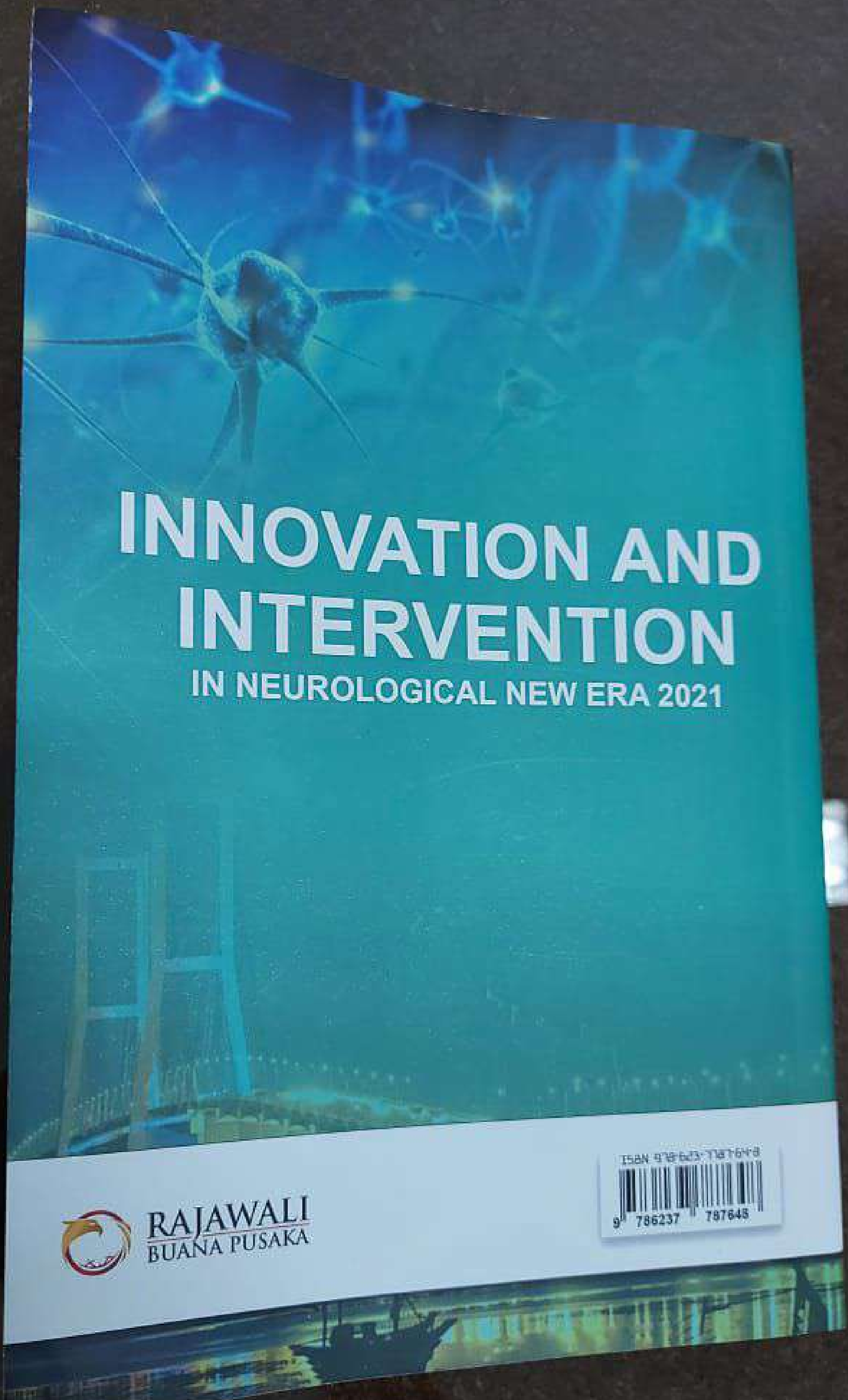
INNOVATION AND
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# Daftar Isi

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# Functional Neurovascular Anatomy Of The Spinal Cord

*Viskasari P. Kalanjati*

## INTRODUCTION

Spinal cord (*medulla spinalis*) is the caudal, elongated and cylindrical part of the central nervous system (CNS), which is resided at the vertebral canal; this structure extends from the medulla oblongata cranially to the conus medullaris caudally. Until the 3rd month of fetus occupies entire vertebral canal, thereafter the vertebral column grows faster, thus the caudal end of the cord is ± reaching the LIII at birth, and at LI-LII in adult, thus cervical cord segments are located ± 1 spine higher than the corresponding vertebrae, thoracic ± 2 spines higher, lumbar 3-4 spines higher. A segmental structure (metameric) is formed from rostral to caudal (C1-C8, T1-T12, L1-L5, S1-S5 and Co-metameres). The spinal cord approximately has a cylindrical shape, with 2 enlargements/ intumescentia; C5-T1 (maximum at C6 ± 38 mm) and L1-S3 (maximum at S1 ±35 mm wide); from conus medullaris at the caudal tip is the filum terminale attached to the dorsal surface of coccyx, the lumbo-sacral radix form a cluster of cauda equina that resides at the caudal part of the spinal canal.[1-3]

The spinal cord is covered by a pachymeninx (serous layer of duramater, with subdural space at the deeper side and epidural space at the superficial layer contains fat and plexus venosus) and 2 leptomeninx (arachnoidmater and piamater, with subarahnoid space filled with CSF in between and ended at S2). The denticula ligaments at the departure point of adjacent posterior and anter radices resided at the lateral side serve to lay the spinal cord in middle of the subarachnoid space.[4-6]

## DISCUSSION

### General Anatomy of The Spinal Cord

The *medulla spinalis* is the structure where sensory, motor a autonomic innervation for the trunk and limbs are controlled coordinated; it has a central core of *substantia griseus*, predomin composed of nerve cell bodies, and a superficial layer of substa alba mainly contins the nerve fibres e.g. Cornu dorsalis of the su stantia griseus mostly contains sensory neurons whereas the corn ventralis mainly contains motor neurons; and the cornu latera contains the preganglionic sympathetic neurons of the autono nervous system. The cornu dorsalis is the primary location of p mary afferent fibres terminal. This includes the substantia gela nosa (Rexed's laminae I-III), which is vital in the transmission nociceptive impulses to the encephalon. The neurones of the co nu lateralis contain preganglionic sympathetic cells, as the corn ventralis contains alpha and gamma motor neurons as parts of lower motor neurones (LMN) of the peripheral nervous system. the columna of the spinal cord runs the ascending and descendi tracts, which connect the spinal cord with the encephalon. The ma sensory-ascendens tracts are the dorsal columns, the spinothala tracts and the spinocerebellar tracts; whilst the corticospinal trac a pyramidal motor-descendens tract.[5,7-9]

The tip of the cornu dorsalis is where the Rexed's laminae I-I located and are also named substantia gelatinosa that receives m elinated (group Aδ) and unmyelinated (group C) afferents lin to the nociceptive sensory predominantly using the glutamate neurotransmitter and substance-P. A complex inter-connection tween different diameter of afferents fibres of the spinothalamic spinoreticular tracts with the inetrneurones and the fibres of descending tracts may overlap the impulses from one another th rubbing a sore spot may relieve the nociceptive pain. High le



of endogenous opioid peptide i.e. enkephalin which may decreases release of Substance P is also secreted in these areas (Gate Control Theory of pain) (figure 1). The lamina VII of C8–L3 mainly contains the cells of Clarke's column (thoracic nucleus, nucleus dorsalis), which are the origin of the dorsal spinocerebellar tract), the inputs come from e.g. Muscle spindles, Golgi tendon organs, tactile and pressure receptors. This layer also contains the preganglionic sympathetic neurones that form the cornu lateralis (T1-L2), and at S2–S4 contains the preganglionic parasympathetic neurones.[5,7-9]

**Figure 1.** Lamination of the spinal cord horn (Rexed's laminae).[3]

The afferent fibres enter cornu dorsalis via the dorsal roots and divide into ascending and descending branches, mostly ended near the entry point (i.e. cutaneous afferents) but may travel in the dorsolateral fasciculus known as the Lissauer's tract, at the superficial tip; and to the deeper layers. At the cornu ventralis, lamina IX corresponds to groups of motor neurones that innervate skeletal muscle. Two types of motor neurones are the α which innervate extrafusal muscle fibres, and γ-motor neurones, which innervate intrafusal muscle fibres in the muscle spindle. In the cervical and lumbar enlargements that innervate the arms and legs, respectively, these are well developed. Neurones innervating axial musculatures are typically located in the medial and for the appendicular muscles are more lateral. In C3-C5 the nucleus phrenic where motor neurones innervate the diaphragm via N. Phrenicus is resided and vital for respiratory function. This area also receives certain input of dorsal root afferents i.e. from muscle spindles of stretch reflex and from descending pathways for motor control.

**Figure 3.** The segmental levels of the spinal cord and their relations to the verteb

Approximately 75-90% of these fibres will decussate at the de cussatio pyramidalis located at the border between the spinal co and the lower edn of the medulla oblongata; the rest of these fibr will cross at more caudal levels before exiting the spinal cord as th spinal nerves (the lateral *vs.* the ventral corticospinal tracts). Th **rubrospinal tract** controls the flexor muscle groups of the inferi extremities, the fibres comes from the nucleus ruber of the tegmen tum mesencephali whilst decussate at the ventral tegmentum a receives affernes from the motor cortex and neo-cerebellum stru tures as part of extra-pyramidal pathway. The **tectospinal** tra plays role in the visual pathway, fibres will decussate at the dors tegmental decussation and receives inputs from the contralateral the colliculus superior at tectum mesencephali. The **vestibulosp nal tract** descends from the vestibular nuclei at the brainstem, th lateral tract originates from the ipsilateral lateral vestibular nucle and mediates excitation of inferior extensor muscles. The retic



**lospinal tracts** descend from the pons and medulla; involve in the control of reflexes, muscle tone (together with the emboliforme and globose nuclei of the cerebellum), and vital functions (in coordination to the reticular formation nuclei of the brainstem).[3,15-16]

## STRUCTURE OF THE SPINAL CORD BLOOD SUPPLY EMBRYOLOGY

### Vertebral Artery

A marked variation between individuals is shown due to differences in embryonic development (table 1-3). The vertebral arteries start to develop at day 32 to 40 of gestational period which will fuse and shaping longitudinal anastomoses connect the cervical intersegmental arteries (ISA) of the primitive paired dorsal aorta. Later, the 7th ISA remains to form the proximal subclavian artery which branches off vertebral artery. As the juncture of primitive dorsal aorta receded, the vertebral artery shaped as beaded and contortuous anastomoses, and the basilar artery would then be formed by left and right primitive vertebral arteries fusion.[1,3,11]

### Spinal Arteries

Spinal arteries develop from an anterior and posterior segemental artery network of the cord. Two primitive longitudinal systems grow and will fuse as a longitudinal ventral median of anterior spinal artery (ASA), prior to a various regression of segmental alimentary vessels (predominantly in the thoracic and lumbar levels), which is completed by the 4th month of fetal life. Segmental arteries sprouts from the intercostal and lumbar arteries, the radicular arteries represent vital sources reinforce the anterior and posterior spinal arteries. From specific period of neurulation, each cord metamere is supported bilaterally by radicular vessels. These vessels will run in the intervertebral canals as the spinal arteries and penetrate the spinal meninges to follow the nerve roots. They derive from e.g.vertebral, thyrocervical, costocervical, (ascending cervical, deep cervical, ascending pharyngeal), occipital, posterior intercostal, lumbar and lateral sacral vessels.

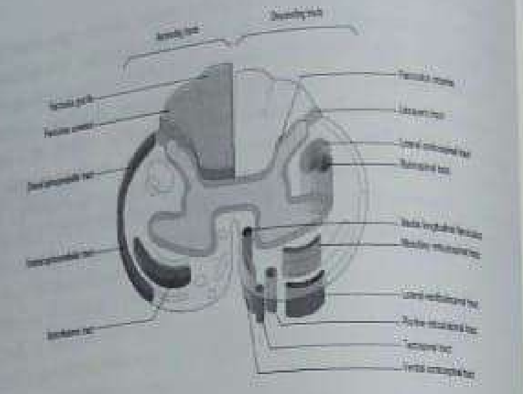


**Figure 2.** The coronal section of the spinal cord showing the ascendens and the descendens tracts of the columna medulla spinalis.[5]

## Nervi Spinales

The 31 pairs of spinal nerves originate from the spinal cord, the ventral and dorsal roots carrying motor and sensory fibres, respectively. The soma of the efferent neurones are in the substantia griseus and the sensory resides in the dorsal root ganglia, the fibres compose the peripheral nervous system run via the foramen intervertebrale. Several traumatic injury of the cord and the nerve roots dislocation, cervical spondylosis (radiating pain, paraesthesia, weakness and wasting muscles, loss of tendon reflexes, accordingly).

### Spinal Reflex

The spinal reflex mediates via the mono- and poly-synaptic pathyways. The monosynaptic stretch reflex produces deep tendon reflexes subserved by specific cord segments i.e. Biceps reflex: C5-C6, brachioradial reflex (supinator jerk): C5-C6, triceps reflex: C6-C7, quadriceps reflex (knee jerk): L3-L4, Achilles tendon reflex (ankle jerk): S1-S2. Also known as the myotatic reflex, this pathway is regulated by gamma motor neurones of the stretched muscle spindle produces muscle contraction to maintain the muscle tone (figure 3). Whilst the polisynaptic flexor and cross extensor reflex mediates limb withdrawal from noxious stimuli.



### Structure of The Funiculus of Medulla Spinalis

In the column of the spinal cord, the ascendens and descendens tracts of sensory and motor nerve fibres run. The ascending tracts carry afferent information to conscious and subconscious levels. The dorsal funiculi composed of fasciculus gracilis and cuneatus serve the proprioceptive and fine touch, where first-order neurones are at the ipsilateral gracilis and cuneatus nuclei, and the second-order neurones decussate and go to the ventroposterolateral and ventroposteromedial nucleus of thalamus before the third-order neurones synapse at Brodmann area 3,1,2 in the somatosensory cortex of the parietal lobe. Tabes dorsalis, vitamin B12 deficiency and other lesions may lead to ataxia and loss of discriminative touch. The spinothalamic tract is another ascending fibre bundle carries pain, temperature, touch and pressure, with second-order neurones in the cornu dorsalis.[5,14-16]

This tract would decussates and pass to the sensory nuclei of thalamus and fibres project at similar ways to the dorsal column tract. Syringomyelia may lead to dissosiative sensory impairment of the spinothalamic tract. **Spinocerebellar tracts**, on the other hand, have a muscle, joint and tactile information involved in extrapyramidal motor control which lesions lead to ataxia (e.g. Friedreich's ataxia) (figure 2).[5,15-16] The descending tracts carry efferent motor outputs; the **corticospinal tract**, for example, controls distinct, trained movements, particularly of the inferior extremities. This tract originates from the pre-centralgyrus of the frontal lobe, and the fibres descend via the capsula interna, crus cerebrimof the mesencephalon, tegmentum pontis to the pyramis of the medulla oblongata.[5,9,16]

Most of these radicular arteries will regress; the remains form anastomoses with ASA dan PSAs. The branches from various arteries formed the radicular arteries, these tributary vessels support the longitudinal artery system of the cord especially for the segments lower than cervical metemeres.[2,3,11]

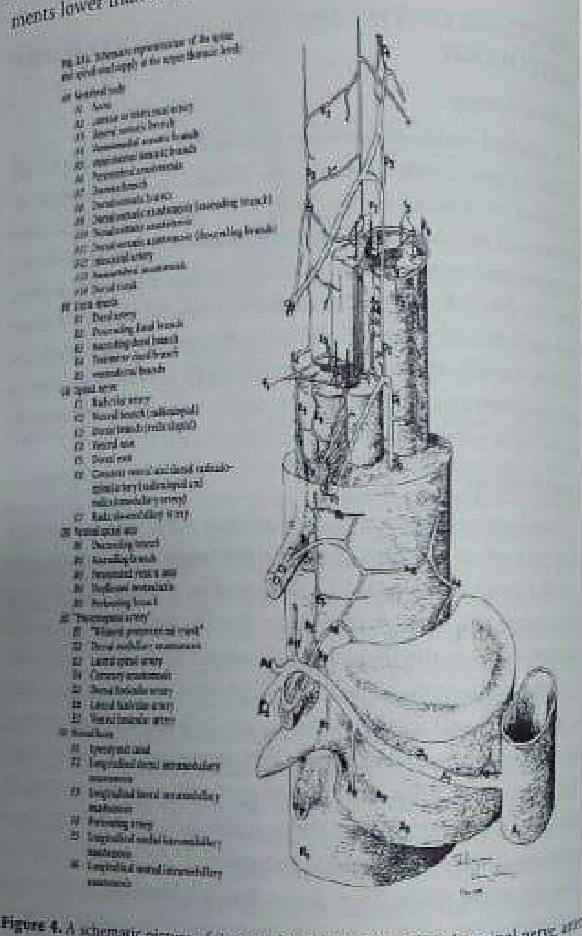
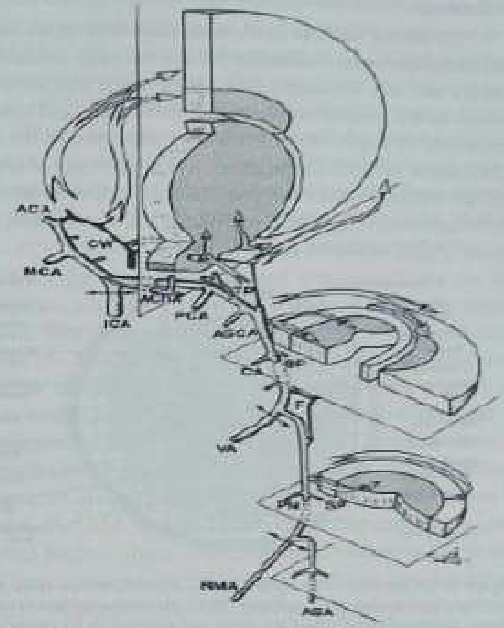


Figure 4. A schematic picture of the vertebral body, dural sheath, spinal nerve, anterior and posterior spinal axis and the cornu dorsalis.[11]




| Vertebral level | Right side, n (%) | Left side, n (%) |
|---|---|---|
| 4th cervical | 3 (1.5) | 1 (0.5) |
| 5th cervical | 13 (6.5) | 35 (7.3) |
| 6th cervical | 179 (89.5) | 179 (87) |
| 7th cervical | 5 (2.5) | 18 (5) |
| Total | 200 | 245 |

**Figure 5.** The structure of arterial supply of the encephalon and the spinal cord shows a rather similar pathways in terms of the anastomoses and fusions, as well as the bifurcations that make the centrifugal appearance surrounding the brain and along the neural tube derivative of the segmental spinal cord (long open curved arrow) (VA: vertebral artery, ASA: anterior spinal artery, RMA: radiculomedullary artery, PN: pial network, CA: circumferential artery, CWA: circulus arteriosus of Willis, F: fusion, ICA: internal carotid artery, ASCA: anterior superior cerebellar artery, ACA: anterior cerebral artery, MCA: middle cerebral artery, PCA: posterior cerebral artery, SP: sulcal perforator artery, BP: basilar perforator artery, TP: Thalamo perforator artery, AchA: anterior choroidal artery). The below table shows variations of the vertebral artery entrance into vertebral canal.[11]

**Table 1.** The arterial supply of the spinal nerves.[11]

| Special nerve root | Peripheral nerves | Source of supply Usual -> to -> unusual |
|---|---|---|
| C1-C2 | Phrenic Nerves | Occipital-vertebral-PICA |
| C3 | | Asc.Pharyngeal-Asc. Cervical-Vertebral |
| C4 | | Asc. Cervical-Vertebral |
| C5 | Brachial Plexus | Asc. Cervical-Vertebral-Costocervical |
| C6 | | Certebral-Costocercical-Asc.cervical |
| C7 | | Costocervical |
| C8 | | Costocervical |
| T1-T2 | | Costocervical-Supreme Intercostal |
| T3-T4-T5 | | Supreme intercostal- costocervical |
| T6-T12 | | Corresponding intercostal |
| L1-L4 | Lumbosacral Plexus and Sciatic Nerve | Corresponding lumbal |
| L5 | | Illiolumbal-middle sacral |
| S1 | | Lateral sacral-illiolumbar-middle sacral |
| S2-S5 | | Lateral sacral |

The posterior spinal arteries (PSAs), which are more redundant than the ASA, form a plexiform network and supply posterior 1/3 of the cord (dorsal horn and columns, with variable supply to the lateral corticospinal tracts). Together with ASA, PSAs run inferior to conus medullaris, where the diameter of ASA is the largest. After passing the conus and filum terminale, these vessels end as a group of rami cruciantes (figure 8).[2,3,11]

**Table 2.** The morphological extrinsic arterial variation of the spinal cord.[11]

| | Cervical | Upper ½ thoracic | Lower ½ thoracic | Lumbo-sacral |
|---|---|---|---|---|
| Radicular arteries | Cervical enlargement | | Thoracic-lumbar enlargement 550-1200μ | |
| | Anterior N= 2-4 | N= 2-3 | | N=0-4 |
| | Posterior N=3-4 | N = 6-9 | | N=0-3 (150-400 μ) |
| Anterior spinal artery | 200-500 μm | Could be discontinued 200-400 μm | | 500-800 μm filum artery |
| Posterolateral spinal artery | 100-200 μm | <250 μm midline posterior spinal artery | 200 μm | 100-400 μm |
| Fenestration duplication | - Frequently >50%<br>- Sulcal artery = pseudo-duplication<br>- Descending sulcal trunk | rare | rare | exceptional |



**Table 3.** The internal arterial supply of the spinal cord.[11]

| | Cervical | Upper ½ thoracic | Lower ½ thoracic | Lumbo-sacral |
|---|---|---|---|---|
| Radial arteries and vasa corona | 100-200 μm<br>N=60-80<br>n=3-10/cm | Territory 15-20%<br>80-120 μm Ascending course<br>N=70-100n=3-10/cm | | Territory 30-50%<br>250 μm<br>N = 80-100<br>n = 6-10/ cm |
| Anterior spinal artery | Perforators 50 μm | Transparen-chymatous pial ascending anastomoses | | 60 μm |
| Intrincsic branching | Horizomtal | Ascending and descending | | Horizontal |

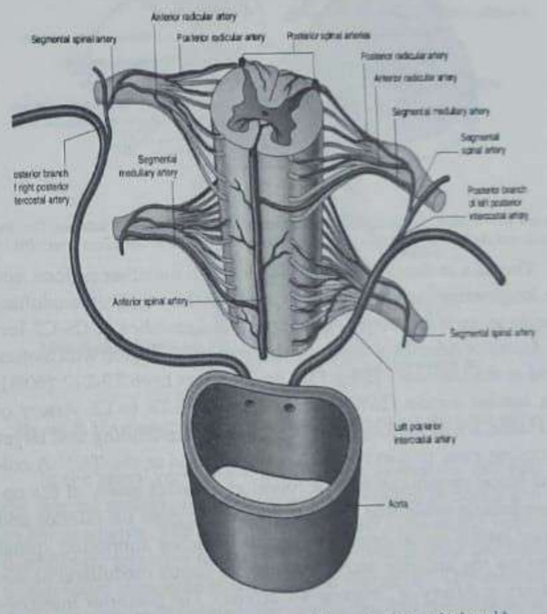



**Figure 7.** The segmental arterial supply of the spinal cord.[4]

The number and diameter of anterior segmental vessels are p adoxical. These arteries come from various sources i.e. in the c vicothoracic region the intercostal arteries come from the aorta costocervical trunk, a branch of the subclavian artery; the 1st a 2nd posterior intercostal arteries of supreme intercostal artery branch of the costocervical trunk of the subclavian artery). Branch of dorsal side of the thoracic aorta and the subcostal artery, toget with small segmental arteries from the aorta at 1 to 2 vertebral le els inferior to their perfusion area are sometimes traveling crania of their site of origin to supply the lower part.[2,3,11]

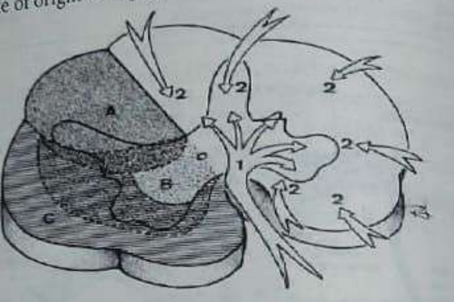



**Figure 8.** The axial distribution of the sulcocomissural (1), radial (2) arteries. The d sal (A) and the lateral (C) areas overlap with the ventral area of the sulcal aretry (3)

The ASA in thoracic level is smaller than the other regions, a the longitudinal artery system is supported by radiculomedulla arteries at each segment i.e. by Artery of Lazorthes at C5-C7 le els, Artery of Adamkiewicz at the thoracolumbar region which ofte found at the left-side (75%). This artery arises from T9-T12 (60%) from lumbar region (25%) and 10% from T6-T8 to L2. Artery o von Haller, a hairpin loop as it branches into ascending and large descending rami to join the ASA, can be found at the T5.[1-3] A co lateral blood supply can also be found as a Basket artery of the co nus medullaris whilst the internal iliac artery gives off inferior an superior lateral sacral branches, which branches supported spinal arteries via the anterior sacral foramen for conus medullaris as co nus artery or Artery of Desproges-Gotteron. The posterior interco tal arteries that enter the neural foramen and penetrating the du as the radiculomeningeal (dural) artery supply both the nerve ro



and its dura, the radiculomedullary artery, the anterior and posterior radicular artery supply the anterior and posterior nerve roots, and medullary artery also support the ASA and PSAs (figure 9).[1,3,11]

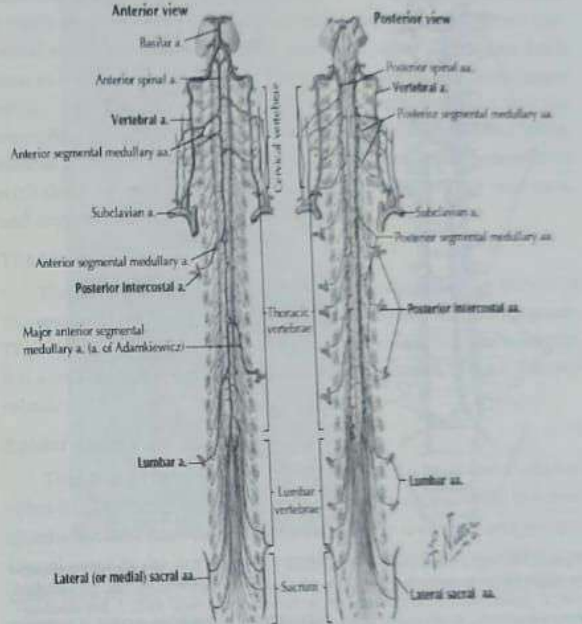



**Figure 9.** The diagram of arterial structure from the ventral and dorsal side of the spinal cord.

In the spinal cord, the veins are more symmetric and vast than the arterial system with less variation of ventral to dorsal and right to left segments. The anterior median vein runs at the ventral median fissure receiving drainage from the ventral horn and funiculus, to the filum terminale at the terminal thecal sac. The median veins drain into the radiculomedullary veins, leaving the intradural space at the root sheath.[11,12,15]

## Histology

The arterial wall has layers, from superficial to the deeper pa[illegible] are tunica adventitita formed by fibrous and loose connective tiss[illegible] nerves and vasa vasorum whilst tunica media composed predo[illegible] nantly by the smooth muscle and fibrous tissue, and tunica inti[illegible] composed of a layer of flat epithelium. However, in the arteries [illegible] CNS, sparse external elastic lamina and relative lack of tunica me[illegible] and adventitia are observed. The landmark of first intradural bran[illegible] in the anterior is the ophthalmic artery; and the posterior cerebell[illegible] artery (PICA) of the V4 at the dorsal par

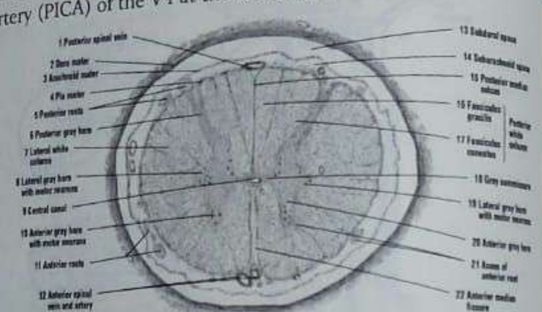


**Figure 6.** The histology of the coronal section of the midthoracic spinal cord in H[illegible] staining shows the funiculum at the peripheral part whilst the horn or cornu at the ventral, dorsal and lateral side of the deeper part surrounding the central canal of th[illegible] spinal cord.[7]

## Vascular Anatomy of The Spinal Cord

There are 4 parts of vertebral arteries, V1-V4, the first part [illegible] origin of the right and left subclavian artery, although in 80-90% [illegible] running cranially to enter the C6 or C7 transverse foramen whilst [illegible] 2-6% of cases the origin of the left vertebral artery comes from th[illegible] aortic arch between the left common carotid artery and left subcl[illegible] vian artery. Other variation includes VA from the aortic arch the[illegible] runs into the transverse foramen of C5; the left VA is from the le[illegible] common carotid artery or external carotid artery; the right verteb[illegible] artery is from the aorta, carotid arteries, or brachiocephalic trun[illegible] and the findings of rami musculares in the cervical part. The VA[illegible] runs cranially from C2-C6, where A. Meningeal Anterior sprouts a[illegible]



proximately at C2-C3, whereas falx cerebelli and occipital posterior fossa medial duramater are supplied by the posterior meningeal artery. The VA3 is a wide external cervical loop at C2-C1 that is prone to pseudoaneurysm or dissection. This part passes away at the superior of atlas (C1) transverse foramen, then located superior to the C1 corpus before goes posteromedially around the atlantooccipital articulation to posterior and acutely turn anterosuperiorly and penetrates duramater at the foramen magnum. Several variations reported are the persistent 1st intersegmental artery resides at the inferior of C1 arch, just after exiting the C2 transverse foramen (3-4%).

The VA4 is the last one and located intracranially via the foramen magnum, where the branches include the anterior spinal artery (ASA), two posterior spinal arteries (PSAs), and the rami perforantes. The ASA and two PSAs branch off at the distal vertebral arteries at foramen magnum, whilst ASA then resided on the median ventral sulcus, the PSAs run parallel to each other in a dorsal paramedian area.[2,3,11] Posterior Inferior Cerebellar Arteries (PICA) that might be from the VA4, has several variations include vertebral arteries are not fused to form the basilar artery rather to end in PICA. The ASA may also from the PICA, and is supported by segmental feeders where its central branches supply the anterior 2/3 of the cord (cornu ventralis, spinothalamic and corticospinal tracts).[2,3,11]Approximately 2-3 anterior and posterior radiculomedullary arteries arise from the vertebral arteries in the cervical segment, largest is the artery of intumescentia cervicalis starts at the C4-C8 (most common at C6 nerve root) (figure 4-5).[5,9,11] The ASA and PSAs are supported by 8 to 10 Aa. Medullares Segmentale (from A. Spinalis Segmentalis); the largest is A. Radicularis Magna (of Adamkiewicz) usually developes at the left thoracolumbar segments to support the inferior part of the spinal cord including the intumescentia lumbalis (figure 7). A copy of ASA untill the C5-C6 level are reported often, the branches supply the lamina VIII-IX of the ventral horn, lamina VII of the lateral horn, the central grey matter of lamina X, the ventrolateral funiculi and the anterior part of the dorsal horn.[1,2,11] Meanwhile the vasocorona arteries supply piamater spinalis, whilst the PSAs and the pial arterial plexus (vasocorona) supply dorsal funiculi e.g. the I – VI Rexed laminae.[1-3]