OBJECTIVES
After studying the material of this lecture, the student should be familiar with:
1. Surface anatomy of the spinal cord.
2. Internal structure and organization of the spinal cord.
3. Spinal and peripheral nerves, including functional components and the concept of reflex organization.

I. GROSS ANATOMY OF THE SPINAL CORD

A. The spinal cord is continuous superiorly with the medulla oblongata of the brain and extends inferiorly to its tapering lower portion, the conus medullaris, where it ends at the L1/L2 vertebral level. Below this level, the pia mater continues inferiorly as the filum terminale, which becomes invested at the bottom of the dural sac by dura, and then collectively as the coccygeal ligament, it anchors the cord to the coccyx.

B. The spinal cord has two enlargements at the cervical and lumbar levels. The cervical enlargement gives rise to the nerves of the brachial plexus which innervates the upper limbs. The lumbar enlargement gives rise to the nerves that contribute to the lumbosacral plexus which innervates the lower limbs.
C. The spinal cord has 31 segments (8 cervical, 12 thoracic, 5 lumbar, 5 sacral, and 1 coccygeal), with the segments having named spinal nerves exiting the spinal column at each level through the *intervertebral foramin*. Spinal nerves C1-C7 exit above the vertebrae of the same number, while C8 exits below the C7 vertebra, and T1- C8 exit below the vertebra of the same number. Differences in growth between the spinal column and spinal cord result the extended growth of spinal roots from the lumbar, sacral and coccygeal segments, forming a bundle called the *cauda equina* (horse’s tail).

D. Spinal Cord Meninges: dura mater, arachnoid membrane, pia mater

The dura mater is separated from the inside of the vertebral canal by the *epidural space*. The *dural sac* extends inferiorly to vertebral level S2. The *arachnoid* lines the dural sac, pushed against the inside of the dura by CSF pressure in the *subarachnoid space*. The *pia mater* is on the surface of the spinal cord. Its outer layer (*epipia*) loosely invests the blood vessels. Its inner layer (*intimal pia*) forms the pia-glial limiting membrane of the spinal cord with astrocytic processes that extend to the surface.

The pia mater gives rise to about 20 pairs of *denticulate ligaments* that pierce through the arachnoid to attach to the dura, and anchor the cord within the dural sac. The *filum terminale* (into the coccygeal ligament) anchors the cord inferiorly.

E. Lumbar Puncture

Since the spinal cord ends at vertebral level L2, the dural sac (which extends inferiorly to S2) only contains the descending dorsal and ventral roots of the cauda equina, and thus a *lumbar puncture* can safely be performed below L2 into the *lumbar cistern* of the subarachnoid space to sample CSF.
II. SECTIONAL ANATOMY OF THE SPINAL CORD

A. GRAY MATTER VS. WHITE MATTER

The gray matter of the spinal cord consists of neurons (somata and dendrites), portions of myelinated and unmyelinated axons either entering or leaving the gray matter, and supportive neuroglial cells. The gray matter is divided into dorsal (posterior), lateral and ventral (anterior) horns, and the intermediate zone.

The white matter of the spinal cord consists of myelinated tracts, and supportive neuroglial cells (fibrous astrocytes, interfascicular oligodendrocytes). The white matter is divided into dorsal (posterior) funiculus, lateral funiculus, and ventral (anterior) funiculus.
**Gray Matter**

1. Dorsal horn (sensory): consists of mainly *interneurons* (whose processes remain within the spinal cord) and *projection neurons* (whose axons collect into long ascending sensory pathways).

2. Ventral horn (motor): contains *cell bodies of large motor neurons* that supply skeletal muscle. These occur in groups or clusters related to specific muscles.

3. Intermediate gray zone includes:
   a) *Intermediolateral cell column* (T1-L3) contains preganglionic sympathetic neurons for entire body.
   b) *Sacral parasympathetic nucleus* located S2-S4 (does not form a distinct lateral horn).
   c) *Clarke’s nucleus* (T1-L2) - collection of large cells on the medial surface of the base of the posterior horn. Particularly prominent at lower thoracic levels. Relays information to the cerebellum.

**White Matter**

1. Dorsal funiculi (sensory) consists of:
   a) *Gracile fasciculus* (present throughout the cord)
   b) *Cuneate fasciculus* (laterally located above mid thoracic levels)
   c) the gracile and cuneate fasciculi contain ascending axons originating from dorsal root ganglia and other ascending fibers that originate from axons of neurons in the dorsal grey.
   d) axons are added to the lateral side of each dorsal funiculus as the spinal cord is ascended

2. Lateral funiculi (both sensory and motor tracts)

3. Ventral funiculi (motor tracts)
   a) descending ventral corticospinal tract
   b) vestibulospinal tract
   c) reticulospinal tract
B. REXED’S LAMINAEM & CORRESPONDING NUCLEI

The nuclei in the spinal cord gray matter occupy cytoarchitectural laminae. These are based upon their pattern of cellular morphology and are referred to as Rexed’s laminae I through X.

Laminae I through VI are in the dorsal horn, Lamina VII occupies the intermediate zone, and Laminae VIII and IX are in the ventral horn. Lamina X corresponds to the gray commissure.

Among the major gray matter nuclei, the *posteromarginal nucleus* is located in lamina I, the *substantia gelatinosa* occupies laminae II and upper III, the *nucleus proprius* encompasses lower III, IV and upper V. The *nucleus dorsalis of Clarke* is located in lamina VII, and lamina IX is comprised of the individual *motor cell columns* in the ventral horn.
Table 1. Location of Principal Nuclei in the Spinal Cord

<table>
<thead>
<tr>
<th>Nucleus</th>
<th>Location</th>
<th>Rexed's Lamina</th>
<th>Spinal Cord Level</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Posteromarginal nucleus</td>
<td>Dorsal horn</td>
<td>I</td>
<td>All levels</td>
<td>Receive and relay somatic and visceral sensory input from dorsal roots</td>
</tr>
<tr>
<td>Substantia gelatinosa</td>
<td>Dorsal horn</td>
<td>II-III</td>
<td>All levels</td>
<td></td>
</tr>
<tr>
<td>Nucleus proprius</td>
<td>Dorsal horn</td>
<td>III-V</td>
<td>All levels</td>
<td></td>
</tr>
<tr>
<td>Nucleus dorsalis of Clarke</td>
<td>Intermediate zone</td>
<td>VII</td>
<td>C8-L2</td>
<td>Relays proprioceptive information from lower half of body; cells of origin of dorsal spinocerebellar tract</td>
</tr>
<tr>
<td>Interomediolateral nucleus</td>
<td>Intermediate zone</td>
<td>VII</td>
<td>T1-L2</td>
<td>Preganglionic sympathetic neurons</td>
</tr>
<tr>
<td>Interomediomedial nucleus</td>
<td>Intermediate zone</td>
<td>VII</td>
<td>T1-L2</td>
<td>Relay nucleus for visceral reflexes</td>
</tr>
<tr>
<td>Sacral autonomic nucleus</td>
<td>Intermediate zone</td>
<td>VII</td>
<td>S2-S4</td>
<td>Preganglionic parasympathetic neurons</td>
</tr>
<tr>
<td>Medial motor cell column</td>
<td>Ventral horn</td>
<td>IX</td>
<td>All levels</td>
<td>Lower motor neurons innervating proximal (axial) muscles</td>
</tr>
<tr>
<td>Lateral motor cell column</td>
<td>Ventral horn</td>
<td>IX</td>
<td>C5-T1 L1-S3</td>
<td>Lower motor neurons innervating distal (appendicular) muscles of upper and lower extremities</td>
</tr>
</tbody>
</table>

C. SPINAL CORD VARIATIONS

At different levels (the spinal cord varies:
1) in size and shape (e.g., cervical and lumbar enlargements),
2) in the relative proportion of gray and white matter:
   *Gray matter increases in cervical and lumbar regions* which serve to innervate the extremities.
   *White matter increases at higher cord levels with a greater number of ascending and descending fibers*.
3) in the disposition and configuration of the gray matter (e.g., interomediolateral cell columns in segments T1 to L2 which contain preganglionic sympathetic efferent neurons).
III. SPINAL AND PERIPHERAL NERVES

A. Each spinal cord segment has a pair of spinal nerves associated with it. Each spinal nerve is formed by two roots, a dorsal root (afferent, sensory) and a ventral root (efferent, motor). The dorsal root has a swelling, the dorsal root ganglion, which contains the unipolar neuron cell bodies of primary sensory afferent fibers. The ventral root contains motor (efferent) fibers that transmit impulses from multipolar cells in the ventral or lateral horns of the spinal cord to muscles and glands.

B. The dorsal and ventral roots come together at the intervertebral foramen to form the spinal nerve. Distal to its emergence from the vertebral column, the spinal nerve divides into a dorsal ramus (branch) that innervates the general region and intrinsic musculature of the back, and a ventral ramus that innervates the general region and musculature of the neck, thorax, abdomen, perineum and extremities.
The ventral rami of several spinal nerves unite to form plexuses (e.g., C5-T2 contribute to the brachial plexus, T12-L4 contribute to the lumbar plexus, L4-S4 contribute to the sacral plexus), which give rise to peripheral nerves (e.g., radial nerve, tibial nerve, etc.) that extend into the upper and lower extremities.

C. Each spinal nerve and peripheral nerve contains myelinated and unmyelinated axons, collected into bundles, or fascicles, surrounded by a connective tissue sheath.

1. Epineurium—surrounds entire peripheral nerve; dense fibrous connective tissue that is continuous centrally with the dura mater of the spinal nerves and cord.
2. Perineurium—surrounds fascicles of nerve fibers; dense concentric layers of collagen strands
3. Endoneurium—surrounds single peripheral nerve fibers (individual axons); delicate collagenous fibers outside the axis cylinder and myelin sheath.
IV. FUNCTIONAL COMPONENTS OF SPINAL NERVES

Each spinal nerve contains a variety of functional components. Spinal nerves are classified as mixed nerves, because they are made of both sensory and motor fibers. The functional components of spinal nerves are categorized as follows:

1. General Somatic Afferent (GSA)- from receptors in skin and skeletal muscle
2. General Visceral Afferent (GVA)- from receptors in smooth muscle lining the walls of organs and blood vessels
3. General Somatic Efferent (GSE)- to skeletal muscle
4. General Visceral Efferent (GVE)- autonomic fibers to smooth and cardiac muscle

V. DERMATOMAL DISTRIBUTION OF PERIPHERAL NERVES

The peripheral distribution of spinal nerves follows a specific distribution pattern. The localization of segments involved in spinal cord lesions can be determined based upon knowledge of this peripheral distribution of spinal nerves from each segment of the cord. During development, each segment of the neural tube differentiates in conjunction with a specific somite. Each pair of spinal nerves innervates symmetrically arranged paired somites. Efferent fibers in a single dorsal root innervate cutaneous areas called dermatomes, also derived from the somites. The segmental distribution of spinal nerves is thus accurately projected onto the surface of the body. Consequently, spinal cord lesion can be localized by noting deficits in movement secondary to the paralysis of certain muscles and/or by mapping the cutaneous areas displaying anesthesia, analgesia, or hyperalgesia.
VI. SPINAL REFLEXES

Local circuitry in the spinal contributes to reflexive responses. Another diagnostic tool for localizing spinal cord lesions utilized reflexes which involve lower motor neurons (motor neurons in the anterior horn of the spinal cord). The two neuron, monosynaptic reflex (e.g., patellar reflex) is the simplest case. This reflex consists of an afferent neuron (unipolar neuron in the dorsal root ganglion) innervating a neuromuscular spindle and an efferent neuron (motor anterior horn neuron) innervating muscle fibers.
Other *multisynaptic reflexes* (e.g., flexor reflex) involve an *interneuron* (in posterior horn or in intermediate zone) positioned between the afferent neuron and the motor neuron.

Since the majority of muscles are innervated by two or three, and occasionally even four, ventral roots, injury to a single ventral root may only weaken a muscle or have no apparent effect. Five essential elements are required for most spinal reflexes: 1) peripheral receptors, 2) sensory neurons, 3) internuncial neurons, 4) motor neurons, and 5) terminal effectors (muscle).