrae connections and the long spinous processes.

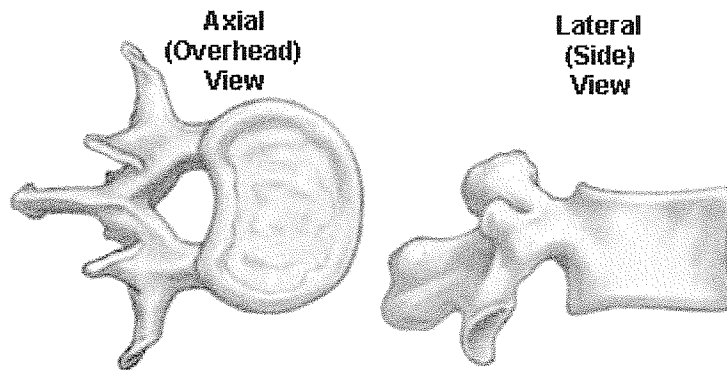
### Posterior (Back) View Thoracic Spine and Rib Cage



### Lumbar Vertebrae (L1 – L5)

The lumbar vertebrae graduate in size from L1 through L5. These vertebrae bear much of the body's weight and related biomechanical stress. The pedicles are longer and wider than those in the thoracic spine. The spinous processes are horizontal and more squared in shape. The intervertebral foramen (neural passageways) are relatively large but nerve root compression is more common than in the thoracic spine.

### Lumbar Vertebrae



### Purpose of the Vertebrae

Although vertebrae range in size; cervical the smallest, lumbar the largest, vertebral bodies are the weight bearing structures of the spinal column. Upper body weight is distributed through the spine to the sacrum and pelvis. The natural curves in the spine, kyphotic and lordotic, provide resistance and elasticity in distributing body weight and axial loads sustained during movement.

The vertebrae are composed of many elements that are critical to the overall function of the spine, which include the intervertebral discs and facet joints.

### Functions of the Vertebral or Spinal Column Include:

#### Protection

- Spinal Cord and Nerve Roots
- Many internal organs

**Base for Attachment**

- Ligaments
- Tendons
- Muscles

**Structural Support**

- Head, shoulders, chest
- Connects upper and lower body
- Balance and weight distribution

**Flexibility and Mobility**

- Flexion (forward bending)
- Extension (backward bending)
- Side bending (left and right)
- Rotation (left and right)
- Combination of above

**Other**

- Bones produce red blood cells
- Mineral storage

**Sacral Spine**

The Sacrum is located behind the pelvis. Five bones (abbreviated S1 through S5) fused into a triangular shape, form the sacrum. The sacrum fits between the two hipbones connecting the spine to the pelvis. The last lumbar vertebra (L5) articulates (moves) with the sacrum. Immediately below the sacrum are five additional bones, fused together to form the Coccyx (tailbone).

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## Spine Basics

Understanding your spine and how it works can help you better understand some of the problems that occur from aging or injury.

Many demands are placed on your spine. It holds up your head, shoulders, and upper body. It gives you support to stand up straight, and gives you flexibility to bend and twist. It also protects your spinal cord.

### Spinal Curves

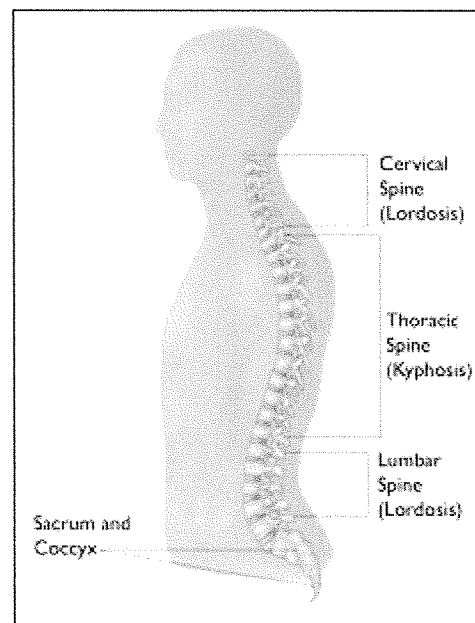
Your spine is made up of three segments. When viewed from the side, these segments form three natural curves. The "c-shaped" curves of the neck (cervical spine) and lower back (lumbar spine) are called lordosis. The "reverse c-shaped" curve of the chest (thoracic spine) is called kyphosis.

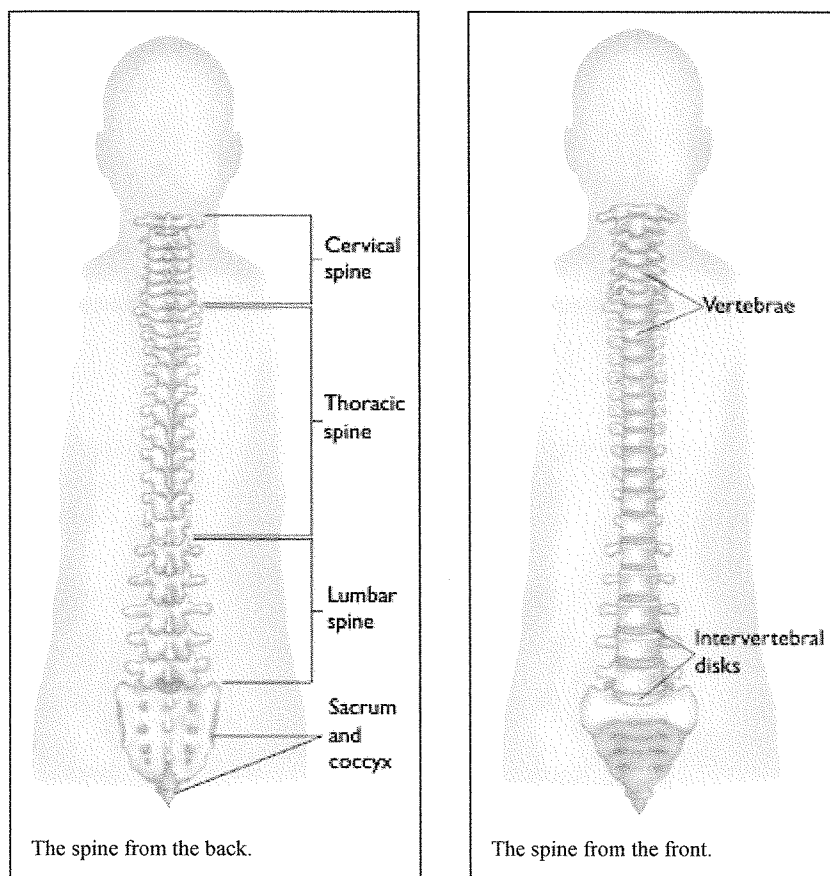
These curves are important to balance and they help us to stand upright. If any one of the curves becomes too large or small, it becomes difficult to stand up straight and our posture appears abnormal.

Abnormal curvatures of the spine are also referred to as spinal deformity. These types of conditions include kyphosis of the thoracic spine ("hunchback") and lordosis of the lumbar spine ("swayback").

Scoliosis is another type of spinal deformity. When viewing the spine from the front or back, scoliosis is a sideways curvature that makes the spine look more like an "S" or a "C" than a straight "I."

### Parts of the Spine





Your spine is made up of small bones, called vertebrae, which are stacked on top of one another and create the natural curves of your back.

### ***Vertebrae***

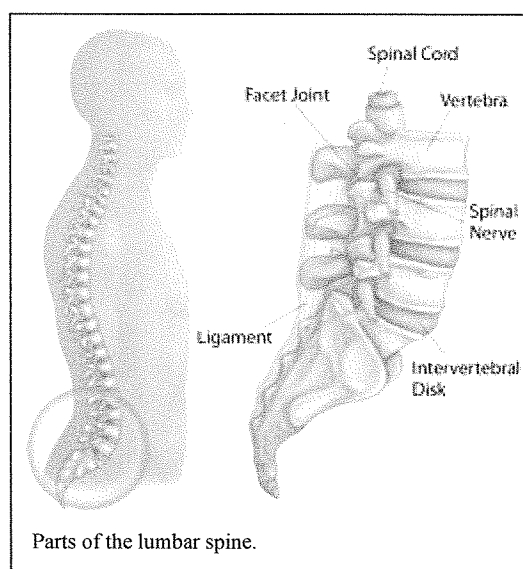
These bones connect to create a canal that protects the spinal cord.

The cervical spine is made up of seven small vertebrae that begin at the base of the skull and end at the upper chest. The thoracic spine is made up of 12 vertebrae that start from the upper chest to the middle back and connect to the rib cage. The lumbar vertebra consists of five larger vertebrae. These vertebrae are larger because they carry more of your body's weight.

### ***Spinal Cord and Nerves***

The spinal cord extends from the skull to your lower back and travels through the middle part of each stacked vertebra, called the central canal. Nerves branch out from the spinal cord through openings in the vertebrae and carry messages between the brain and muscles.

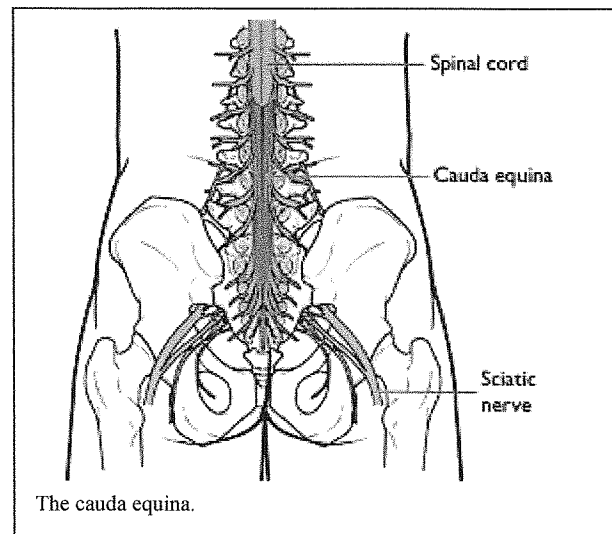
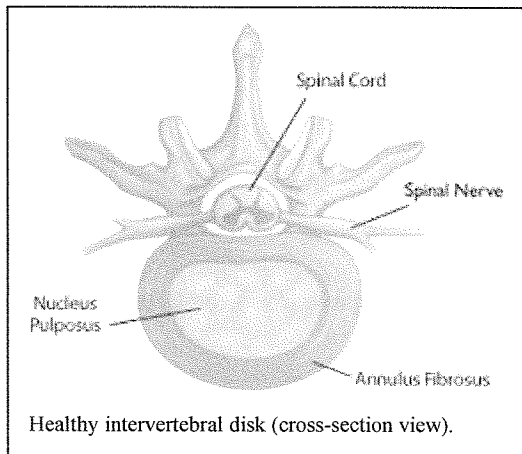
The spinal cord ends around the first and second lumbar vertebrae in the lower back and continues as nerve roots. This bundle of nerve roots is called the cauda equina. They exit the spinal canal through openings in the vertebrae (foramen), just like other nerve roots.



### ***Muscles and Ligaments***

These provide support and stability for your spine and upper body. Strong ligaments connect your vertebrae and help keep the spinal column in position.





### ***Intervertebral Disks***

Intervertebral disks sit in between the vertebrae. They are flat and round, and about a half inch thick.

Intervertebral disks are made up of two components.

**Nucleus pulposus.** The nucleus pulposus is jelly-like and makes up the center of the disk. The jelly is partly made of water and gives the disk flexibility and strength.

**Annulus fibrosus.** This is the flexible outer ring of the disk. It is made up of several layers, similar to elastic bands.

When you are standing or moving, weight is put onto the nucleus. In response, the nucleus expands. The annulus holds the nucleus in place. This allows movement to take place, yet maintains the strength of the spine. In effect, disks act as shock absorbers for the spine.

The intervertebral disk is a very important structure. Many nerve endings supply the annulus and, as a result, an injured annulus can cause pain.

### ***Facet Joints***

Between the back of the vertebrae are small joints that also help your spine move. These facet joints have a cartilage surface, very much like a hip or a knee joint does. The facet joints are important for allowing rotation of the spine but may develop arthritis and become a source for low back or neck pain.

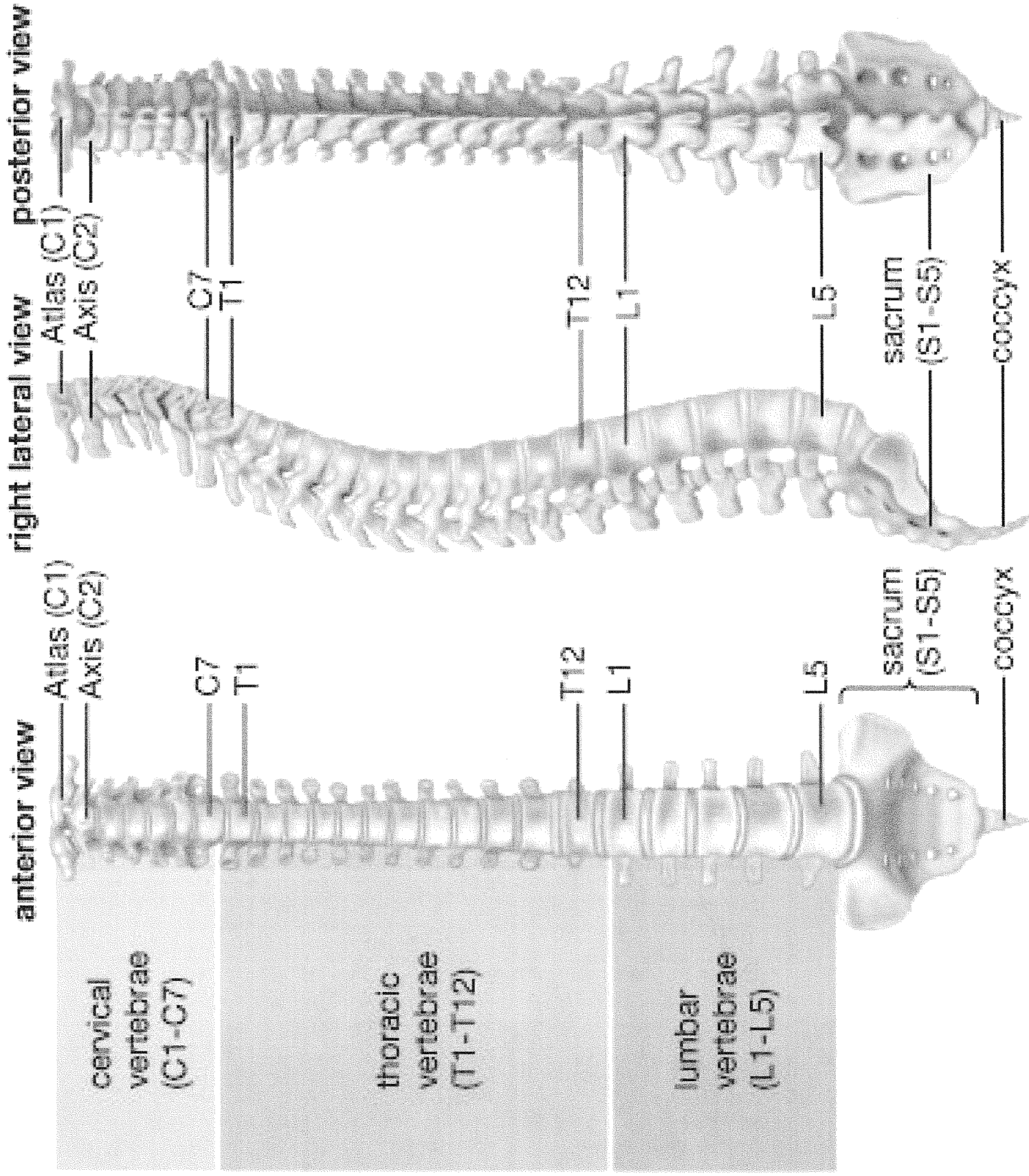
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## Chapter 3: Anatomy of the Spinal Cord

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### 3.1 Introduction

The spinal cord is the most important structure between the body and the brain. The spinal cord extends from the foramen magnum where it is continuous with the medulla to the level of the first or second lumbar vertebrae. It is a vital link between the brain and the body, and from the body to the brain. The spinal cord is 40 to 50 cm long and 1 cm to 1.5 cm in diameter. Two consecutive rows of nerve roots emerge on each of its sides. These nerve roots join distally to form 31 pairs of **spinal nerves**. The spinal cord is a cylindrical structure of nervous tissue composed of white and gray matter, is uniformly organized and is divided into four regions: cervical (C), thoracic (T), lumbar (L) and sacral (S), (Figure 3.1), each of which is comprised of several segments. The spinal nerve contains motor and sensory nerve fibers to and from all parts of the body. Each spinal cord segment innervates a dermatome (see below and Figure 3.5).

### 3.2 General Features

1. Similar cross-sectional structures at all spinal cord levels (Figure 3.1).
2. It carries sensory information (sensations) from the body and some from the head to the central nervous system (CNS) via afferent fibers, and it performs the initial processing of this information.
3. Motor neurons in the ventral horn project their axons into the periphery to innervate skeletal and smooth muscles that mediate voluntary and involuntary reflexes.
4. It contains neurons whose descending axons mediate autonomic control for most of the visceral functions.
5. It is of great clinical importance because it is a major site of traumatic injury and the locus for many disease processes.

Figure 3.1  
Schematic dorsal and lateral view of the spinal cord and four cross sections from cervical, thoracic, lumbar and sacral levels, respectively.

Although the spinal cord constitutes only about 2% of the central nervous system (CNS), its functions are vital. *Knowledge of spinal cord functional anatomy makes it possible to diagnose the nature and location of cord damage and many cord diseases.*

### 3.3 Segmental and Longitudinal Organization

The spinal cord is divided into four different regions: the cervical, thoracic, lumbar and sacral regions (Figure 3.1). The different cord regions can be visually distinguished from one another. Two enlargements of the spinal cord can be visualized: The cervical enlargement, which extends between C3 to T1; and the lumbar enlargements which extends between L1 to S2 (Figure 3.1).

The cord is segmentally organized. There are 31 segments, defined by 31 pairs of nerves exiting the cord. These nerves are divided into 8 cervical, 12 thoracic, 5 lumbar, 5 sacral, and 1 coccygeal nerve (Figure 3.2). Dorsal and ventral roots enter and leave the vertebral column respectively through intervertebral foramen at the vertebral segments corresponding to the spinal segment.

Figure 3.2  
Drawing of the 8, 12, 5, 5 and 1  
cervical, thoracic, lumbar, sacral and  
coccygeal spinal nerves and their exit  
from the vertebrae, respectively.

The cord is sheathed in the same three meninges as is the brain: the pia, arachnoid and dura. The dura is the tough outer sheath, the arachnoid lies beneath it, and the pia closely adheres to the surface of the cord (Figure 3.3). The spinal cord is attached to the dura by a series of lateral denticulate ligaments emanating from the pial folds.

Figure 3.3

The three spinal cord meninges. The denticulate ligament, the dorsal root ganglion (A), and an enlarged drawing of the meninges (B).

During the initial third month of embryonic development, the spinal cord extends the entire length of the vertebral canal and both grow at about the same rate. As development continues, the body and the vertebral column continue to grow at a much greater rate than the spinal cord proper. This results in displacement of the lower parts of the spinal cord with relation to the vertebrae column. The outcome of this uneven growth is that the adult spinal cord extends to the level of the first or second lumbar vertebrae, and the nerves grow to exit through the same intervertebral foramina as they did during embryonic development. This growth of the nerve roots occurring within the vertebral canal, results in the lumbar, sacral, and coccygeal roots extending to their appropriate vertebral levels (Figure 3.2).

All spinal nerves, except the first, exit below their corresponding vertebrae. In the cervical segments, there are 7 cervical vertebrae

and 8 cervical nerves (Figure 3.2). C1-C7 nerves exit above their vertebrae whereas the C8 nerve exits below the C7 vertebra. It leaves between the C7 vertebra and the first thoracic vertebra. Therefore, each subsequent nerve leaves the cord below the corresponding vertebra. In the thoracic and upper lumbar regions, the difference between the vertebrae and cord level is three segments. Therefore, the root filaments of spinal cord segments have to travel longer distances to reach the corresponding intervertebral foramen from which the spinal nerves emerge. The lumbosacral roots are known as the cauda equina (Figure 3.2).

Each spinal nerve is composed of nerve fibers that are related to the region of the muscles and skin that develops from one body somite (segment). A spinal segment is defined by dorsal roots entering and ventral roots exiting the cord, (i.e., a spinal cord section that gives rise to one spinal nerve is considered as a segment.) (Figure 3.4).

Figure 3.4

(A) Drawing of the spinal cord with its spinal roots. (B) Drawing of the spinal vertebra. (C) Section of the spinal cord, its meninges and the dorsal and ventral roots of three segments.

A **dermatome** is an area of skin supplied by peripheral nerve fibers originating from a single dorsal root ganglion. If a nerve is cut, one loses sensation from that dermatome. Because each segment of the cord innervates a different region of the body, dermatomes can be precisely mapped on the body surface, and loss of sensation in a dermatome can indicate the exact level of spinal cord damage in clinical assessment of injury (Figure 3.5). It is important to consider that there is some overlap between neighboring dermatomes. Because sensory information from the body is relayed to the CNS through the dorsal roots, the axons originating from dorsal root ganglion cells are classified as primary sensory afferents, and the dorsal root's neurons are the first order (1°) sensory neuron. Most axons in the ventral roots arise from motor neurons in the ventral horn of the spinal cord and innervate skeletal muscle. Others arise from the lateral horn and synapse on autonomic ganglia that innervate visceral organs. The ventral root axons join with the peripheral processes of the dorsal root ganglion cells to form mixed afferent and efferent spinal nerves, which merge to form peripheral nerves. Knowledge of the segmental innervation of the cutaneous area and the muscles is essential to diagnose the site of an injury.

Figure 3.5

Innervation arising from single dorsal root ganglion supplied specific skin area (a dermatome).

The numbers refer to the spinal segments by which each nerve is named C = cervical; T = thoracic; L = lumbar; S = sacral spinal cord segments (dermatome).

### 3.4 Internal Structure of the Spinal Cord

A transverse section of the adult spinal cord shows white matter in the periphery, gray matter inside, and a tiny central canal filled with CSF at its center. Surrounding the canal is a single layer of cells, the ependymal layer. Surrounding the ependymal layer is the gray matter – a region containing cell bodies – shaped like the letter “H” or a “butterfly”. The two “wings” of the butterfly are connected across the midline by the dorsal gray commissure and below the white commissure (Figure 3.6). The shape and size of the gray matter varies according to spinal cord level. At the lower levels, the ratio between gray matter and white matter is greater than in higher levels, mainly because lower levels contain less ascending and descending nerve fibers. (Figure 3.1 and Figure 3.6).

Figure 3.6

Spinal cord section showing the white and the gray matter in four spinal cord levels.

The gray matter mainly contains the cell bodies of neurons and glia and is divided into four main columns: dorsal horn, intermediate column, lateral horn and ventral horn column. (Figure 3.6).

The dorsal horn is found at all spinal cord levels and is comprised of sensory nuclei that receive and process incoming somatosensory information. From there, ascending projections emerge to transmit the sensory information to the midbrain and diencephalon. The intermediate column and the lateral horn comprise autonomic neurons innervating visceral and pelvic organs. The ventral horn comprises motor neurons that innervate skeletal muscle.

At all the levels of the spinal cord, nerve cells in the gray substance are multipolar, varying much in their morphology. Many of them are Golgi type I and Golgi type II nerve cells. The axons of Golgi type I are long and pass out of the gray matter into the ventral spinal roots or the fiber tracts of the white matter. The axons and dendrites of the Golgi type II cells are largely confined to the neighboring neurons in the gray matter.

A more recent classification of neurons within the gray matter is based on function. These cells are located at all levels of the spinal cord and are grouped into three main categories: root cells, column or tract cells and propriospinal cells.

The root cells are situated in the ventral and lateral gray horns and vary greatly in size. The most prominent features of the root cells are large multipolar elements exceeding 25  $\mu\text{m}$  of their somata. The root cells contribute their axons to the ventral roots of the spinal nerves and are grouped into two major divisions: 1) somatic efferent root neurons, which innervate the skeletal musculature; and 2) the visceral efferent root neurons, also called preganglionic autonomic axons, which send their axons to various autonomic ganglia.

The **column or tract cells** and their processes are located mainly in the dorsal gray horn and are confined entirely within the CNS. The axons of the column cells form longitudinal ascending tracts that ascend in the white columns and terminate upon neurons located rostrally in the brain stem, cerebellum or diencephalon. Some column cells send their axons up and down the cord to terminate in gray matter close to their origin and are known as intersegmental association column cells. Other column cell axons terminate within the segment in which they originate and are called intrasegmental association column cells. Still other column cells send their axons across the midline to terminate in gray matter close to their origin and are called commissure association column cells.

The **propriospinal cells** are spinal interneurons whose axons do not leave the spinal cord proper. Propriospinal cells account for about 90% of spinal neurons. Some of these fibers also are found around the margin of the gray matter of the cord and are collectively called the fasciculus proprius or the propriospinal or the archispinothalamic tract.

### 3.5 Spinal Cord Nuclei and Laminae

Spinal neurons are organized into nuclei and laminae.

### 3.6 Nuclei

The prominent nuclear groups of cell columns within the spinal cord from dorsal to ventral are the marginal zone, substantia gelatinosa, nucleus proprius, dorsal nucleus of Clarke, intermediolateral nucleus and the lower motor neuron nuclei.

Figure 3.7  
Spinal cord nuclei and laminae.

Marginal zone nucleus or posterior marginalis, is found at all spinal cord levels as a thin layer of column/tract cells (column cells) that caps the tip of the dorsal horn. The axons of its neurons contribute to the lateral spinothalamic tract which relays pain and temperature information to the diencephalon (Figure 3.7).

Substantia gelatinosa is found at all levels of the spinal cord. Located in the dorsal cap-like portion of the head of the dorsal horn, it relays pain, temperature and mechanical (light touch) information and consists mainly of column cells (intersegmental column cells). These column cells synapse in cell at Rexed layers IV to VII, whose axons contribute to the ventral (anterior) and lateral spinal thalamic tracts. *The homologous substantia gelatinosa in the medulla is the **spinal trigeminal nucleus**.*

Nucleus proprius is located below the substantia gelatinosa in the head and neck of the dorsal horn. This cell group, sometimes called the chief sensory nucleus, is associated with mechanical and temperature sensations. It is a poorly defined cell column which extends through all segments of the spinal cord and its neurons contribute to ventral and lateral spinal thalamic tracts, as well as to spinal cerebellar tracts. The axons originating in nucleus proprius project to the thalamus via the spinothalamic tract and to the cerebellum via the ventral spinocerebellar tract (VSCT).

Dorsal nucleus of Clarke is a cell column located in the mid-portion of the base of the dorsal horn. The axons from these cells pass uncrossed to the lateral funiculus and form the dorsal (posterior) spinocerebellar tract (DSCT), which subserve unconscious proprioception from muscle spindles and Golgi tendon organs to the cerebellum, and some of them innervate spinal interneurons. The dorsal nucleus of Clarke is found only in segments C8 to L3 of the spinal cord and is most prominent in lower thoracic and upper lumbar segments. *The homologous dorsal nucleus of Clarke in the medulla is the accessory cuneate nucleus, which is the origin of the cuneocerebellar tract (CCT).*

Intermediolateral nucleus is located in the intermediate zone between the dorsal and the ventral horns in the spinal cord levels. Extending from C8 to L3, it receives viscerosensory information and contains preganglionic sympathetic neurons, which form the lateral horn. A large proportion of its cells are root cells which send axons into the ventral spinal roots via the white rami to reach the sympathetic tract as preganglionic fibers. Similarly, cell columns in the intermediolateral nucleus located at the S2 to S4 levels contain preganglionic parasympathetic neurons (Figure 3.7).

Lower motor neuron nuclei are located in the ventral horn of the spinal cord. They contain predominantly motor nuclei consisting of  $\alpha$ ,  $\beta$  and  $\gamma$  motor neurons and are found at all levels of the spinal cord--they are root cells. The  $\alpha$  motor neurons are the final common pathway of the motor system, and they innervate the visceral and skeletal muscles.

### 3.7 Rexed Laminae

The distribution of cells and fibers within the gray matter of the spinal cord exhibits a pattern of lamination. The cellular pattern of each lamina is composed of various sizes or shapes of neurons (cytoarchitecture) which led Rexed to propose a new classification based on 10 layers (laminae). This classification is useful since it is related more accurately to function than the previous classification scheme which was based on major nuclear groups (Figure 3.7).

Laminae I to IV, in general, are concerned with exteroceptive sensation and comprise the dorsal horn, whereas laminae V and VI are concerned primarily with proprioceptive sensations. Lamina VII is equivalent to the intermediate zone and acts as a relay between muscle spindle to midbrain and cerebellum, and laminae VIII-IX comprise the ventral horn and contain mainly motor neurons. The axons of these neurons innervate mainly skeletal muscle. Lamina X surrounds the central canal and contains neuroglia.

**Rexed lamina I** – Consists of a thin layer of cells that cap the tip of the dorsal horn with small dendrites and a complex array of nonmyelinated axons. Cells in lamina I respond mainly to noxious and thermal stimuli. Lamina I cell axons join the contralateral spinothalamic tract; this layer corresponds to nucleus posteromarginalis.

**Rexed lamina II** – Composed of tightly packed interneurons. This layer corresponds to the substantia gelatinosa and responds to noxious stimuli while others respond to non-noxious stimuli. The majority of neurons in Rexed lamina II axons receive information from sensory dorsal root ganglion cells as well as descending dorsolateral fasciculus (DLF) fibers. They send axons to Rexed laminae III and IV (fasciculus proprius). High concentrations of substance P and opiate receptors have been identified in Rexed lamina II. The lamina is believed to be important for the modulation of sensory input, with the effect of determining which pattern of incoming information will produce sensations that will be interpreted by the brain as being painful.

**Rexed lamina III** – Composed of variable cell size, axons of these neurons bifurcate several times and form a dense plexus. Cells in this layer receive axodendritic synapses from A $\beta$  fibers entering dorsal root fibers. It contains dendrites of cells from laminae IV, V and VI. Most of the neurons in lamina III function as propriospinal/interneuron cells.

**Rexed lamina IV** – The thickest of the first four laminae. Cells in this layer receive A $\beta$  axons which carry predominantly non-noxious information. In addition, dendrites of neurons in lamina IV radiate to lamina II, and respond to stimuli such as light touch. The ill-defined nucleus proprius is located in the head of this layer. Some of the cells project to the thalamus via the contralateral and ipsilateral spinothalamic tract.

**Rexed lamina V** – Composed neurons with their dendrites in lamina II. The neurons in this lamina receive monosynaptic information from A $\beta$ , Ad and C axons which also carry nociceptive information from visceral organs. This lamina covers a broad zone extending across the neck of the dorsal horn and is divided into medial and lateral parts. Many of the Rexed lamina V cells project to the brain stem and the thalamus via the contralateral and ipsilateral spinothalamic tract. Moreover, descending corticospinal and rubrospinal fibers synapse upon its cells.

**Rexed lamina VI** – Is a broad layer which is best developed in the cervical and lumbar enlargements. Lamina VI divides also into medial and lateral parts. Group Ia afferent axons from muscle spindles terminate in the medial part at the C8 to L3 segmental levels and are the source of the ipsilateral spinocerebellar pathways. Many of the small neurons are interneurons participating in spinal reflexes, while descending brainstem pathways project to the lateral zone of Rexed layer VI.

**Rexed lamina VII** – This lamina occupies a large heterogeneous region. This region is also known as the zona intermedia (or intermediolateral nucleus). Its shape and boundaries vary along the length of the cord. Lamina VII neurons receive information from Rexed lamina II to VI as well as visceral afferent fibers, and they serve as an intermediary relay in transmission of visceral motor neurons impulses. The dorsal nucleus of Clarke forms a prominent round oval cell column from C8 to L3. The large cells give rise to uncrossed nerve fibers of the dorsal spinocerebellar tract (DSCT). Cells in laminae V to VII, which do not form a discrete nucleus, give rise to uncrossed fibers that form the ventral spinocerebellar tract (VSCT). Cells in the lateral horn of the cord in segments T1 and L3 give rise to preganglionic sympathetic fibers to innervate postganglionic cells located in the sympathetic ganglia outside the cord. Lateral horn neurons at segments S2 to S4 give rise to preganglionic neurons of the sacral parasympathetic fibers to innervate postganglionic cells located in peripheral ganglia.

**Rexed lamina VIII** – Includes an area at the base of the ventral horn, but its shape differs at various cord levels. In the cord enlargements, the lamina occupies only the medial part of the ventral horn, where descending vestibulospinal and reticulospinal fibers terminate. The neurons of lamina VIII modulate motor activity, most probably via  $\gamma$  motor neurons which innervate the intrafusal muscle fibers.

**Rexed lamina IX** – Composed of several distinct groups of large  $\alpha$  motor neurons and small  $\gamma$  and  $\beta$  motor neurons embedded



within this layer. Its size and shape differ at various cord levels. In the cord enlargements the number of  $\alpha$  motor neurons increase and they form numerous groups. The  $\alpha$  motor neurons are large and multipolar cells and give rise to ventral root fibers to supply extrafusal skeletal muscle fibers, while the small  $\gamma$  motor neurons give rise to the intrafusal muscle fibers. The  $\alpha$  motor neurons are somatotopically organized.

**Rexed lamina X** – Neurons in Rexed lamina X surround the central canal and occupy the commissural lateral area of the gray commissure, which also contains decussating axons.

In summary, laminae I-IV are concerned with exteroceptive sensations, whereas laminae V and VI are concerned primarily with proprioceptive sensation and act as a relay between the periphery to the midbrain and the cerebellum. Laminae VIII and IX form the final motor pathway to initiate and modulate motor activity via  $\alpha$ ,  $\beta$  and  $\gamma$  motor neurons, which innervate striated muscle. All visceral motor neurons are located in lamina VII and innervate neurons in autonomic ganglia.

### 3.8 White Matter

Surrounding the gray matter is white matter containing myelinated and unmyelinated nerve fibers. These fibers conduct information up (ascending) or down (descending) the cord. The white matter is divided into the dorsal (or posterior) column (or funiculus), lateral column and ventral (or anterior) column (Figure 3.8). The anterior white commissure resides in the center of the spinal cord, and it contains crossing nerve fibers that belong to the spinothalamic tracts, spinocerebellar tracts, and anterior corticospinal tracts. Three general nerve fiber types can be distinguished in the spinal cord white matter: 1) long ascending nerve fibers originally from the column cells, which make synaptic connections to neurons in various brainstem nuclei, cerebellum and dorsal thalamus, 2) long descending nerve fibers originating from the cerebral cortex and various brainstem nuclei to synapse within the different Rexed layers in the spinal cord gray matter, and 3) shorter nerve fibers interconnecting various spinal cord levels such as the fibers responsible for the coordination of flexor reflexes. Ascending tracts are found in all columns whereas descending tracts are found only in the lateral and the anterior columns.

Figure 3.8

The spinal cord white matter and its three columns, and the topographical location of the main ascending spinal cord tracts.

Four different terms are often used to describe bundles of axons such as those found in the white matter: funiculus, fasciculus, tract, and pathway. Funiculus is a morphological term to describe a large group of nerve fibers which are located in a given area (e.g., posterior funiculus). Within a funiculus, groups of fibers from diverse origins, which share common features, are sometimes arranged in smaller bundles of axons called fasciculus, (e.g., fasciculus proprius [Figure 3.8]). Fasciculus is primarily a morphological term whereas tracts and pathways are also terms applied to nerve fiber bundles which have a functional connotation. A tract is a group of nerve fibers which usually has the same origin, destination, and course and also has similar functions. The tract name is derived from their origin and their termination (i.e., corticospinal tract - a tract that originates in the cortex and terminates in the spinal cord; lateral spinothalamic tract - a tract originated in the lateral spinal cord and ends in the thalamus). A pathway usually refers to the entire neuronal circuit responsible for a specific function, and it includes all the nuclei and tracts which are associated with that function. For example, the spinothalamic pathway includes the cell bodies of origin (in the dorsal root ganglia), their axons as they project through the dorsal roots, synapses in the spinal cord, and projections of second and third order neurons across the white commissure, which ascend to the thalamus in the spinothalamic tracts.

### 3.9 Spinal Cord Tracts

The spinal cord white matter contains ascending and descending tracts.

**Ascending tracts** (Figure 3.8). The nerve fibers comprise the ascending tract emerge from the first order (1°) neuron located in the dorsal root ganglion (DRG). The ascending tracts transmit sensory information from the sensory receptors to higher levels of the CNS. The ascending gracile and cuneate fasciculi occupying the dorsal column, and sometimes are named the dorsal funiculus. These fibers carry information related to tactile, two point discrimination of simultaneously applied pressure, vibration, position, and movement sense and conscious proprioception. In the lateral column (funiculus), the neospinothalamic tract (or lateral spinothalamic tract) is located more anteriorly and laterally, and carries pain, temperature and crude touch information from somatic and visceral structures. Nearby laterally, the dorsal and ventral spinocerebellar tracts carry unconscious proprioception information from muscles and joints of the lower extremity to the cerebellum. In the ventral column (funiculus) there are four prominent tracts: 1) the paleospinothalamic tract (or anterior spinothalamic tract) is located which carry pain, temperature, and information associated with touch to the brain stem nuclei and to the diencephalon, 2) the spinoolivary tract carries information from Golgi tendon organs to the cerebellum, 3) the spinoreticular tract, and 4) the spino-tectal tract. Intersegmental nerve fibers traveling for several segments (2 to 4) and are located as a thin layer around the gray matter is known as fasciculus proprius, spinospinal or archispinothalamic tract. It carries pain information to the brain stem and diencephalon.

**Descending tracts** (Figure 3.9). The descending tracts originate from different cortical areas and from brain stem nuclei. The descending pathway carry information associated with maintenance of motor activities such as posture, balance, muscle tone, and visceral and somatic reflex activity. These include the lateral corticospinal tract and the rubrospinal tracts located in the lateral column (funiculus). These tracts carry information associated with voluntary movement. Other tracts such as the reticulospinal vestibulospinal and the anterior corticospinal tract mediate balance and postural movements (Figure 3.9). Lissauer's tract, which is wedged between the dorsal horn and the surface of the spinal cord carry the descending fibers of the dorsolateral funiculus (DLF), which regulate incoming pain sensation at the spinal level, and intersegmental fibers. Additional details about ascending and descending tracts are described in the next few chapters.

Figure 3.9  
The main descending spinal cord tracts.

### 3.10 Dorsal Root

Figure 3.10  
Spinal cord section with its ventral and dorsal root fibers and ganglion.

Information from the skin, skeletal muscle and joints is relayed to the spinal cord by sensory cells located in the dorsal root ganglia. The dorsal root fibers are the axons originated from the primary sensory dorsal root ganglion cells. Each ascending dorsal root axon, before reaching the spinal cord, bifurcates into ascending and descending branches entering several segments below and above their own segment. The ascending dorsal root fibers and the descending ventral root fibers from and to discrete body areas form a spinal nerve (Figure 3.10). There are 31 paired spinal nerves. The dorsal root fibers segregate into lateral and medial divisions. The lateral division contains most of the unmyelinated and small myelinated axons carrying pain and temperature information to be terminated in the Rexed laminae I, II, and IV of the gray matter. The medial division of dorsal root fibers consists mainly of myelinated axons conducting sensory fibers from skin, muscles and joints; it enters the dorsal/posterior column/funiculus and ascend in the dorsal column to be terminated in the ipsilateral nucleus gracilis or nucleus cuneatus at the medulla oblongata region, i.e., the axons of the first-order ( $1^{\circ}$ ) sensory neurons synapse in the medulla oblongata on the second order ( $2^{\circ}$ ) neurons (in nucleus gracilis or nucleus cuneatus). In entering the spinal cord, all fibers send collaterals to different Rexed lamina.

Axons entering the cord in the sacral region are found in the dorsal column near the midline and comprise the fasciculus gracilis, whereas axons that enter at higher levels are added in lateral positions and comprise the fasciculus cuneatus (Figure 3.11). This orderly representation is termed "somatotopic representation".

Figure 3.11  
Somatotopic representation of the spinal thalamic tract and the dorsal column.

### 3.11 Ventral Root

Ventral root fibers are the axons of motor and visceral efferent fibers and emerge from poorly defined ventral lateral sulcus as ventral rootlets. The ventral rootlets from discrete spinal cord section unite and form the ventral root, which contain motor nerve axons from motor and visceral motor neurons. The  $\alpha$  motor nerve axons innervate the extrafusal muscle fibers while the small  $\gamma$

motor neuron axons innervate the intrafusal muscle fibers located within the muscle spindles. The visceral neurons send preganglionic fibers to innervate the visceral organs. All these fibers join the dorsal root fibers distal to the dorsal root ganglion to form the spinal nerve (Figure 3.10).

### 3.12 Spinal Nerve Roots

The spinal nerve roots are formed by the union of dorsal and ventral roots within the intervertebral foramen, resulting in a mixed nerve joined together and forming the spinal nerve (Figure 3.10). Spinal nerve rami include the dorsal primary nerves (ramus), which innervates the skin and muscles of the back, and the ventral primary nerves (ramus), which innervates the ventral lateral muscles and skin of the trunk, extremities and visceral organs. The ventral and dorsal roots also provide the anchorage and fixation of the spinal cord to the vertebral cauda.

### 3.13 Blood Supply of the Spinal Cord

The arterial blood supply to the spinal cord in the upper cervical regions is derived from two branches of the vertebral arteries, the anterior spinal artery and the posterior spinal arteries (Figure 3.12). At the level of medulla, the paired anterior spinal arteries join to form a single artery that lies in the anterior median fissure of the spinal cord. The posterior spinal arteries are paired and form an anastomotic chain over the posterior aspect of the spinal cord. A plexus of small arteries, the arterial vasocorona, on the surface of the cord constitutes an anastomotic connection between the anterior and posterior spinal arteries. This arrangement provides uninterrupted blood supplies along the entire length of the spinal cord.

Figure 3.12  
The spinal cord arterial circulation.

At spinal cord regions below upper cervical levels, the anterior and posterior spinal arteries narrow and form an anastomotic network with radicular arteries. The radicular arteries are branches of the cervical, trunk, intercostal & iliac arteries. The radicular arteries supply most of the lower levels of the spinal cord. There are approximately 6 to 8 pairs of radicular arteries supplying the anterior and posterior spinal cord (Figure 3.12).

## Test Your Knowledge

Question 1

A

B

C

D

E

The spinal cord...

- A. Occupies the lumbar cistern
- B. Has twelve (12) cervical segments
- C. Contains the cell bodies of postganglionic sympathetic efferent neurons
- D. Ends at the conus medullaris

**E. Has no arachnoid membrane**

Question 2

A

B

C

D

E

Which of the following tracts crosses at the spinal cord level of entry?

- A. Corticospinal
- B. Ventral spinothalamic
- C. Ventral spinocerebellar
- D. Anterior spinocerebellar
- E. Dorsal spinocerebellar

Question 3

A

B

C

D

E

The blood supply for the corticospinal tract is derived from the:

- A. Vertebral arteries
- B. Posterior spinal arteries
- C. Anterior spinal artery
- D. Basilar artery
- E. Posterior communicating artery

Question 4

A

B

C

D

E

In the laminar somatopic organization of the dorsal columns, the most lateral fibers represent:

- A. Sacral region
- B. Thoracic region
- C. Lumbar region
- D. Cervical region
- E. Coccygeal region

Question 5

A

B

C

D

E

Syringomyelia syndrome occurs with selective spinal lesions in the:

- A. Dorsal root ganglia
- B. Fibers decussating in the spinal white commissure
- C. Fibers of the anterior spinal thalamic tract
- D. Ventral root ganglia
- E. Fibers of the dorsal spinocerebellar tract

Question 6

A

B

C

D

E

Spinal root neurons are:

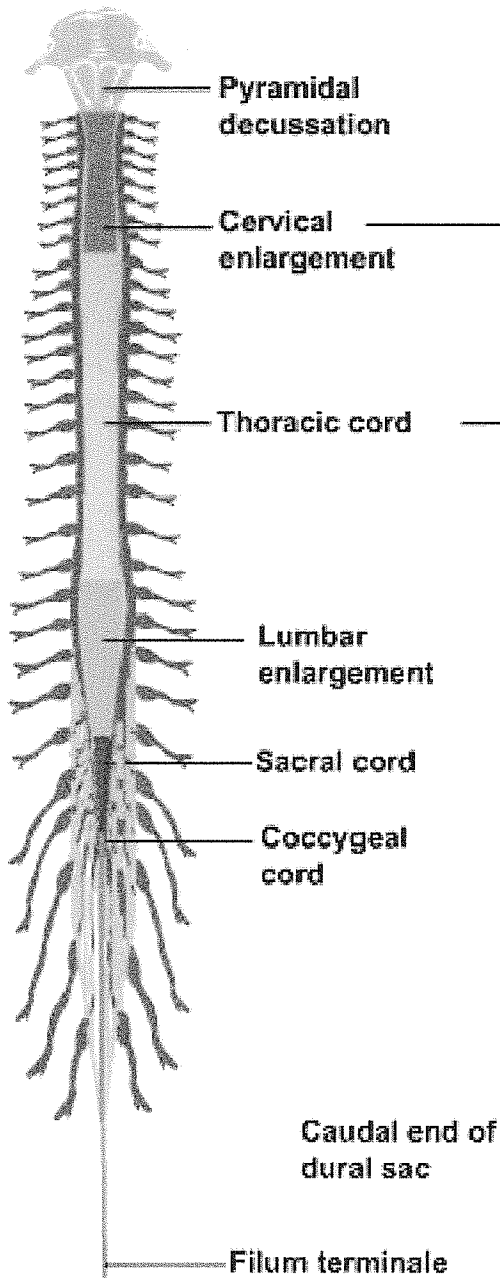
- A. Neurons in the laminae II
- B. Motor neurons
- C. Somatic efferent neurons
- D. Internuncial neurons
- E. Commissural neurons



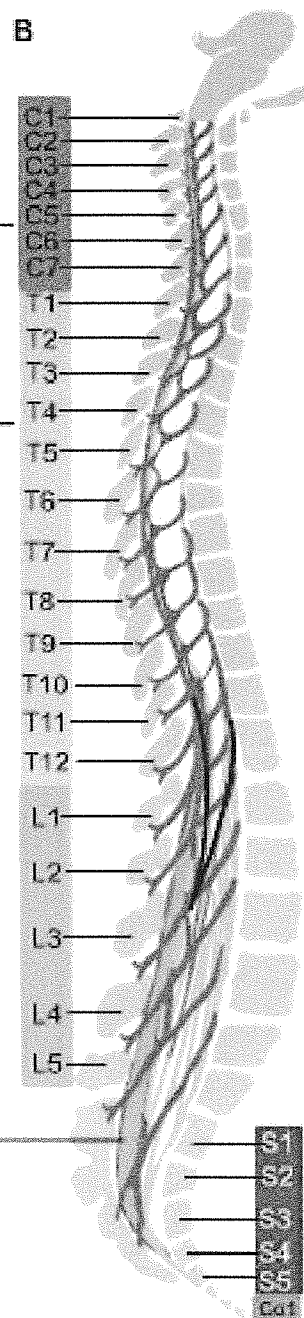
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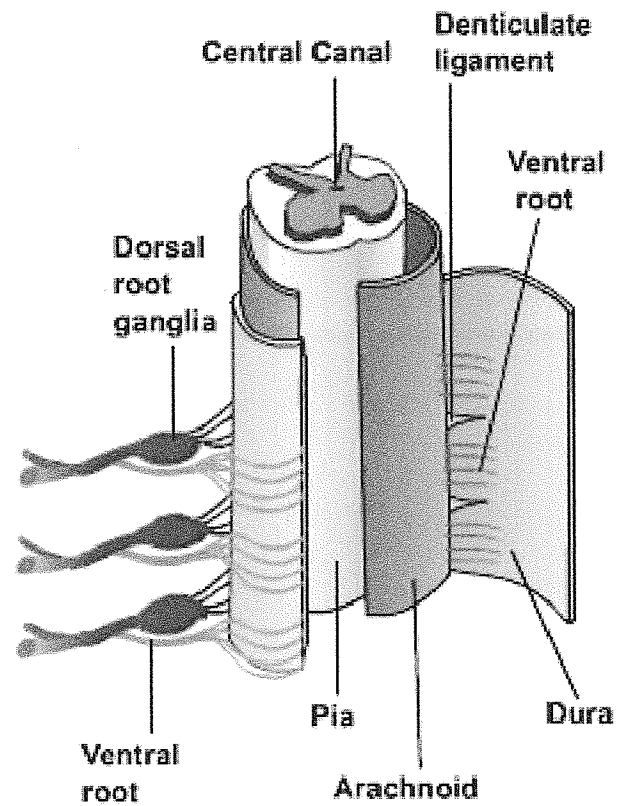
A



B



C

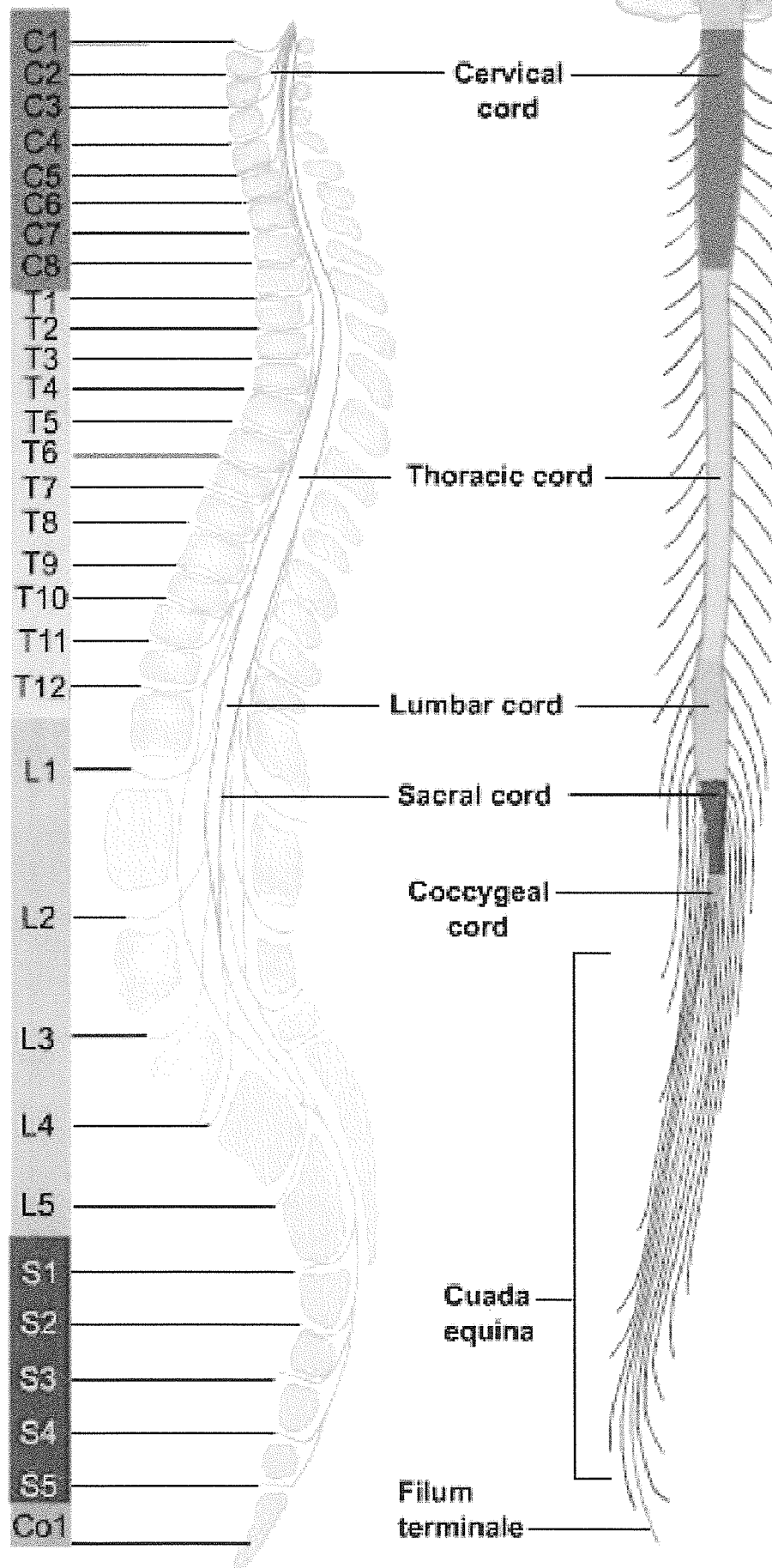


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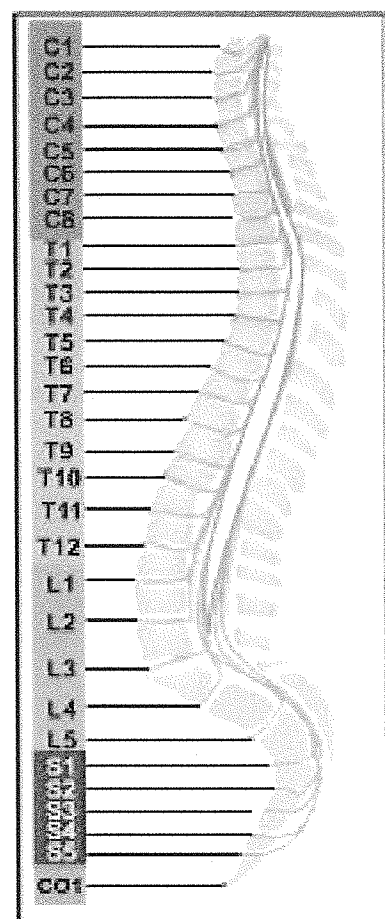
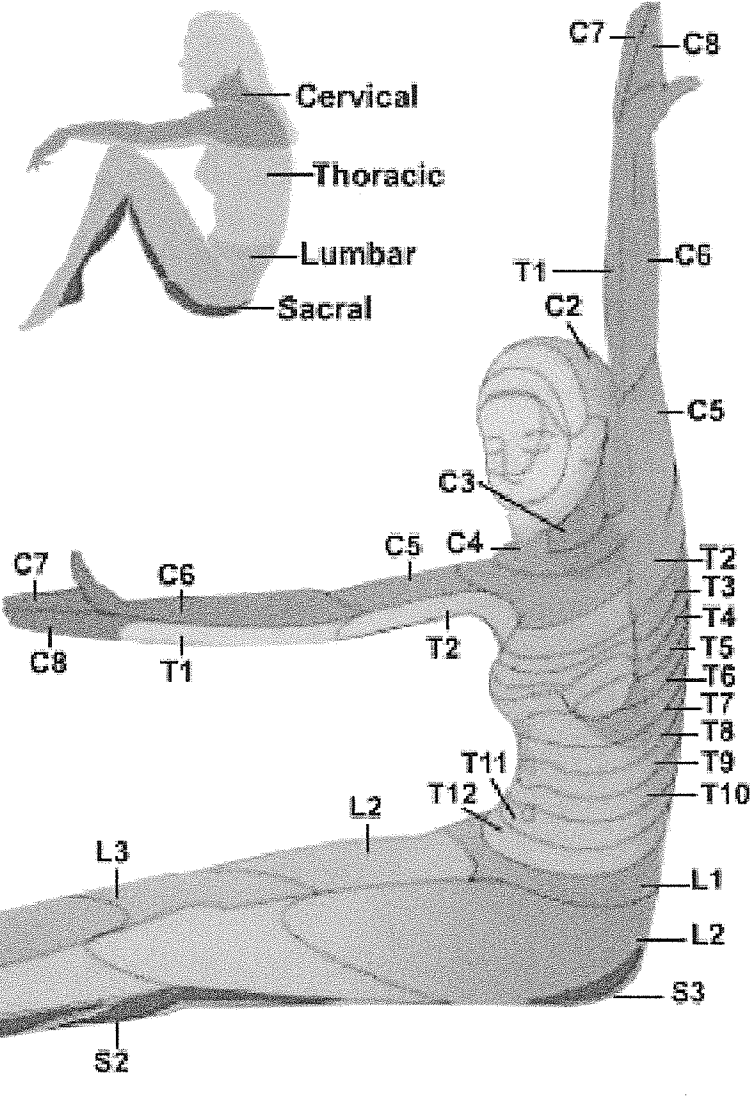
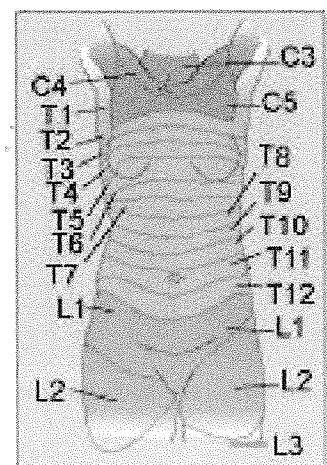
FIGURE 3.4

FIGURE 3.2

**Spinal Nerves**







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FIGURE 3-5