Seminars in ULTRASOUND CT and MRI

Spinal Cord Anatomy and Clinical Syndromes

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We review the anatomy of the spinal cord, providing correlation with key functional and clinically relevant neural pathways, as well as magnetic resonance imaging. Peripherally, the main descending (corticospinal tract) and ascending (gracilis or cuneatus fasciculi and spinothalamic tracts) pathways compose the white matter. Centrally, the gray matter can be divided into multiple laminae. Laminae 1-5 carry sensitive neuron information in the posterior horn, and lamina 9 carries most lower motor neuron information in the anterior horn. Damage to the unilateral corticospinal tract (upper motor neuron information) or gracillis-cuneatus fasciculi (touch and vibration) correlates with ipsilateral clinical findings, whereas damage to unilateral spinothalamic tract (pain-temperature) correlates with contralateral clinical findings. Damage to commissural fibers correlates with a suspended bilateral "girdle" sensory level. Autonomic dysfunction is expected when there is bilateral cord involvement.
Semin Ultrasound CT MRI 37:360-371

Introduction

The first known graphic example of a spinal cord injury can be seen in *The Dying Lioness*, a stone panel from the Assyrian Palace of Assurbanipal, c. 650 BC.[1,2] The panel depicts a lioness injured by arrows transversing its back and trying to crawl with clearly paralyzed lower extremities. It is clear that the Assyrians had an understanding of basic cord function. However, little was known of the cord function before Galen's anatomical studies (130-200 AD). Over the centuries, we have made progress. Here, we describe up-to-date anatomical and functional concepts of the spinal cord with correlation with magnetic resonance imaging (MRI) and important clinical syndromes. Note, as MRI correlation is stressed, most anatomical graphics might differ in orientation from classic anatomical and clinical textbooks.

Embryology and Gross Anatomy

Unlike other parts of the central nervous system, the spinal cord is the one that preserves the embryologic tubular-like appearance. Similar to the developing brain, 3 embryonic layers such as matrix, mantle, and marginal layer, can be clearly recognized in the human cord after the closure of the neural tube. The matrix layer, surrounding the ependymal central canal, originates the neuroblasts that migrate predominantly through a process known as radial migration (Fig. 1). However, in the brain, the massive radial migration of neuroblasts ends in the marginal layer to form the neocortex; in the spinal cord, the migration ends in the mantle layer and remains in direct contact with the matrix layer, to conform a zone of periventricular gray matter. At the same time, the marginal layer in the cord is transformed into a peripheral zone of white matter fibers (Figs. 1 and 2).

The motor neurons differentiate early in the outermost portions of the anterior (basal plate) mantle layer, and their axons penetrate the marginal layer to conform the ventral root fibers. The spinal ganglia, carrying sensory information and deriving from the neural crest, form bipolar cells with central and peripheral processes (Fig. 1). Although the central processes constitute the dorsal root fibers that penetrates the marginal layer in the posterior aspect of the cord (alar plate), the peripheral processes join the ventral root fibers to form the mixed (ie, afferent and efferent) spinal nerves near the intervertebral foramina. Hence, the cord acquires its characteristic H or butterfly shaped central zone of gray matter (Fig. 2).

There are usually 31 pairs of spinal nerves, thus the spinal cord can be subdivided in the same number of segments (8 cervical, 12 thoracic, 5 lumbar, 5 sacral, and 1 coccygeal). The corresponding spinal cord segments are designed accordingly as C1-C8, T1-T12, etc (Fig. 3).[3] With the exception of C1, all segments have ventral and dorsal nerve roots, and the conjoined spinal nerve exit through the intervertebral foramen. The C1 spinal nerve exits between the cranial occipital bone

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 http://dx.doi.org/10.1053/j.sult.2016.05.002
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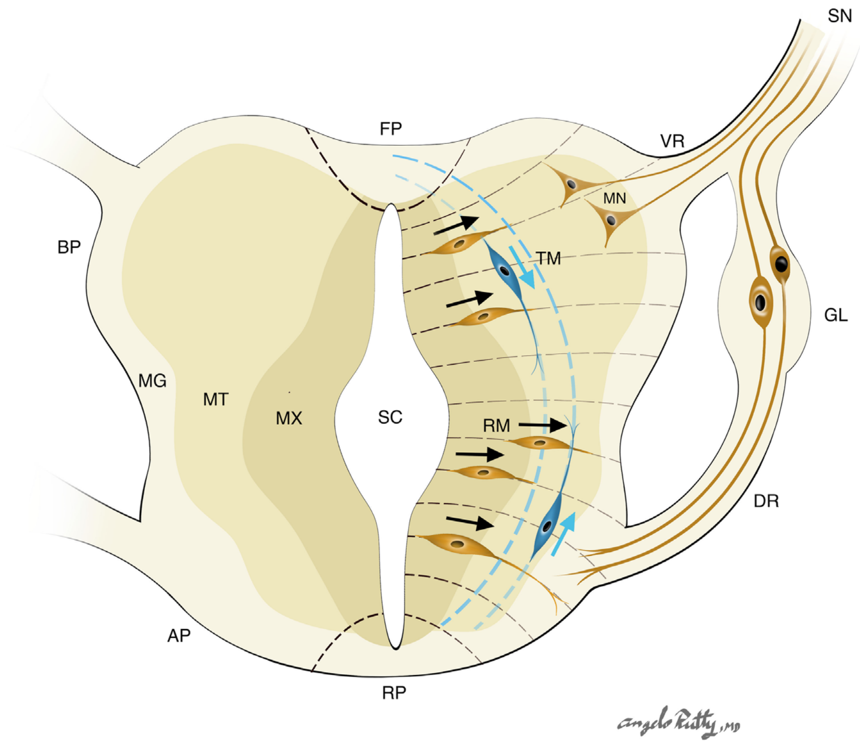

Figure 1 Spinal cord embryology. Representation of a transverse section of the spinal cord at 6 weeks of intrauterine life. AP, alar plate; BP, basal plate; DR, dorsal root; FP, foot plate; GL, dorsal root ganglion; MN, motoneurons; MG, marginal layer; MT, mantle layer; MX, matrix layer; RM, radially migrating neuroblasts; RP, roof plate; SC, spinal canal; SN, spinal nerve; TM, tangentially migrating neuroblasts; VR, ventral root. (Adapted and modified from Nieuwenhuys et al.[6])

and the first cervical vertebra. Although the presence of ventral nerve roots in the C1 segment is constant, the presence of dorsal nerve roots is variable (Fig. 4). Tubbs et al[4] found that the C1 segment has no dorsal nerve roots in approximately 54% of cadaveric specimens. When the dorsal nerve roots were present, only 28% had a dorsal root ganglion, and in 50% the spinal accessory nerve joined the dorsal rootlets. This complex anatomy can be important in cases where rhizotomy is considered for alleviation of pain.

Until the 12th week of intrauterine life, the cord has the same longitudinal dimension as the spinal canal. Subsequently, there is a discrepancy due to a faster longitudinal growth of the spinal canal as compared to a slower growing of the cord. Eventually, at birth, the conus

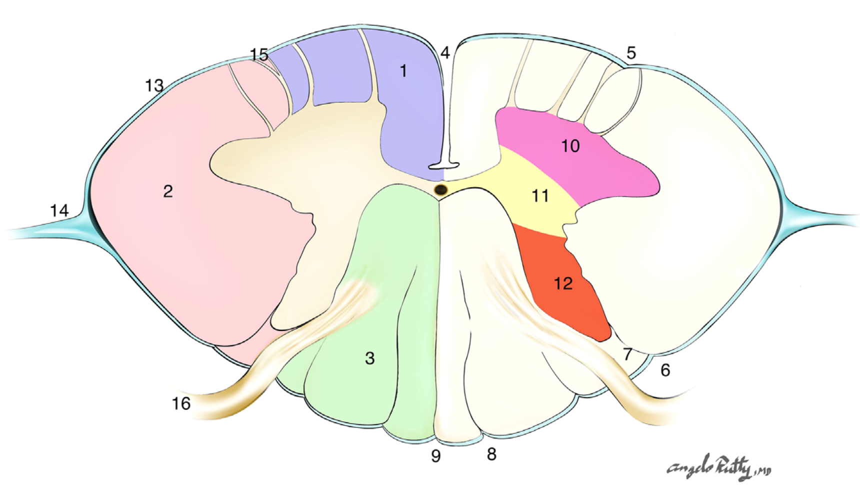

Figure 2 Gross anatomy of the spinal cord in adulthood. Representation of a transverse section of the cervical segment. 1, anterior funicle; 2, lateral funicle; 3, posterior funicle; 4, anterior median fissure; 5, anterolateral sulcus; 6, posterolateral sulcus; 7, Lissauer's tract; 8, posterior intermedian sulcus; 9, posterior median sulcus; 10, anterior horn; 11, intermediate gray zone; 12, posterior horn; 13, pia-arachnoid; 14, denticulate ligament; 15, ventral nerve roots; 16, dorsal nerve root.