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SPINAL ANATOMY

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1. The Vertebral Column as a Whole

The vertebral column is situated in the median line, as the posterior part of the trunk. It *(backbone)* consists of a series of 26 individual irregular bones called vertebrae, separated by fibrocartilaginous intervertebral discs and are secured to each other by interlocking processes and binding ligaments. There are 7 **cervical,** 12 **thoracic,** 5 **lumbar,** 5 fused **sacral,** and 4-5 fused **coccygeal vertebrae** [1-8]**.** The vertebrae in the upper three regions of the column are known as true or movable vertebrae. Vertebrae enclose and protect the spinal cord, support the head and upper extremities while permitting freedom of movement, articulate with the rib cage, and provide for the attachment of various muscles and visceral organs [5,9,10]. The fibrocartilaginous intervertebral discs lend flexibility to the vertebral column and absorb vertical shock. This structural arrangement permits limited movement between adjacent vertebrae but extensive movement for the vertebral column. The lateral opening windows between the vertebrae are called *intervertebral foramina* that allow passage of spinal nerves [10,11].

The vertebral column contains several important anatomical curves. Viewed laterally, the **cervical, thoracic, lumbar curves** are designated by the type of vertebrae they include (Figure 1). The **cervical curve** begins from apex of the odontoid process, continues to the middle of the second thoracic vertebra. The **thoracic curve** begins from middle of the 2nd vertebra and continues to the middle of the 12th thoracic vertebra. The **lumbar curve** begins at the middle of the last thoracic vertebra, ends at the sacrovertebral angle. The **pelvic curve** *(sacral curve)* is formed by the shape of the sacrum and coccyx. The curves play an important functional role in increasing the strength and maintaining the balance of the upper part of the body. These spinal curves also make possible a bipedal stance. The four vertebral curves are not present in an infant. First, the cervical curve begins to develop at about 3-4 months. The lumbar curve develops as a child begins to walk. The vertebral canal follows the different curves of the column [3,5,6,10-12].

2. General Characteristics of Vertebrae

The vertebrae are similar in their general characteristics from one region to another. A **typical vertebra** consists of two essential parts, an anterior segment, drumshaped **body,** and a posterior part, the **vertebral** or **neural arch.** These formed the **vertebral foramen,** through which the spinal cord passes**.** The vertebral arch consists of two supporting **pedicles** and two arched **laminae.** Seven processes arise from the vertebral arch of a typical vertebrae: one **spinous process,** two **transverse processes,** four **articular processes** [4,8,10] (Figure 2)**.**

Between the pedicles of adjacent vertebrae are the **intervertebral foramina,** one on either side, for the transmission of the spinal nerves and vessels [4,8,10].

The **body (***corpus vertebræ***)** is the largest part of a vertebra. Its upper and lower surfaces give attachment to the intervertebral fibrocartilages. The **pedicles (***radices arci vertebræ***)** are two short, thick processes, which project backward, one on either side, from the upper part of the body. The **laminae** are two broad plates directed backward and medially away
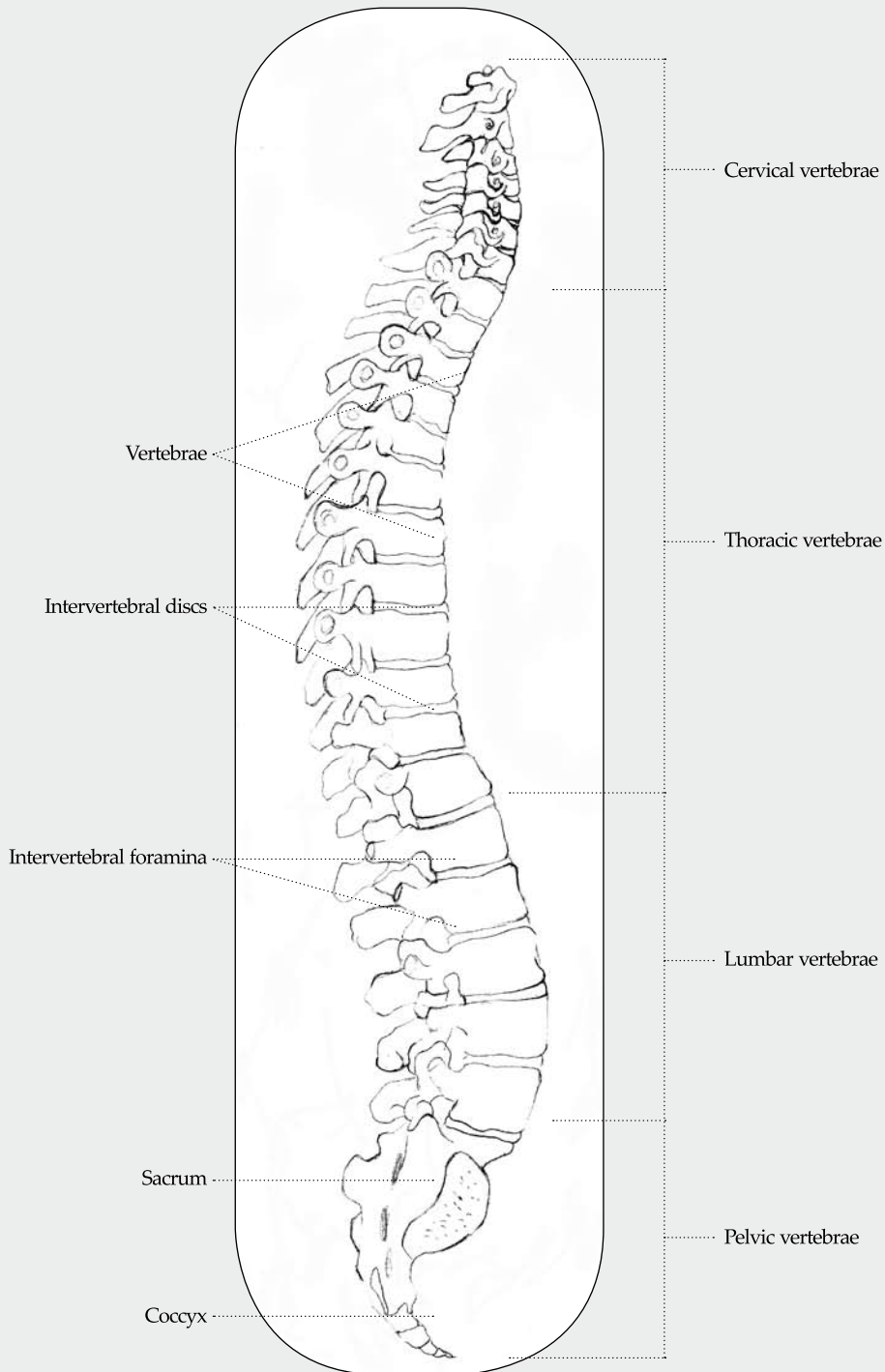
Figure 1:
Vertebral Column (lateral view).

Cervical vertebrae

Thoracic vertebrae

Vertebrae

Intervertebral discs

Lumbar vertebrae

Intervertebral foramina

Sacrum

Pelvic vertebrae

Coccyx

from the pedicles. Their upper borders and the lower parts of their anterior surfaces are rough for the attachment of the ligamenta flava. The spinous process (*processus spinosus*) protrudes backward and downward from the vertebral arch. The transverse processes (*processus transversi*) extend laterally from each side of a vertebra at the point where the lamina joins the pedicle. The spinous process and transverse processes serve for the attachment of muscles and ligaments. The two superior and two inferior articular processes limit twisting and rotational movement of the vertebral column [4,5,8,10,12].

3. Regional Characteristics of Vertebrae

3.a. Cervical Vertebrae *(Vertebrae Cervicales)*

The bone tissue of cervical vertebrae is more dense than that found in the other vertebral regions, and the cervical vertebrae are the smallest of the true vertebrae. The seven cervical vertebrae support the head. Cervical vertebrae are distinguished from those of the thoracic or lumbar regions by the presence of a **transverse foramen** *(foramen transversarium)* in each transverse process. The vertebral arteries, veins and a plexus of sympathetic nerves pass through this opening in the upper six vertebrae. Cervical vertebrae *(C2–C6)* generally have a short and bifid, the two divisions being often of unequal size, spinous process. The bifid spinous processes increase the surface area for attachment of the nuchal ligament *(ligamentum nuchæ)*. The first cervical vertebra *(atlas)* has no spinous process, is ring-like in nature, and consists of an anterior and a posterior arch. The spinous process of 7th cervical vertebra *(vertebra prominens)* is not bifid and is more prominent than those of the other cervical vertebrae. The atlas has no body, but it does have a rudimentary spinous

process called the **posterior tubercule.** The tiny size of this process prevents any interference with movements between atlas and skull. It also has cupped **superior articular surfaces** that articulate with the oval condyles of the occipital bone, and are importantly adapted to the nodding movements of the head. The second cervical vertebra is named the **axis** *(C2)*. It forms the pivot upon which the atlas rotates. It also has a strong **odontoid process** which rises perpendicularly from the upper surface of the body that aids in the rotation with the atlas allowing for the movement of the head from side to side [4,5,8,10,12].

3.b. Thoracic Vertebrae *(Vertebrae Thoracales)*

Thoracic vertebrae are intermediate in size between those of the cervical and lumbar regions and articulate with the ribs to form the posterior anchor of the rib cage. The twelve thoracic vertebrae are larger than the cervical vertebrae and increase in size from cranial to caudal, the upper vertebrae being much smaller than those in the lower part of the region. They have facet joints on the posterolateral sides of the bodies for articulation with the heads of the ribs. The tubercles of the ribs also articulates with the transverse processes of the vertebra. The 11th and 12th thoracic vertebrae have articulation area with the ribs on the transverse processes. Thoracic vertebrae
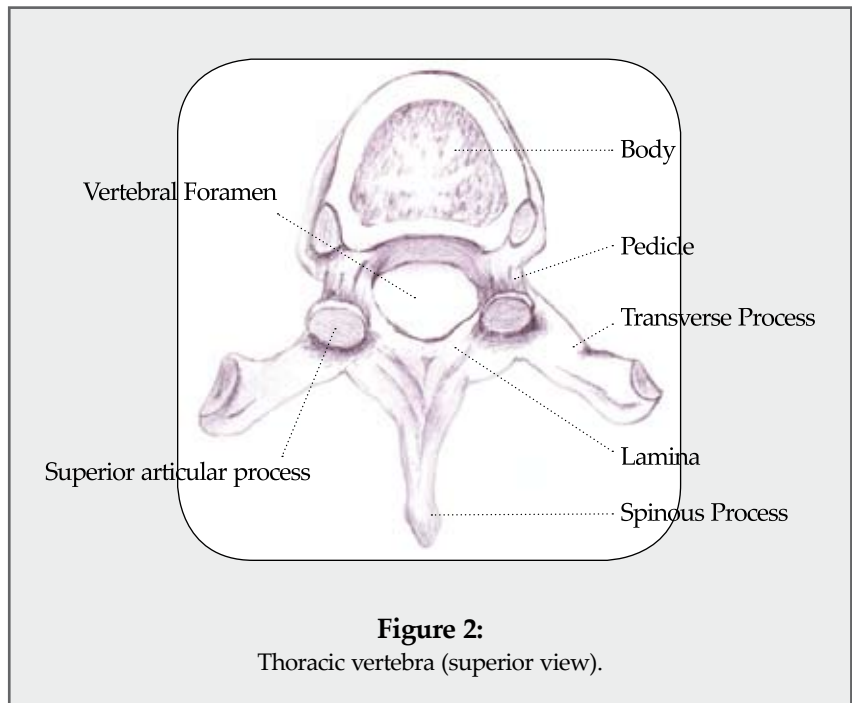

Figure 2:
Thoracic vertebra (superior view).

have a long spinous process that is directed obliquely downward. The **bodies** of the thoracic vertebrae resemble respectively those of the cervical and lumbar vertebrae at the ends of the thoracic region. They are heart-shaped in the middle of the thoracic region [4,5,8,10,12].

3.c. Lumbar Vertebrae *(Vertebrae Lumbales)*

The five lumbar vertebrae are the largest segments of the movable part of the vertebral column, and easily identified by their heavy bodies, the absence of a foramen in the transverse process and thick, blunt spinous processes. Their articular processes are also distinctive in that the facet articulation surface of the superior articular processes project dorsally and medially and the facet articulation surface of the inferior articular processes are directed forward and laterally [4,5,8,10,12].

3.d. Sacrum *(os sacrum)*

The sacrum is a large, triangular bone, situated in the lower part of the vertebral column and provides a strong foundation for the pelvic girdle. It consists of five sacral vertebrae which are united in the adult. The sacrum has an ear-shaped, extensive **auricular surface** on each lateral side for the formation of a **sacroiliac joint** with the ilium. A **middle sacral crest *(crista sacralis mediana)*** is formed along the posterior surface *(facies dorsalis)* by the fusion of the rudimentary spinous processes. Lateral to the articular processes are the four **posterior sacral foramina that arise** on either side of the crest and allow for the passage of the posterior divisions of the sacral nerves from the spinal cord. The **sacral canal *(canalis sacralis)*** is the triangular cavity within the sacrum that is continuous with the vertebral canal. Paired **superior articular processes** are oval, concave, and directed dorsally and medially. They articulate with the 5th lumbar vertebra, occur from the roughened **sacral tuberosity** along the lateral surface. The smooth, concave anterior surface *(facies pelvina)* of the sacrum forms the posterior surface of the pelvic cavity. Its middle part is crossed by four **transverse ridges** denoting the fusion of the vertebral bodies. At the ends of the ridges are the paired **anterior sacral foramina.** The anterior and upper margin of the anterior surface of the sacrum, is known as the **sacral promontory,** is an important obstetric landmark for pelvic measurements [4,5,8,10,12].

3.e. Coccyx

The triangular coccyx *(tailbone)* consists of three to five fused rudimentary vertebrae. The first and largest **coccygeal** vertebra commonly is not fused with the second vertebra. It has two long **coccygeal cornua,** which are attached by ligaments to the lower end of the sacrum [4,5,8,10,12].

4. Spinal Cord (Medulla Spinalis)

Spinal cord which is the part of central nervous system *(CNS)* lies within the vertebral canal. Its average length is 42-45 cm, its diameter 1 cm, its weight 30 g and it constitutes 2% of the CNS. Spinal cord extends from the upper border of atlas to the lower border of first lumbar (L_1) vertebra in males, to the middle level of second lumbar (L_2) vertebra in females. It may extend to the lower border of third lumbar (L_3) vertebra in newborns. It is continuous rostrally with the medulla oblongata and caudally with the filum terminale [1,2,7].

The spinal cord is enclosed by vertebral column, periosteum, fat and connective tissue, dura mater, arachnoid mater and pia mater. These three membranes are continuous with the cranial meninges. The space between periosteum and spinal dura mater is called *epidural space (cavum epidurale)* and, similarly, the space between spinal dura mater and spinal arachnoid mater is called *subdural space (cavum subdurale)* and merely being potential. The *subarachnoid space (cavum subarachnoidea)* lies between spinal arachnoid mater and spinal pia mater and it contains cerebrospinal fluid *(CSF)*. This anatomy is of clinical relevance because the lumbar cistern (at locations below the conus medullaris) can be used as a site of lumbar puncture and sampling of the CSF [2,7,9,10] (Figure 3).

Vertebral column: It consists of 33-34 vertebras *(7 cervical, 12 thoracic, 5 lumbar, 5 sacral, 4-5 coccygeal)* which are united by 23 intervertebral discs. Its average length is 70 cm in males and 60 cm in females. Spinal cord lies in the vertebral canal which is located in the middle of vertebral column [5,10,12].

Spinal dura mater: It extends from foramen magnum to the second sacral vertebra. Spinal cord is enclosed in a tube shaped dura mater. The lower end descends to the coccyx forming a fibrous band *(coccygeal ligament)* [1,2,7].

Spinal arachnoid mater: It lies deep to spinal dura mater and extends to the S_2 vertebra [1,2,7].

Spinal pia mater: It is firmly united to the surface of spinal cord and continuous with the cranial pia mater. It divides into two layers called *lamina externa* and *lamina interna*. The lamina interna closely invests the spinal cord. The lamina externa forms the *denticulate ligaments* which lie on each side of spinal cord and connect the spinal cord with the dura mater. It has bow shaped recesses at the levels of the spinal nevre roots. There are 21 pairs of denticulate ligaments. They protect the spinal cord during movement by connecting it to the dura mater [1,2,7].

4.a. External Features

The spinal cord is divided into five parts, namely cervical, thoracic, lumbar, sacral and coccygeal. There is an enlargement each in cervical and lumbosacral parts. Cervical enlargement *(intumescentia cervicalis)* is located between C_3 and Th_2 vertebrae. Lumbosacral enlargement *(intumescentia lumbosacralis)* extends from Th_{9-10} to L_{1-2} vertebrae. Spinal nerves *(brachial and lumbosacral plexus)* which emerge from these enlargements innervate upper and lower extremities. The cervical enlargement is 38 mm and the lumbosacral enlargement is 35 mm width [1,2,7,9,10].

The lower termination of spinal cord is called the *conus medullaris* due to its shape which resembles a cone. The enlargement of the central canal at the end of the conus medullaris is called *terminal ventricle (ventriculus terminalis)*. The structure which descends from the apex of conus medullaris and attaches to the base of coccyx is called *filum terminale*. It consists of spinal pia mater superficially and neuroglial elements which lie deep to the pia mater. Its average length is 20 cm and the part which extends to the S_2 vertebra is enclosed in spinal dura mater *(filum terminale internum, piale)*. The central canal is continued into filum for 5-6 mm. A capacious part of subarachnoidal space surrounds the filum terminale

internum; it is site of election for spinal *(lumbar)* puncture. The part which lies distal to this level fuses with investing dura mater *(coccygeal ligament)* and is called *filum terminale externum*. Since the spinal cord ends at the level of L_1 vertebra, nerve roots below this level descend as a collection of fibers *(approximately 10-23 cm)* before passing through intervertebral foramina. This structure resembles a horse tail and therefore it is called *cauda equina* [1,2,7,9,10].

The parenchymal tissue of the spinal cord has four primary aspects. *Anterior median fissure* is deep longitudinal fissure *(average depth is 3 mm)* along to the anterior aspect. *Posterior median sulcus* and *posterior median septum* which is a continuation of the posterior median sulcus is present in the posterior aspect of spinal cord. Two structures seperate the spinal cord into right and left halves. Also there are two sulci in each half, one of them is the *anterolateral sulcus (shallow furrow occasionally present)* and the other is *posterolateral sulcus*. Ventral roots of spinal nerves *(radix anterior)* emerge from anterolateral sulcus and dorsal roots of spinal nerves *(it is strictly rootlets and called radix posterior)* enter the cord along the posterolateral sulcus. The anterolateral sulcus and the posterolateral sulcus divide each half of the spinal cord into three parts which are *anterior funiculus*, *lateral funiculus* and *posterior funiculus* [1,2,7,9,10].

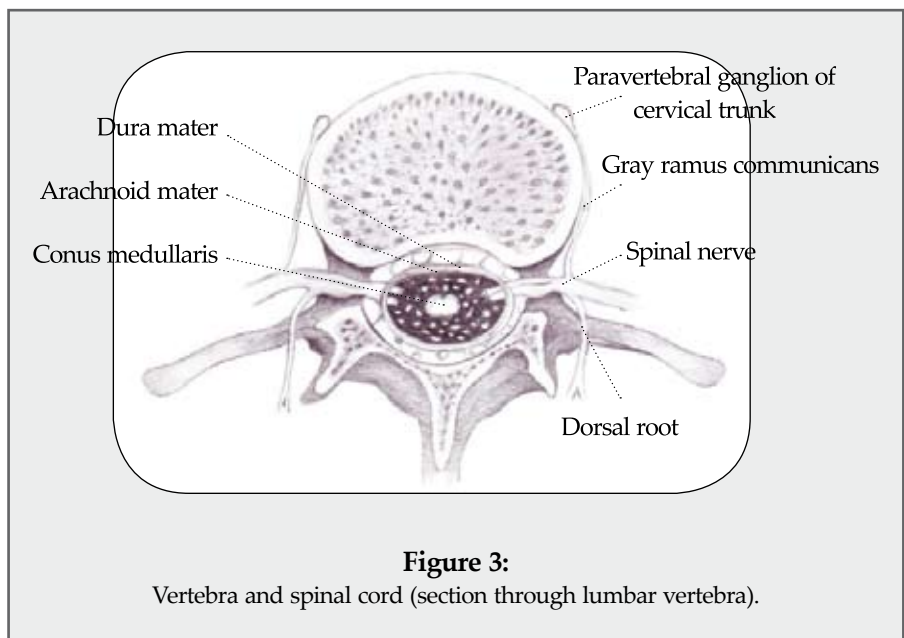There is a third sulcus, *posterior intermediate sulcus*, which extends rostrally along the posterior aspect of

Figure 3:
Vertebra and spinal cord (section through lumbar vertebra).

Labels: Dura mater, Arachnoid mater, Conus medullaris, Paravertebral ganglion of cervical trunk, Gray ramus communicans, Spinal nerve, Dorsal root

spinal cord and it is seen in the cervical and upper thoracic segments. It divides the area between posterolateral sulcus and posterior median sulcus into two parts which are fasciculus gracilis *(medial)* and fasciculus cuneatus *(lateral)* [1,2,7,9,10].

We mentioned above that sensorial fibers enter the spinal cord via the *radix posterior (sensoria)* and motor fibers emerge from *radix anterior (motoria).* Both of the roots unite in the intervertebral foramen to form *spinal nerve*. There are 31 pairs of spinal nerves. They are named according to the level where they leave the intervertebral foramen. The region of spinal cord associated with the emergence of a pair of spinal nerves is called a *spinal segment*. There are 8 cervical, 12 thoracic, 5 lumbar, 5 sacral and 1 *(or 3)* coccygeal segments [1,2,7,9,10].

Spinal nerve: It is approximately 2-2.5 cm long and contains mixed type fibers. It divides into ventral *(anterior ramus)* and dorsal *(posterior ramus)* branches just after leaving the intervertebral foramen. Ventral branches are larger and connect to form plexuses. Dorsal branches are smaller and innervate the muscles of the posterior regions of the back and additionally to the cutaneous areas associated with this musculature [1,2,7].

Spinal ganglion: It is a group of neurons where sensorial fibers in the spinal nerve make synapses in radix posterior [1,2,7].

4.b. Internal Structure

Spinal cord consists of the outside myelin-rich white matter *(substantia alba)* and inside myelin-poor gray matter *(substantia grisea).*

White matter *(substantia alba)*: It contains glia cells and myelinated nerve fibers which are also called a tractus or fasciculus. It completely surrounds the gray matter and contains nerve pathways. The area between anterior median fissure and anterior horn is called *funiculus anterior. Funiculus posterior* is situated between the posterior horn and posterior median septum [1,2,7,10].

The area between ventral and dorsal horns is called *funiculus lateralis.* Anterior white commissure *(commissura alba anterior)* and posterior white commissure *(commissura alba posterior)* connect the left and right white matter [1,2,7,10].

Gray matter *(substantia grisea)*: This contains neuronal cell bodies and dendrites. In transverse sections, it is butterfly or H shaped and has a ventral projection called the *cornu anterior* and a dorsal projection called the *cornu posterior* on each side. The two horns lie throughout the spinal cord and form *gray collumns* [1,2,7,10].

Ventral horns *(or ventral gray column)* are the site of origin of somatomotor fibers. Dorsal horns *(or dorsal gray column)* are the place where sensorial fibers form synaptic connections. A mass of gray matter which is called *pars intermedia* connects dorsal and ventral horns. Anterior and posterior gray commissures connect pars intermedia of left and right sides [1,2,7,10] (Figure 4).

A lateral horn *(or lateral gray column)* is present between Th_1 and $L_{2(3)}$ spinal segments. This lateral horn *(columna intermediolateralis)* consists of 14 segments and it is the site of origin of sympathetic fibers. First 4 segments are called *centrum ciliospinale (center of Budge)* and it is the site of origin of the sympathetic fibers innervating the structures in the neck and above this level [1,2,7,10].

In the centre of the spinal gray matter, a canal which is called *central canal* extends along the spinal cord. It contains cerebrospinal fluid *(CSF)* and originates as a continuation of 4th ventricle and, rostrally, it extends into the filum terminale and terminates after a course of 5-6 mm. It is oblitered remains of the embryonic neural tube lumen [1,2,7,10].

Substantia geletinosa centralis is a narrow zone around the central canal with processes from ependymal cells. *Anterolateral nucleus* is situated anterolaterally in the anterior horn. It is localized in segments C_{4-8} and L_2-S_1 and innervates the muscle of the limbs [1,2,7,10].

Spinal laminae (Rexed's laminae): The spinal gray matter is divided into 10 laminae on the basis of neuronal size, shape and density. These laminae, with poorly defined boundaries, are numbered dorsoventrally using roman numerals. Their clinical relevance has not yet been well articulated or defined.

Spinal lamina I: Marginal nucleus.

Spinal lamina II: Gelatinous substance *(substantia gelatinosa)*. It is glassy substance above the apex of the posterior horn. It consist primarily of glia and small ganglion cells.

Spinal lamina III-IV: Nucleus proprius. These four laminae contain synapses of cutaneous sensorial fibers.

Spinal lamina V-VI: They contain synapses of proprioceptive afferent fibers and fibers from motor cortex. They play a role in movement regulation.

Spinal lamina VII: It has connections with mesencephalon and cerebellum. It is involved in the regulation of posture. There are also sympathetic *(nuc. intermediolateralis, nuc. intermediomedialis, nuc. thoracicus posterior)* and parasympathetic *(nuc. parasympathici sacrales)* nuclei located in this lamina.

Spinal lamina VIII: It contains interneurons. It connects with especially neurons in the ventral horn *(Lamina IX).*

Spinal lamina IX: It contains alpha motor neurons and which innervate skeletal muscles, gama motor neurons which innervate intrafusal muscle fibers and interneurons.

Spinal lamina X: A part of sensorial fibers form synapses here [1,2,7,9,10].

There are three kinds of cells in gray matter:

a) *Funicular cells:* These are afferent *(receptor)* cells which extend from gray matter to white matter.

b) *Radicular cells:* These are efferent cells which extend to spinal nerves.

Renshaw cells: They are located in the ventral horn and depending on the aim of movement. They regulate the number of muscle fibers which are to take part in the movement.

c) *Inner cells:* They do not extend out of the gray matter and they form connections between neurons.

- Association cells: They lie sagitally in the same segment.

- Comissural cells: They lie transversally in the same segment and connect the gray matters of each side.

- Projection cells: They lie vertically and extend to other segments [1,2,7].

4.c. Vessels

Arteries: The spinal cord is mainly supplied from spinal branch of vertebral, deep cervical, intercostals and lumbar arteries. These arteries form longitudinal channel along the spinal cord [1,2,7,10].

Vertebral artery: It is the largest branch of subclavian artery and it originates from the initial portion of the artery. It courses upwards through the foramen transversarium above the C_6 vertebra and enters the cranium through the foramen magnum. Two of its branches are related to the spinal cord:

1- Anterior spinal artery: It is formed by the fusion of two trunks which originate from vertebral arteries just before they join to form basilar artery. It descends in the anterior median fissure and extends to the conus medullaris. It supplies the anterior 2/3 of the spinal cord [1,2,7,10].

2- Posterior spinal arteries: It is formed by the posterior branches of vertebral arteries at the level of medulla oblongata. Unlike the anterior spinal artery, it descends as two seperate trunks along the posterior surface of the cord. It supplies the posterior 1/3 of the spinal cord [1,2,7,9,10].

Spinal branches (rr. spinales): They originate from neighboring arteries (*a. cervicalis ascendens, a. cervicalis profunda, aa. intercostales posteriores, aa. lumbales ve a. sacralis lateralis*). These segmental arteries enter the vertebral canal through the intervertebral foramina and then divide into peripheral and neural branches. The neural branch pierces the spinal dura mater and
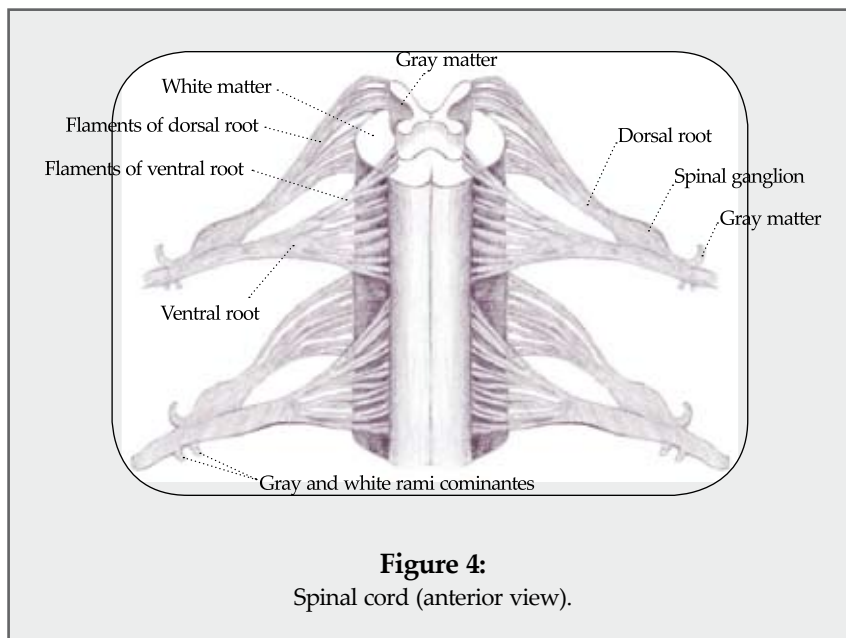

Figure 4:
Spinal cord (anterior view).

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divides into anterior *(rr. radiculares anterior)* and posterior radicular *(rr. radiculares posterior)* which follow the nerve roots. The posterior radicular arteries supply the dorsal root ganglion. These terminal branches anastomose with anterior and posterior spinal arteries and form a vascular plexus called *arterial vasocorona* [1,2,7,9,10].

Veins: Spinal veins drain into six tortuous longitudinal channels. They run along the arteries and also connect together freely and form a venous plexus called *venous vasocorona*. These drain into the epidural venous plexus via anterior and posterior radicular veins. Epidural venous plexus *(plexus venosus vertebralis externus anterior at posterior)* joins with vertebral vein, sigmoid sinus and occipital sinus at the level of foramen magnum [1,2,7,9,10].

4.d. Functions

1- To transmit all sensory information *(except cranial nerves)* coming from the body.

2- To transmit the somatomotor stimuli coming from encephalon to target organs.

3- To provide autonomic innervation.

4- Reflex responses: The stimuli which are generated at the receptors in muscles, joints or skin are processed in the spinal cord without transmission to higher levels control and the motor response which is activated as a result of this is called spinal reflex. It may be either monosynaptic or polysynaptic depending on the number of interneurons involved [1,2,7,9,10].

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