Functional Anatomy of the Spinal Cord

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Basic Anatomy of the Spinal Cord

Located in the upper two-thirds of the spinal canal, within the hollow portion of a multiarticulated flexible structure called the vertebral column, the SC has a length of approximately 45 cm in humans. The vertebral column is divided into cervical, thoracic or dorsal, lumbar, and sacrococcygeal vertebral segments. Each vertebral segment is formed by bony and cartilaginous components, known as a functional spinal unit (FSU). The FSU can be defined as the smallest physiological motion segment of the vertebral column capable of motion that exhibits biomechanical characteristics similar to those of the entire spine [18]. The SC extends from the foramen magnum at the base of the skull to a cone-shaped termination, the conus medullaris, which is anchored caudally to the coccyx through a non-neural filament known as the filum terminale. Nerve fibers emerge from the SC in an uninterrupted series of dorsal and ventral roots, which join to form 31 spinal nerves: 8 cervical, 12 thoracic or dorsal, 5 lumbar, 5 sacral, and 1 coccygeal. The thoracic, lumbar, and sacral nerves are numbered after the vertebra just rostral to the respective foramen through which they pass (i.e., T12 nerves are caudal to the T12 vertebral body). Conversely, the cervical nerves are numbered for the vertebral body just caudal (i.e., the C1 nerve roots are rostral to the C1 vertebral body, while the C8 nerves are rostral to the body of T1). This distribution explains the different lengths and orientation of each pair of nerve roots: in fact, since the SC is shorter than the vertebral column, the lumbar and sacral nerves develop long roots running caudally below the conus medullaris in the spinal cistern to form the cauda equina.

The three meningeal layers surrounding the SC are a continuation of those found around the brain. The most external layer, the dura mater, does not adhere to the vertebral bone, contrary to the dura of the brain. The spinal dura terminates with a cul-de-sac at the sacral level (S1–S2) forming the dural sac. Overlying the dura is the epidural space, containing fat and vessels, and underlying the dura is the arachnoid space, containing the cerebrospinal fluid (CSF). The third meningeal layer, the pia mater, follows the contours of the SC as well as the arteries and veins supplying the SC; of note, the pia is firmly attached to the dura by a series of 22 denticulate ligaments. These ligaments begin at the foramen magnum and are located on each side of the cord in the interval between two adjacent spinal nerve roots, being attached to the SC roughly halfway between the dorsal and ventral nerve root entry

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zones. The meningeal layers and the compartments they create represent important anatomical regions: the epidural space is where anesthetic drugs are injected to induce local anesthesia during surgical procedures or childbirth; and the arachnoid space in the lumbar cistern, extending from L2 to S2, is the ideal place for CSF collection and injection of drugs or contrast medium through lumbar puncture (ideally performed at the L3/4, L4/5 or L5/S1 interlaminar spaces).

Embryology

The neural tube is the primordial structure for the CNS, with the neural crest appearing at approximately 20 days of gestation and giving rise to a number of neural and nonneural derivatives (including neurons, meningeal cells, etc.). During the third week of gestation, mesenchymal tissue from the mesoderm differentiates into segmented somites. The segmented somites are bilateral structures that develop on either side of the notochord while distending the overlying ectoderm. These somites differentiate into the sclerotome and myodermatome during the fourth week of gestation. The genes regulating the direction and order of the craniocaudal axis development and differentiation are known as Hox genes: spinal congenital anomalies may result from their mutations [15]. Adjacent to the neural tube are 31 pairs of somites; those embryonic segmental structures differentiate into muscles as well as bony and connective tissues, which are arranged in sequence from the first cervical through the coccygeal levels. Each pair of nerves develops in association with each pair of somites. The apparent segmentation of the SC is dependent upon the development of paired segmental spinal nerves and radicular vessels on both sides of the midline. The bilateral neural crest in fact becomes segmented into paired units, one pair for each future sensory dorsal root ganglion of each spinal nerve.

Up to the third fetal month, the SC extends throughout the entire length of the developing vertebral column. The growth of the SC over the subsequent months leads to the elongation of the roots of the spinal nerves between the SC and the intervertebral foramina, so that at birth the caudal end of the SC is located at the level of L3. As a result of canalization and retrogressive differentiation, an ependymal lined space known as the central canal forms at the innermost portion of the SC and terminates at the conus medullaris with the ventriculus terminalis, or fifth ventricle [5]. This structure, which is filled with CSF, is described in the literature as a normal developmental phenomenon, especially in newborns and during childhood, with regression in the adult life. Persistence of this structure may in fact lead to a pathological condition called dilatation of the ventriculus terminalis [9].

Functional Spinal Segments

Each portion of the SC where the corresponding pairs of ventral and dorsal roots attach is called a spinal segment. As such, each spinal segment (except the upper cervical segments) is located slightly higher than the respective FSU. The rootlets forming each nerve root enter the root sleeve after passing obliquely, laterally, and caudally within the vertebral canal. The sleeve contains motor and sensory roots separated by the interradicular septum. The dorsal and ventral roots come together and form the spinal nerve root. Before forming the spinal nerve root, the dorsal root contains an oval enlargement called the dorsal root ganglion.

The cell bodies of motor neurons and interneurons are located in an area of gray matter within the SC, characterized by a butterfly-like shape. The white matter surrounding this gray matter structure is made of the nerve fibers and glia of ascending and descending tracts, as shown in Fig. 1.1. As a result, the nerve fibers of the gray matter are oriented in the transverse plane, whereas those of the white matter are oriented in the longitudinal plane parallel to the neuraxis. The gray matter has been parceled anatomically, primarily on the basis of the microscopic appearance, into nuclei and laminae. This organization is often referred to as being composed of ten laminae, named after the anatomist Rexed, resulting in a posterior horn (laminae I through VI), an

intermediate zone (lamina VII), an anterior horn (laminae VIII to IX), and a region surrounding the central canal (lamina X) [19]. Figure 1.1 and Table 1.1 provide details regarding the anatomical organization of the ten Rexed laminae and their specific functions.

The horns of the gray matter contain different classes of functional neurons: second-order interneurons in the dorsal horn process sensory information from the first-order sensory afferents; this may eventually result in di-, tri-, or polysynaptic pathways [6, 7]. Ventral horns contain motoneurons of various types: fundamentally, α-motoneurons innervating skeletal muscle fibers and γ-motoneurons innervating extrafusal motor fibers in muscle spindles.

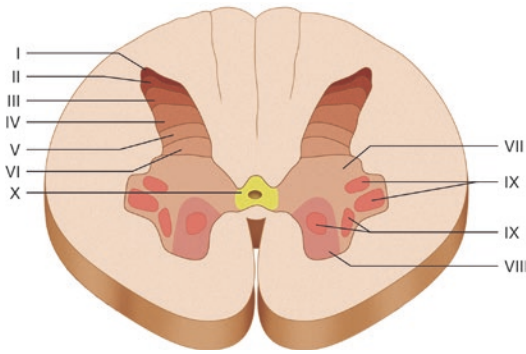

Fig. 1.1 Anatomical distribution of Rexed laminae

As the rostrocaudal distribution of motor neurons follows the body scheme, with more rostral segments innervating muscles of more proximal joints and vice versa, the SC shows two enlarged segments innervating the upper (cervical or brachial enlargement; C5–T1) and lower extremities (lumbosacral enlargement; L3–S2). Also, the spatial distribution of motoneurons within the ventral horn is structurally organized with those innervating axial or proximal muscles located more medially, and those innervating distal muscles in upper and lower extremities located more laterally. Finally, the lateral horn is found at the thoracic and upper lumbar segments only and contains preganglionic sympathetic neurons whose axons reach the sympathetic ganglia adjacent to the vertebral bodies through white communicating rami from the ventral roots. Preganglionic

Table 1.1 Anatomy and function of Rexed laminae

Lamina	Anatomical location	Fibers	Function of fibers
I	Posteromarginal nucleus	Aδ	Sensation of temperature and fast pain
II	Substantia gelatinosa	C	Sensation of slow pain
III	Nucleus proprius	A-b	Mechanoreceptors for touch and proprioception
IV	Nucleus proprius	A-b	Mechanoreceptors for touch and proprioception
V	Nucleus dorsalis	Aδ, C	Receives information on pain sensation and movement
VI	Nucleus dorsalis	Ia/A-alpha Ib/A-alpha/Golgi	Spinal reflexes, integration of somatic motor function
VII	Intermediolateral (IML) cell column, intermediate gray, intermediomedial (IMM) cell column	Spinocerebellar tract C8–L3: nucleus dorsalis T1–L2: IML S2–S4 preganglionic sacral autonomic nucleus	Preganglionic parasympathetic neurons
VIII	Anterior fasciculus	Descending tracts	Modulate muscular tone and movement
IX	Anterior horn	Somatic α- and γ-motor neurons	Innervation of extrafusal fibers of skeletal muscle Innervation of intrafusal fibers of neuromuscular spindles
X	Perimeter of the central canal	Anterior commissure tracts	Decussation of axons

parasympathetic neurons are located similarly at the S2–S4 levels for visceral innervations [21].

Different classes of spinal interneurons are involved in the process of sensory-motor integration, typically being localized in Rexed laminae VII and VIII. Experimental studies have documented how this integration of motor commands and sensory feedback signals is used to control muscle activity during movement. The sum of convergent inputs from sensory neurons and from the central pattern generator (CPG), neural networks that produce rhythmic patterned outputs without sensory feedback, gives rise to the activity of the interneurons. During locomotion, the firing level of interneurons is modulated via excitation or inhibition depending on the reflex pathways, so that different patterns of interneuronal activity determine which pathways are open, blocked, or modulated at any given moment [20].

Spinal Pathways

The white matter is organized within the SC into the following three columns: posterior, lateral, and anterior. Those fibers form tracts that eventually represent the components of sensory, motor, propriospinal, and autonomic pathways; Fig. 1.2 provides further anatomical details of these tracts.

The posterior column is found between the posterior horns of the gray matter, and it is divided by the posterior median septum in the midline. The posterior column contains the fasciculus cuneatus laterally and the fasciculus gracilis medially. These tracts carry ascending information of proprioception, vibration, and light touch sensation. Fasciculus gracilis carries information from lower limbs while fasciculus cuneatus carries information from upper limbs.

The lateral column lies between the dorsal and ventral root entry zones. It is composed of the lateral corticospinal tract and the lateral spinothalamic tract. The lateral corticospinal tract carries descending information regarding voluntary motor function. The lateral corticospinal tract, along with the small anterior corticospinal tract, and the very small anterior lateral corticospinal tract make up the cortical spinal system. With the exception of axons from the anterior corticospinal tract, the axons in corticospinal tract cross over at the pyramids of the medulla. The lateral spinothalamic tract carries ascending information for pain and thermal sensation. This tract decussates upon entry to the spinal cord and as a result carries the impulses from the contralateral side of the body. In the posterior lateral periphery of the spinal cord, the posterior spinocerebellar tract is found. This tract is an uncrossed tract that carries ascending information regarding fine coordination of limb movement and posture.

The anterior column of the white matter is found between the anterior median fissure and the

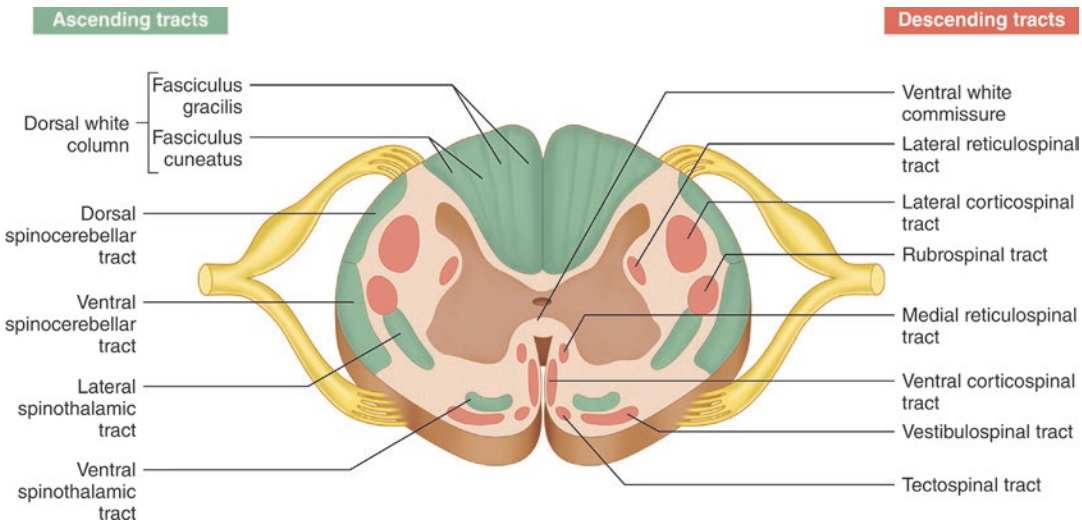

Fig. 1.2 Cross-sectional diagram of the spinal cord with details of ascending and descending tracts

anterior root entry zone. This column contains the anterior corticospinal tract and the anterior spinothalamic tract. The ascending fibers of the anterior spinothalamic tract convey impulses associated with light touch. The anterior corticospinal tract is a descending uncrossed tract responsible for fine motor skills.

Fibers and Spinal Nerves

The fibers contained within each spinal nerve can be responsible for general somatic (innervating the outer body and extremities) or general visceral (innervating the internal organs) functions and therefore can be either afferent or efferent depending on their primarily sensory or motor role.

The dorsal roots are sensory stations consisting of afferent fibers that convey input via spinal nerves from the sensory receptors in the body to the SC. The dorsal root ganglion described above contains the unipolar cell bodies of those neurons. The sensory afferents with their cell bodies and central axon are called first-order neurons. The central axon enters the SC at the level of the posterolateral sulcus, whereas the peripheral axons reach the related receptor in the peripheral tissues. As anticipated, the skin segment supplied by each spinal nerve is called a dermatome. Dermatomes tend to functionally overlap; thus, the loss of one dorsal root usually results in hypesthesia (reduced sensation) rather than anesthesia (complete loss of sensation). The afferent fibers responsible for general somatic and general visceral sensation can be classified according to their conduction velocity into groups I to IV. The fibers of groups I, II, and III are myelinated which allow for faster conduction velocity, while those of group IV are unmyelinated. As described above, the ventral roots are predominantly embodied into the motor pathways, while the lateral horns are autonomic relays. Of note, some sensory fibers have been identified as well within ventral roots [7].

Each α-motor neuron and the muscle fibers it innervates constitute a motor unit; given the specific focus of this book on the pathologies of the cervical spine, a schematic representation of the spinal nerves radiating in the upper limbs is

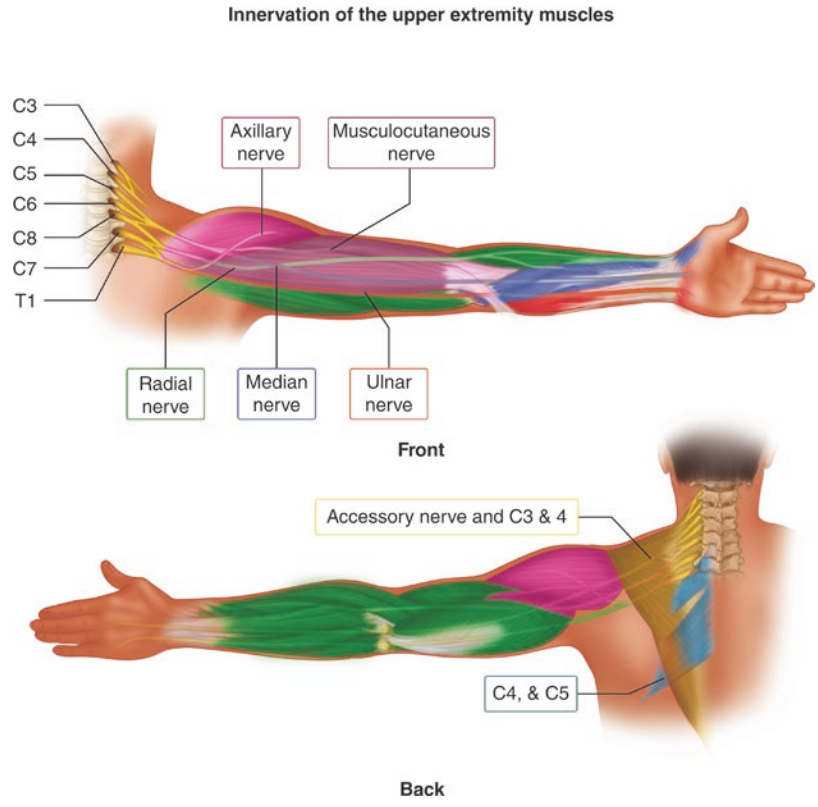

Fig. 1.3 Spinal nerves radiating into the upper limb

Table 1.2 Characteristics and functions of motor neurons as well as autonomic and sensory fibers

Fiber type and innervation	Role	Conduction velocity (m/s)	Diameter (μm)
Motor neurons Anterior horns – ventral roots			
Alpha (A-α) Impulses to end plates of voluntary muscle fibers	Voluntary muscle contraction	15–120 Myelinated	12–20
Gamma (A-γ) Impulses to motor endings of intrafusal fibers of muscle spindle	Fine adjustment of muscle tone	10–45 Myelinated	2–10
Autonomic fibers	*Thoracolumbar intermediate zone (T1–L2) sympathetic system – ventral roots* *Sacral (S3–S4) parasympathetic system – ventral roots*		
Preganglionic fibers (B) Impulses to sympathetic/parasympathetic ganglions	Regulating Heart rate Gastrointestinal and bladder activities	3–15 Myelinated	>3
Postganglionic fibers (C) Impulses to visceral organs		2 Unmyelinated	1
Sensory fibers Dorsal root ganglion – dorsal roots			
Ia (A-α) Impulses from the muscle spindles	Muscle tone	70–120 Myelinated	12–20
Ib (A-α) Impulses from the Golgi tendon organs	Light touch and pressure	70–120 Myelinated	12–20
II (A-β) Impulses from encapsulated skin and joint (Meissner's and Pacinian) receptors	Touch, pressure, and vibratory sense	30–70 Myelinated	5–14
III (A-δ) Impulses from non-encapsulated skin endings	Pain and temperature	12–30 Myelinated	2–7
IV(C) Impulses from non-encapsulated skin endings	Pain and temperature	0.5–2 Unmyelinated	0.5–1

shown in Fig. 1.3. The number of muscle fibers in each motor unit ranges from just 3–8 muscle fibers in small, finely controlled, extraocular muscles of the eye to as many as 2000 muscle fibers in postural muscles of the legs [10]. Regardless of their motor or sensory nature, fibers are also classified based on their conduction velocity into A, B, and C. A fibers are further classified depending on their size into α, β, γ, and δ [13]. Table 1.2 provides a summary of nerve fiber classification.

Vascularization of the Spinal Cord

The blood supply to the SC is provided craniocaudally by one anterior and two posterior spinal arteries and horizontally by several radicular arteries originating at various levels, whereas the radicular arteries vascularize the ventral and dorsal roots [2]. A graphical representation of the horizontal vascularization of the SC is provided in Fig. 1.4. A precise description of the spinal vascular territories aids understanding of many pathologic conditions, especially those referring to spinal syndromes, as well as relatively safe surgical entry zones [8].

Originating from the fusion of the vertebral arteries, the anterior spinal artery is located within the pia mater in the median sulcus. The anterior spinal artery descends in front of the SC continuing as a slender twig on the filum terminale and gives off, along its course, to central branches supplying the anterior third of the SC. The anterior vertebral artery also receives several small branches, known as anterior segmental medullary arteries, which enter the vertebral canal through the intervertebral foramina. These feeders originate from the ascending cervical artery (a branch of the inferior thyroid artery) in the neck, the intercostal arteries in the thorax, and the lumbar artery, iliolumbar artery,

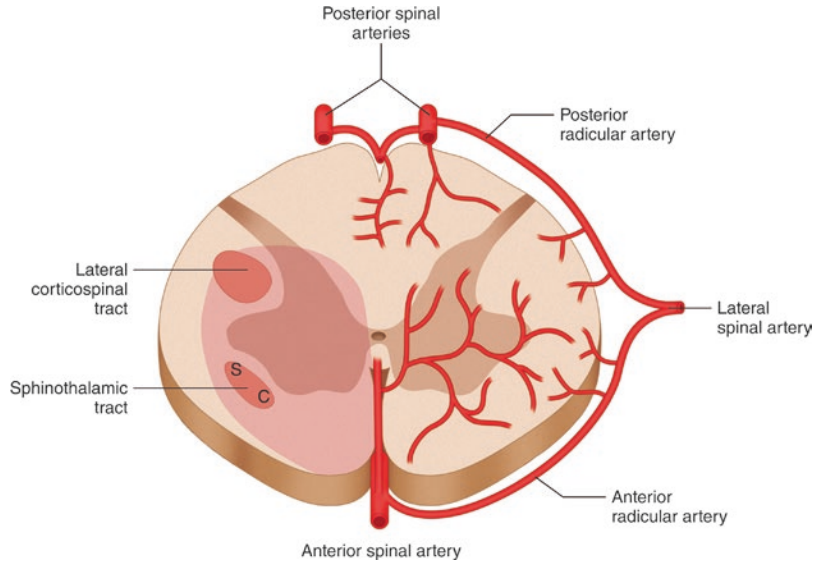

Fig. 1.4 Anatomical distribution of anterior and posterior vertebral arteries to the spinal cord

and lateral sacral arteries in the abdomen and pelvis. Of note, the artery of Adamkiewicz, usually originating from an intercostal artery at the level of the 8th to 12th vertebral body (roughly in 75% of the cases), is the largest anterior segmental medullary artery and the major supply to the lower two-thirds of the spinal cord [14].

The posterior spinal arteries irrigate the posterior third of the cord; they arise from the vertebral arteries in 25% of the cases and from the posterior inferior cerebellar arteries in the remaining 75%. Unlike the anterior spinal artery, the posterior spinal arteries are rather discontinuous in the tract between the subaxial cervical and thoracic spine, showing instead a tendency to create anastomoses and a characteristic basket which angiographically defines the caudal portion of the SC and its transition to the cauda equine. Beside the fasciculus gracilis and cuneatus, the lateral columns of the SC depend on the posterior spinal arteries for their arterial supply.

The venous drainage from the SC largely follows its arterial supply: it is in fact characterized longitudinally by two median veins, one located in the anterior fissure and the other behind the posterior sulcus of the SC with four lateral veins running behind the ventral and dorsal roots. The spinal veins form a minute, tortuous venous plexus situated in the pia mater and freely communicate with the internal vertebral plexus in the epidural space. The internal and external vertebral plexuses eventually drain into the intervertebral veins, which once out of the intervertebral foramina drain toward the vertebral vein in the neck, the intercostal veins in the thorax, and the lumbar and lateral sacral veins in the lumbosacral region. Of note, contrary to the intervertebral veins, the spinal veins are valveless.

Spinal Cord and the Respiratory Drive

Although respiratory drive centers lie in the brainstem, further integration is provided by anterior horn cells of the upper cervical SC. The main respiratory muscles are under both voluntary and involuntary control. Voluntary control arises from the motor and premotor cortex and descends through the corticospinal tract, while involuntary control is mediated by both rhythmic and nonrhythmic systems including the pneumotaxic and apneustic centers in the pons, as well as the ventral and dorsal respiratory groups in the medulla. The pneumotaxic and apneustic centers regulate the speed of inhalation and exhalation by inhibitory and stimulatory impulses, located in the rostral lateral pons and lower pons/medulla oblongata, respectively. The ventral and dorsal respiratory groups regulate

the rhythm of inhalation and exhalation. The groups are located in the reticular formation of the medulla and include the following nuclei: the nucleus ambiguous and nucleus of the tractus solitarius [16].

The phrenic nerve provides motor stimuli to the diaphragm, the primary muscle of inspiration, and thus plays a central role in the breathing process. Contributions to the phrenic nerves originate from the C3, C4, and C5 segments. Many accessory muscles contribute to the inspiratory (I) and expiratory (E) processes by regulating the elevation of the ribs, expansion of the rib cage, or compression of the abdominal wall. They include the following:

(a) The intercostal muscles (innervations T2 to T11), which are arranged as three layers: external layer (I), internal layer, and an incomplete innermost layer (E).
(b) The posterior thoracic muscles which include the serratus posterior (E, innervations T1–T5) but also the levatores costarum brevis and longus (I, innervations T2–T12).
(c) The pectoralis muscles, major and minor (I, innervations C4–T1).
(d) The trapezius, scalene, and sternocleidomastoid muscles (I, innervations C2–C6).
(e) The serratus anterior (I, innervations C5–C7) and levator scapulae (I, innervations C1–C4).
(f) The abdominal muscles, including the rectus abdominis, transverse abdominis, and external and internal oblique muscles (E, innervation T7–L1).

Because of the association of cervical spinal cord injury with respiratory dysfunction, the neurologic examination of cervical spinal cord injury includes a respiratory functional assessment. Given the above, a complete transection of the SC at the C1 to C3 levels is almost always fatal unless immediate respiratory support is provided. In the case of complete C4 injuries, the C3 segment may be preserved providing innervation to the diaphragm and allowing it to provide adequate function to support respiration. In this scenario, the respiratory rate is increased, and the patient uses accessory breathing muscles such as the sternocleidomastoid and trapezius to compensate. Due to the limited functioning of the diaphragm, the patient is unable to cough effectively and requires frequent suctioning. In the management of C1 to C4 injuries, artificial ventilation and tracheostomy are often necessary. Impaired diaphragmatic function is also seen in the initial stages of complete C5 injuries; however, in this case, diaphragmatic function may be fully restored once the spinal shock wears off. C5 also partially innervates levator scapulae and other accessory muscles of respiration mentioned above, thus providing a better vital capacity of the lung when compared with C1 to C4 lesions. On the other hand, patients with a complete C6 injury have intact diaphragmatic function and sufficiently strong respiration, and although intensive monitoring is required, tracheostomy and ventilation support are likely not necessary [23].

Aside from respiratory dysfunction as a result of cervical spine impairment on respiratory musculature, direct injury to the brainstem structures can cause a cervicomedullary syndrome, also referred as cruciate paralysis. The injuries in this syndrome may extend from the pons to C4 or even lower in the cord. The more rostral the lesion, the more severe the clinical manifestations that include respiratory arrest, hypotension, and tetraparesis.

Understanding the Functional Anatomy of the Spinal Cord: Spinal Syndromes and Pain

A deep knowledge of the pathways and vascular supplies described in this chapter is fundamental to clinical practice when it comes to diagnosing myelopathies, spinal cord syndromes, and radiculopathies.

The Brown-Sequard syndrome refers to hemisection of the SC, which may result from intradural or extradural tumors, disk herniation, or epidural hematomas. One of the manifestations of this syndrome is loss of contralateral pain and temperature sensation. This deficit is the result of destruction of decussating spinothalamic tracts.

The motor impairment associated with this condition is due to the destruction of the corticospinal tract. At the level of the spinal cord lesion, the motor impairments manifest with lower motor neuron signals, while distal to the lesion, impairments manifest as upper motor neuron lesions. In this syndrome, deficits with ipsilateral vibration and proprioceptive sensation present due to damage to the dorsal column.

Central cord syndrome, usually resulting from hyperextension cervical traumas, is characterized by damage to the decussating spinothalamic fibers at the center of the SC. This syndrome will cause bilateral pain and loss of temperature sensation from upper extremities, leaving the lower extremities unaffected. Also, the sensation of vibration, tactile and proprioception modalities is spared in this syndrome, creating a dissociated sensory loss. The motor deficits observed in this syndrome are typically prominent in the upper extremities and manifest with lower motor signs [1]. Bladder dysfunction is another common presentation of central cord syndrome [3]. Neurogenic atrophy and paresis can occur in this syndrome if there is involvement of ventral SC. Spastic paralysis can result if there is damage to the corticospinal tract due to involvement of the lateral spinal cord. Involvement of the lateral SC can also affect other structures such as the dorsomedian and ventromedian motor nuclei and the ciliospinal center of Budge at C8–T2 and result in kyphoscoliosis and ipsilateral Horner's syndrome. If the involvement extends to the dorsal columns, loss of vibration and proprioception may take place [11].

Anterior cord syndrome can result from damage to the anterior spinal artery, traumas, and epidural hematomas. Spinal traumas such as dorsally displaced osseous fragments or cervical disk herniations can result in this syndrome, as well as any ischemic event resulting from the blockage of the anterior spinal artery or its various branches. This syndrome is characterized by a bilateral loss of pain and temperature sensation due to destruction of the bilateral spinothalamic tracts. Pressure and light touch sensation are also affected to varying degrees in this syndrome. Flaccid paralysis distal to the lesion results from damage to the anterior horn cells and corticospinal tracts. This flaccid paralysis often progresses to spasticity. Dorsal column function is typically spared with anterior cord syndrome, resulting in dissociation of sensory loss, as vibration and proprioceptive sensations distal to the lesion remain preserved with the loss of pain and temperature sensation. In the initial stages of this syndrome, urinary retention and constipation may be observed. Typically, patients with anterior cord syndrome are areflexic.

Posterior cord syndrome is characterized by a loss of vibration, proprioception, and light touch sensation distal to the lesion. Any mechanism damaging the dorsal columns and affecting their function, such as traumas, infections, or vascular injuries, can result in posterior cord syndrome. The main clinical features are paresthesias and bladder and bowel dysfunction. The paresthesias in posterior cord syndrome can include Lhermitte's sign and lancinating pains on neck flexion. Sensory ataxia may also be present in this syndrome. Motor function, pain, and temperature sensation are often spared in posterior cord syndrome, as there is no involvement of spinothalamic or corticospinal tracts [17].

Pain syndromes can result from any pathology affecting the SC segments that innervate peripheral dermatomes or specific nerve roots resulting in peripheral radiculopathies. They are usually characterized by positive neurological findings such as weakness, areflexia, paresthesia, and numbness in the segmental distribution of the affected spinal nerve; musculature also plays a role in existing loading and painful conditions [12]. Unmyelinated Aδ- and C-type fibers and half of the neural units in the skeletal muscle have been shown to have nociceptive function. The dura mater also contains nociceptive nerve fibers that express calcitonin gene-regulated peptide (CGRP) and substance P; however, the role of the spinal dura mater in the pathogenesis of pain syndromes may be limited to modulation of pain through releasing proinflammatory cytokines [22]. Furthermore, pain syndromes can also result from direct injury to vascular structures (i.e., the vertebral arteries in cervical traumas resulting in a compromise of blood supply to the brain and pressure

gradients around the spinal cord which can potentially lead to nociceptive responses). Finally, myofascial pain syndromes refer to chronic musculoskeletal neck pain that is associated with painful muscular "trigger points" within bands of muscle that replicate symptoms in predictable referral patterns. This condition usually presents without neurologic deficits but is associated with a remarkably decreased range of motion [4].

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