Neuroanatomical Structures of Spinal Cord - A Review

Mohd Yousuf Dar, Kamal Sarma, Muneer Ahmad Dar and Shahraiz Ahmad Chowdhary

Division of Veterinary Anatomy, Faculty of Veterinary Sciences & A.H.S.K. University of Agricultural Sciences & Technology, Jammu-181102 INDIA

*Corresponding author: yousufdar8@gmail.com

Abstract
This review aims to highlight the termination of spinal cord in different species and to focus on gross morphology, cross sections at different levels, compound light microscopic view and electron microscopic view, in vitro and the images under Computed Tomography and Magnetic Resonance Imaging, in vivo. The spinal cord starts from the foramen magnum and ends in to conus medullaris. The caudal extremity of the spinal cord tapers to a point caudal to the lumbar segments and is referred to as the conus medullaris. The cross section of spinal cord varies at different level. Histologically the spinal cord is composed of neurons and neuroglia. Ultrastructurally the organells of the different components of spinal cord can be visible.

Key words: Goat Spinal Cord, Conus Medullaris, Neuroglia, Neuron

Introduction
The central nervous system is comprised of brain and spinal cord. Spinal cord is contained in the vertebral canal (spinal canal) and extends from medulla oblongata to conus medullaris. There is no clear line of demarcation between the end point of brain and starting point of spinal cord. The imaginary line of demarcation of brain and spinal cord is at the level of foramen magnum.

The complete knowledge of anatomy of the spinal cord is prerequisite to make understanding towards the various affections of spinal cord responsible for the clinical manifestations. Although, spinal cord observed in the laboratory has been hardened by fixatives or embalming it should be remembered that during life this structure is quite soft and in a semi gelatinous state (Treuex and Carpenter, 1964).

The spinal cord should be keenly studied grossly as well as microscopically under low and high magnifications including ultra magnifications under electron microscope in vitro. In vivo, study on the spinal cord by Computed Tomography and Magnetic Resonance Imaging is also necessary to nourish the
diagnostic approach of clinical manifestation regarding the spinal cord (Benarroch et al., 1999; Aburahma and Bergan, 2000).

In the domestic animals the structure, topographic position, extension of spinal cord and the number of spinal nerves vary from species to species. Thus, it is necessary to discuss the specific variation among different domestic species for the easy going of various surgical and anesthetic procedures especially in case of spinal anesthesia (O’ Connor, 1980).

**Anatomy of Spinal Cord**

The cranial end of the spinal cord is continuous with the medulla oblongata of the brain at the level of foramen magnum of the skull and it terminates in conus medullaris (Dellmann and Mc Clure, 1975).

The anatomy of spinal cord includes the gross morphology, cross sections at different levels, compound light microscopic view and electron microscopic view, *in vitro* and the images under Computed Tomography and Magnetic Resonance Imaging, *in vivo*.

**Topography**

The spinal cord starts from the foramen magnum and ends in to conus medullaris. It has two enlargements viz. cervical and lumbar enlargement (Treux and Carpenter, 1964; Getty, 1975). The whole spinal cord is present in the vertebral column from occipeto- atlantal articulation but it ends at different levels from lumbar to sacral segments in different animals (Getty, 1975; Ghosh, 2003).

**Specific Variation**

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Species</th>
<th>Vertebral level of termination</th>
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<tbody>
<tr>
<td>1.</td>
<td>Horse</td>
<td>Caudal half of S₂</td>
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<tr>
<td>2.</td>
<td>Ruminants</td>
<td>(i) At 2 month of age: S₂  &lt;br&gt; (ii) At 10 month of age: caudal half of S₂</td>
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<td>3.</td>
<td>Swine</td>
<td>S₂</td>
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<td>4.</td>
<td>Dog</td>
<td>L₆ – L₇</td>
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<td>5.</td>
<td>Cat</td>
<td>L₇ - S₃</td>
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(Getty, 1975; de Lahuta and Habel, 1986)
Gross Morphology

The spinal cord has a shallow longitudinal dorsal median sulcus extending entire length. The dorsal median sulcus divides the dorsal portion of the spinal cord into two halves. The dorsal median septum extends ventrally from the dorsal median sulcus to the grey matter dorsal to the central canal. The dorsal lateral sulcus is shallow, and through it the dorsal rootlets of the spinal nerves enter the spinal cord lateral to the dorsal median sulcus. The dorsal funiculus is the portion of the spinal cord located between the dorsal median sulcus and the dorsal lateral sulcus. It is divided into two parts by the dorsal intermediate sulcus in the cranial half of the thoracic part and the cervical part of the spinal cord. The medial portion of the dorsal funiculus is the gracile fasciculus, and the lateral portion is the cuneate fasciculus (Dellmann and McClure, 1975).

The ventral median fissure extends the entire length on the ventral surface of the spinal cord. It separates the two ventral funiculi on the midline into two parts. The exit of the ventral rootlets of the spinal nerves marks the lateral extent of the spinal funiculi. A very shallow and indistinct ventral lateral sulcus or groove is sometimes present where the ventral rootlets of the spinal nerves exit from the spinal cord. The lateral funiculus is located on the lateral surface of the spinal cord between the entrance of the dorsal rootlets into the spinal cord and the emergence of the ventral rootlets from the spinal cord.

The spinal cord is divided into cervical, thoracic, lumbar, sacral and coccygeal parts. The above parts correspond to the areas of the spinal cord to which the cervical, thoracic, lumbar, sacral and caudal spinal nerves are connected.

The spinal cord may be divided into segments. A spinal cord segment is that part of the cord where a pair of spinal nerve rootlets enters and leaves the spinal cord. The segment is named according to the pair of spinal nerves connected to it e.g. third lumbar segment is connected to L3 spinal nerve. The caudal three cervical and cranial two thoracic segments are larger in diameter and form the cervical enlargement (Intumescentia cervicalis). This enlargement is due to the increased number of nerve fibers and cells in this area which are related to the brachial plexus and muscle of the pectoral limb (Getty, 1975). The lumbar enlargement (Intumescentia lumbalis) occurs in the last three lumbar and first two or three sacral spinal cord segments which are associated with the lumbosacral plexus and the pelvic limb (Dellmann and McClure, 1975).
The caudal extremity of the spinal cord tapers to a point caudal to the lumbar segments and is referred to as the conus medullaris. From the conus a slender non-nervous filament of piamater, the filum terminale, extends caudally in the dural sac. The filum terminale becomes incorporated in the filum of the spinal duramater (Filum durae matris spinalis) at the caudal end of the dural sac (Dellmann and McClure, 1975).

The caudal portion of the spinal cord and the roots of the spinal nerves attached to it, because they resemble the tail of horse, are sometimes referred as cauda equina. During early development the segments of the spinal cord are centered on the level of the intervertebral foramina. Later, as the vertebral column increases in the length more than the spinal cord, the nerve roots must course caudally alongside the spinal cord, as the interval between the origin of the spinal nerve and its intervertebral foramina of exit increases (Romanes, 2004)

**Cross Section**

The spinal cord can be divided into two parts viz. the grey matter and white matter. The grey substance (substantia grisea) of the spinal cord is arranged in columns which extends the entire length of the cord. In the cross section, it appears as the letter ‘H’. The dorsal protuberance on either side is the dorsal horn (cornu dorsale). The ventral protuberance is the ventral horn (cornu ventrale). Both the horns are the largest in the cervical and lumbosacral enlargements. The central intermediate substance is the grey matter surrounding the central canal. The grey matter dorsal and ventral to the central canal is called the dorsal and ventral grey commissure (commissurae griseae) and contains a large number of nerve fibers. The central intermediate substance is continuous with the lateral intermediate substance, which is located between the dorsal and ventral grey horns. The lateral horn (cornu laterale) is the lateral projection of the lateral intermediate substance and is prominent in the thoracolumbar parts of the cord. The dorsal horn is covered by the grey substance of the dorsal horn apex (apex cornus dorsalis) and the substantia gelatinosa. In the cranial cervical area the dorsal grey horn and substantia gelatinosa are continuous with the spinal nucleus of the trigeminal nerve. A lateral projection, the lateral cervical nucleus, extends from the dorsal part of the dorsal horn in the cranial cervical area. The thoracic nucleus, formerly called the dorsal nucleus or Clark’s column, is located at the junction of the medial side of dorsal horn with the central intermediate grey substance in the thoracic and cranial lumbar portions (Getty, 1975).
The white matter (substantia alba) divided into three main regions by the entering dorsal and emerging ventral rootlets of the spinal nerves. The region between the dorsal median sulcus and the septum on the midline and the dorsal rootlets and dorsal horn laterally is dorsal funiculus. The portion between dorsal and ventral rootlets of spinal nerves bordered medially by the grey matter of the dorsal, lateral and ventral horns is the lateral funiculus. The ventral funiculus is between the ventral rootlets and the ventral median fissure. The dorsal portions of the right and left ventral funiculi meet on the midline and form the white commissure. The white matter of the funiculi is more or less divided into bundles of fibers which are functionally associated and referred as tracts.

The dorsal funiculus is divided into two principal parts: the gracile fasciculus extending from the caudal part of the spinal cord to the medulla. The lateral funiculus is made up of the descending tracts namely, lateral pyramidal tract, tectospinal fibers, lateral reticulospinal tract and the dorsolateral tract, which is located deep to the dorsolateral sulcus and contains descending nerve fibers as well as ascending fibers. In lateral funiculus the dorsal and ventral spinocerebellar tracts, spinotectal tract and the spinothalamic tract are found which are ascending tracts.

The ventral funiculus has medial longitudinal fasciculus with the commissurospinal and reticulospinal parts, the ventral pyramidal tract, vestibulospinal tract and spinothalamic tract.

The fasciculi proprii are nerve fibers which are located adjacent to the grey matter and course between adjacent segments or between several segments of the spinal cord (Getty, 1975).

**Cross Sections at Different Levels**

The cross section of spinal cord varies at different level viz. cervical, thoracic, lumbar and sacral.

**Cervical**

The cross section of spinal cord shows its characteristic appearance at lower cervical level i.e. at C7 level, which shows large anterior horn and proportionately a large amount of white matter. The overall shape of the cord is oval (Haines, 2007).

**Thoracic**
At thoracic level its characteristic appearance can be seen at fourth thoracic vertebral level where white matter appears large in relation to the rather diminutive amount of grey matter. Posterior and anterior horns are small, especially when compared to low cervical levels and to lumbar levels. The overall shape of cord is round (Haines, 2007).

**Lumbar**

At lumbar level the characteristic appearance can be observed at the level of fourth lumbar vertebra. Posterior and anterior horns are large in relation to a modest amount of white matter, and the general shape of the cord is round. Fibers of the medial division of the posterior root directly enter the gracile fasciculus (Haines, 2007).

**Sacral**

At sacral level the grey matter occupies most of the cross section; its ‘H’ shaped appearance is not especially obvious at sacro-coccygeal level. The white matter is comparatively thin mantle. The sacral cord is surrounded by the upper portion of the cauda equina (Haines, 2007).

**Compound Microscopic Structure**

Haematoxylin and Eosin staining of the nervous tissue reveals little of the structure of cell bodies and processes. However, the nuclei of the different type of neuroglial cells differ in shape, size and arrangement of the chromatin and thus agglomerations of these cells may be recognized. Metastatic tumors may be identified with H&E and the use of special stains applicable to non-nervous tissue.

In neuro-histology and neuro-pathology, a general picture of the cell population of brain and spinal cord is considered. Metallic impregnation methods are extensively used in neuro-histology and there is at present no way of selectively colouring axons and dendrites with dyes in routine preparations (Drury and Wallington, 1980).

The grey matter and white matter of the tubular shaped spinal cord are localized in the reverse manner of that which composes the brain. The externally positioned white matter is organized into bundles of ascending and descending nerve fibers. Because most of the fibers extend along the longitudinal axis of
the spinal cord, only a few are observed entering the white from the interior grey matter region. However, occasional bundles of nerve fibers can be found externally within the meningeal covering, either entering or exiting the spinal cord (efferent nerves) can be found ventrally, where as those entering the spinal cord (afferent nerves) are seen dorsally (Ham and Cormack, 1987).

When grey matter is viewed histologically in cross section, it appears as a misshapen ‘H’ or perhaps, more accurately, a butterfly profile, with a central canal located in the middle connecting region, known as the grey commissure. The ventral and dorsal prongs are the ventral and dorsal horns, respectively. Within the horns, especially the ventral, the cell bodies of the neurons can be large, consisting of the motor neurons.

Interneurons, including those associated with the somatic motor neurons, are largely located within the dorsal horns. By comparison, visceral neurons are located predominantly between the ventral and dorsal horns in a more lateral position. These neurons are innervated by neurons of the dorsal root ganglion (Samuelson, 2007).

The following components can be seen histologically:

**Neurons**: These are the structural and functional units of the nervous system. Morphologically, neurons feature elongated processes that extend variable distances from the cell body. Neuronal processes usually consist of one axon and multiple dendrites. Metabolically, they are actively involved in maintaining their structural integrity and in synthesizing, packaging, transporting and releasing secretory products (Dellmann and Eurell, 1998).

**Neuroglia or gliocytes**: These are the structures which provide structural and functional support to the neurons. With routine stains, only their nuclei and perikarya are evident. Under compound microscope following gliocytes can be seen in spinal cord.

i. **Astrocytes**: With routine stains, these are identified by their pale, ovoid nuclei, which are largest among glial nuclei. With silver stains, they exhibit numerus that contain glial fibrils. In white matter, the processes are long slender and moderately branched while in grey matter those are shorter and highly branched. Thus, white matter is said to contain fibrous astrocytes whereas grey matter contains protoplasmic astrocytes.
Functionally the astrocytes provide structural support. By storing glycogen and releasing glucose, they represent a source of reserve energy (Dellmann and Eurell, 1998).

ii. **Oligodendrocytes:** They have relatively few branches. In routine stains, they are recognized by their small, spherical, densely stained nuclei. In grey matter, they serve as perineuronal satellites and thus form internode around the axon. In white matter the function is formation of myeline sheath.

iii. **Microglia:** These are the only mesodermal cells in CNS and with routine stains they are identified by small, elongated, chromophilic nuclei. With silver impregnation they are seen as small, elongated cells with polar processes. Functionally they can transform in to macrophages in response to CNS damage.

iv. **Ependymal cells:** They line the central canal within the spinal cord. The cells are cuboidal or columnar with numerus motile cilia. Large molecules from the CNS extracellular space can pass between ependymal cells to CSF i.e. this function are like lympho-drainage system for the CNS.

**Electron Microscopic View**

Ultra structurally the organelles of the different components of spinal cord can be visible. They can be classified into two groups:

**Neurons:**

i. **Cell body:** In electron microscopic view it has centrally positioned, spherical or ovoid nuclei which posses a prominent nucleolus. The chromatin granules occur in clusters. The fine filaments are also present but the relationship both of these structure bear to interface chromosome orientation and its DNA protein distribution is not well understood. The RNA positive nucleolus often has reticulated structure.

ii. **Cell body cytoplasm:** It has clumps of chromatophilic substance which are the aggregation of rough endoplasmic reticulum and named as Nissl’s granules; which are 100-300 A° in diameter. When the axon of neuron is severed not to close to the perikaryon causing irreversible damage, often a redistribution or reduction or even the complete loss of stainable Nissl’s material takes place. Along with r-ER some free ribosomes and polyribosomes are also present.
Golgi complex has a narrow lumina with occasional dialations, usually at the end of profile. The lumina often appeared to be fragmenting in to swarm of vesicles.

Mitochondria are the place where oxidative phosphorylation takes place. These are usually elongated in the longitudinal axis in dendrites and axons and are of several microns.

Bear et al., 1937 demonstrated the presence of longitudinally oriented filaments in axoplasm which were clearly shown by Palay and Palade in 1955. These are the microtubules and neurofilaments which are about 100 Å each.

Other than the above organells lysosomes, centriole and lipid droplets are also present in cell body cytoplasm.

**Neuroglia:** The different gliocytes have their specific structure in electron microscopic view, as:

i. **Astrocytes:** Under electron microscope they feature packed bundles of intermediate filaments made up of glial fibrillar acidic protein. The filaments are denser in fibrous astrocytes than the protoplasmic astrocytes.

ii. **Oligodendrocytes:** Ultrastructurally, their cytoplasm is electron dense and rich in microtubules and organells especially rough endoplasmic reticulum and mitochondria. They lack the gap junctions.

iii. **Microglia:** These cells are described as extremely dense cells by Schultz *et al.*, 1957. The cytoplasm of these cells contains densely packed granules so the channels of the ER appear very pale in contrast. The nucleus is tensed and highly crenated and its outline is hardly distinguishable from the surrounding cytoplasm.

iv. **Ependymal cells:** These cells line the ventricles and central canal of the brain and spinal cord. Their basal processes are usually in direct contact with neuronal and neuroglial processes of the grey and white matter, no basement membrane intervening (Tannyson and Pappas, 1962; Kurtz, 1964; Dellmann, 1998).

**In vivo Imaging of Spinal Cord**

Initially, Survey radiograph and myelography were used to take observations of spinal cord *in vivo*. Kimberger *et al.*, concluded that myelography is superior tool to diagnose the disc alterations than the
survey radiography because myelography locates the intervertebral space and circumferential distribution more accurately.

**In vivo imaging techniques:**

Conventional radiography remains the primary method of diagnostic imaging in veterinary neurology. Contrast radiography improves diagnostic accuracy but may be technically difficult and dangerous. Improvement in the quality and safety of myelography in clinical veterinary practice. Referral of patients for Computed Tomography and Magnetic Resonance Imaging is considered when there is clinical evidence of spinal lesion that cannot be accurately assessed by the conventional radiographic techniques (Bawner, 1990; Sukhiani et al., 1996; Schaer, 2003; Hoskins, 2004).

These imaging techniques are discussed as:

1) **Myelography:** It is accomplished by intrathecal injection of radiographic contrast medium to allow a view of the spinal subarachnoid space and the outer margin of the spinal cord. Myelography defines the location and the nature of the spinal cord involvement when the lesion is invisible or when multiple lesions appear on survey radiographs. Myelography does not allow definite pathological diagnosis of spinal lesions but permits identification of the site of lesions along the spine and also the location of the lesion in relation to the cord and possible complications of myelography include post myelographic seizures and neurological signs associated with trauma caused by improper placement of spinal needle (Maolankar, 2010).

2) **Epidurography and sinus venography:** Epidurography is accomplished by injecting contrast medium in to the epidural space. Sinus venography is filling of vertebral venous sinuses with contrast medium and can be accomplished by injection in to the narrow cavity of vertebrae or by selective catheterization of veins communicating with the venous sinuses. These procedures have been used to evaluate compressive lesion in the lumbosacral vertebral canal of dogs, but may not produce consistent images.

3) **Linear tomography:** By linear tomography, the spine may be radiographed in a series of planes. Structures out of the plane of interest are blurred because of motion of the tube head and
radiographic cassette during the X-ray exposure, effectively eliminating these structures from the visual field. The procedure can be performed with or without myelographic contrast. This technique is limited in veterinary practice due to cost matters.

4) **Computed tomography and Magnetic Resonance Imaging:** CT and MRI offer the possibility of directly viewing the spinal cord in addition to surrounding structures. CT and MRI are used routinely to evaluate the spinal cord in human patients (de Groot *et al.*, 1984). CT is particularly applicable for evaluation of osseous lesions and MRI allows a better direct view of soft tissues. While obtaining CT and MRI images of spine, it is important that the spinal cord do not deviate out of the imaging plane. Accurate positioning of dogs and cats can be difficult because their spines are long and mobile. The small diameter of the cord also makes the spinal MRI more challenging in animals than in human patients. Looking to potential advantages provided by noninvasive, direct viewing of the cord, it is likely that CT and MRI protocols has to be developed for spinal imaging in veterinary practice (Gardian, 1982; Decertains, 1992).

**Tracts of Spinal Cord**

The nerve fibers joined together make tracts which are located in the white matter at different levels. The information from somatic structures are collected in the spinal cord and from here the informations are transferred to the various parts of the brain through ascending tracts. These tracts carry the information related with touch, tactile, pain, pressure and kinesthetic sensation for their final perception in the brain tissues. The nomenclature of the tracts are spinotectal, dorsal spinocerebellar, ventral spinocerebellar, spinoreticular, spino-olivary and spinocervical tracts on the other hand descending tracts are motor in nature responsible to carry information from cerebral cortex and other brain areas and finally up to spinal cord. Some of the important descending tracts are cortico-spinal tract (dorsal and ventral portion), rubrospinal, vestibulo-spinal, tecto-spinal and reticulo-spinal tract (Breazile *et al.*, 1971; Gilman and Winans, 2003; Sharma, 2004).

**Blood Supply of Spinal Cord**

The branch of sub-clavian artery gives rise to vertebral artery, which divides in to dorsal and ventral arteries. They run along with spinal cord and supply to different segment of the cord by entering through inters vertebral foramen as spinal arteries (Ghoshal, 1970) in cervical region.
In the thoracic region the cord gets the blood from supreme inter-costal arteries whereas in lumbar region it is from lumbar arteries. In the sacral region the median sacral artery provides the blood to the cord (Getty, 1975; Ghosh, 2003)

**Functions of Spinal Cord**

i. It serves as a passageway for the activities moving to and fro the brain.

ii. It contains complex reflex mechanism.

iii. It is through the modification of the reflex machinery of the spinal cord that the higher levels of CNS exert their effects upon the skeletal and visceral motor activity.

iv. In animal the cord comprises a much greater percentage of CNS than in man. In primates the spinal cord is no less complex than that of domestic animals, but many of its functions are controlled through higher nervous structures.

**Conclusion**

The spinal cord starts from the foramen magnum and ends in to conus medullaris. The caudal extremity of the spinal cord tapers to a point caudal to the lumbar segments and is referred to as the conus medullaris. The cross section of spinal cord varies at different level. Histologically the spinal cord is composed of neurons and neuroglia. Ultrastructurally the organelles of the different components of spinal cord can be visible. The nerve fibers joined together make tracts which are located in the white matter at different levels. In the thoracic region the cord gets the blood from supreme inter-costal arteries whereas in lumbar region it is from lumbar arteries.

**References**