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Histology of the Peripheral Nervous System

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Winter, 2009
Objectives of PNS Histology:

• Discuss the general division/differences between CNS and PNS
• Appreciate the subdivision into somatic and autonomic nervous system
• Learn about the cellular components and the structural attributes of neuronal cells
• Discuss synaptic connections, using the motor end plate as an example
• Study the formation of the axonal myelin ensheathment
• Compare the histological features of myelinated and unmyelinated axons/nerves
• Recognize nerves in histological sections
• Identify the different connective tissue layers that are associated with nerves
• Understand the different organizational plans that are adopted by neuronal cells
• Identify and compare autonomic and sensory ganglia
• Learn about the basic histological features of the spinal cord
• Understand the organization and functions of mechanosensory receptors and neuromuscular spindles and be able to recognize them
Structural Organization of the Nervous System

- Peripheral nervous system
- Central nervous system (CNS)
- Peripheral nervous system

**Inputs**
- Nose, eye, ear, sensory ganglia, taste buds, skin, muscle, joints, visceral

**Outputs**
- Autonomic ganglion, motor nerve, skeletal muscle, cardiac & smooth muscle & glands

Special senses

- Nerves and ganglia
- Brain and spinal cord
- Brain and spinal cord
- Nerves and ganglia
Functional Organization of the Nervous System

1. **Somatic** (conscious afferent* and efferent, voluntary motor control)

2. **Autonomic** (unconscious efferent, involuntary motor control of internal organs to maintain homeostasis)
   - Sympathetic – thoracolumbar division
   - Parasympathetic – craniosacral division

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* Somatic afferents = sensory fibers from skin, muscle, joints, tendons.

Visceral afferents = sensory fibers from visceral organs; some result in conscious sensations, but others do not. However, they are not considered part of the autonomic nervous system, which is entirely efferent.
Perikarya of sensory neurons are in the PNS, often organized in ganglia.
Motor neuron perikarya: somatic vs. autonomic

Autonomic efferents = two neuron chain, with 1st neuron in the CNS and 2nd neuron in PNS ganglia

Somatic motor neuron perikarya are in the CNS

Cellular Components of the Nervous System

Neurons

Glia (support cells)

Heinrich Wilhelm Gottfried von Waldeyer-Hartz (1836-1921) Proposed the “neuron theory” of the nervous system.

Wheater’s Functional Histology; 5th edition, 2006, Young, Lowe, Stevens and Heath; Churchill Livingstone Elsevier, Fig 7.4d
Neurons come in many shapes and forms.
The cell body of a neuron is referred to as the somata or perikaryons.

*Generic neuron*
Motor neuron with **Nissl** substance
Nissl substance is rough endoplasmic reticulum
Neurons have **dendritic** and **axonal** extension.

The **Law of Dynamic Polarization** states that neuronal signals only travel in one direction, from dendrites to the axon. In humans axons can be up to 1.5 meters in length. In a whale axonal length can reach up to 40 meters.

*Human Histology, 2nd edition, Stevens and Lowe, Mosby; Fig. 6-1*
Nissl substance is found in the neuronal cell body and dendrites, but not in the axon and the axon hillock or axon initial segment. The ability of neurons to synthesize proteins at growth cones and at the presynaptic terminus is very limited.
How do axons grow to reach their targets and how is an adult axon maintained and supplied?

Axonal cytoskeletal elements play a central role in the two types of transport along axons. As shown in this electron micrograph, axons contain two classes of cytoskeletal elements, neurofilaments (NF), which are intermediate filaments, and microtubules (MT).

Slow axonal transport (0.2-8 mm/day) transports many proteins along the axons. The mechanism of slow axonal transport is still controversial (current Stop-Go model).

Fast axonal transport (up to 400 mm/day) is the main mechanism to move cell organelles and membrane vesicles along the axon.
Fast axonal transport goes in both directions (anterograde and retrograde) and relies on the axonal microtubule cytoskeleton.
Microtubule-mediated transport of secretory granules along the axon of a neuron. The majority of granules move toward the growth cone (anterograde transport), but some move away from the growth cone (retrograde transport). There are also some granules that reverse direction, move intermittently, or stall. In this neurite, there is a partial build up of granules in the growth cone; this build up would have become more extensive with time due to the net anterograde granule flux.
Anterograde microtubule-mediated transport is mediated by kinesins and retrograde transport by dyneins. The microtubule-mediated transport enables the tip of an axon to grow during development and to regeneration. During this time is referred to as a growth cone.

Once a growth cone reaches its target, it might form synapses with its target cell. Synapses are predominantly supplied and maintained by fast, microtubule-mediated transport.

Snail growth cone stained for actin and microtubules.  

Drosophila growth cone  


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David Van Vactor, Havard University
Synapses can form between many different parts of neurons and between a neuron and a non-neuronal cell, e.g., a muscle or a secretory cell.

A single neuron can receive activating or inhibiting inputs from thousands of synaptic connections.
At a chemical synapse, neurotransmitter release is triggered by the influx of Ca\(^{2+}\) and postsynaptic neurotransmitter receptors receive the signal.
Neuromuscular junction (motor endplate)
Scanning EM of motor endplate on a muscle fiber
Motor endplates on skeletal muscle fibers

Photograph by AK Christensen from slide by Ray Truex, Dept of Anatomy, Temple Univ. School of Medicine
Myelination in the CNS involves oligodendrocytes and Schwann cells in the PNS.
This electron micrograph of a single myelinated axon shows a series of lighter (intraperiod) and darker (major dense) lines.
This electron micrograph of a single myelinated axon shows a series of lighter (intraperiod) and darker (major dense) lines.
Myelination is a dynamic process, which involves the ensheathment of the axon by the glial cell and subsequently the extrusion of cytoplasm from parts of the glial cell. Adhesive proteins on the cytoplasmic and extracellular side of the plasma membrane contribute to a tight apposition of the lipid bilayers.
Some residual cytoplasm remains in special parts of the myelin sheath.
Schmidt-Lanterman incisures (or clefts) are one type of cytoplasmic remnant, which are believed to be important for the maintenance of the myelin sheet.
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Electron micrograph of a Schmidt-Lanterman incisure
Nodes of Ranvier are areas of the myelinated axon that are not covered by the myelin sheath. They are bordered by paranodal regions, which form **paranodal junctions** with the axonal plasma membrane and also retain some Schwann cell cytoplasm.
Scanning EMs depicting nodes of Ranvier

Color Atlas of Histology; 1992; Erlandsen and Magney; Mosby Book; Fig 9-15
Transmission EM with node of Ranvier and paranodal region

Paranodal junctions

Color Atlas of Histology; 1992; Erlandsen and Magney; Mosby Book; Fig 9.14
Myelinated Nerve Fiber

The increased lipid content of the myelin sheath provides electrical insulation for the underlying axon.
Silver-stained cross section of a myelinated nerve
Nodes of Ranvier in a longitudinal nerve section
Each Schwann cell myelinates a single internode

Internode length can be up to 1.5 mm in the largest nerve fibers
Ion channels are concentrated at the nodes of Ranvier and the myelin sheath acts as an electrical insulator. This allows for saltatory conductance of the action potential and increases the transmission speed of the nerve impuls.

Depending on the diameter of the axon, myelination increases the action potential speed approximately 5 to 50fold (up to >110 m/sec).
One Schwann cell can ensheath multiple axons, but myelinates only one axon.
Small diameter nerve fibers are non-myelinated
Longitudinal section of an unmyelinated nerve
Wavy appearance of nerves
Connective tissue layers found in nerves: endoneurium surrounds axons, perineurium axon fascicles and epineurium the entire nerve.
Connective tissue layers in a peripheral nerve. Tight junctions between perineurium cells form an important isolating barrier.
Connective tissue layers in a peripheral nerve cross section
Three different basic types of neuronal structure
Autonomic ganglia with multipolar neurons are less organized than sensory ganglia (dorsal root ganglia) with pseudounipolar neurons.
Sensory Ganglia

- Two types: spinal (dorsal root) and cranial ganglia associated with spinal and cranial nerves, respectively

- Contain large sensory neurons and abundant small glial cells, called satellite cells

- Sensory neurons are pseudounipolar
Dorsal root ganglion with pseudounipolar neurons
Luxol blue staining of dorsal root ganglion
Efferent autonomic pathways

Autonomic Neurons in Sympathetic Ganglia are multipolar. These neurons are surrounded by satellite cells (glia cells marked by blue arrow heads).
Parasympathetic ganglia are located within or near their effector organs
Neuromuscular spindle (of Kühne)

Gamma motor nerve fibers innervate the intrafusal fibers

Sensory fiber endings are located on modified, small (intrafusal) muscle fibers

Alpha motor nerve fibers innervate the extrafusal fibers

Wheater's Functional Histology; 5th edition, 2006, Young, Lowe, Stevens and Heath; Churchill Livingstone Elsevier, Fig 7.33a
Neuromuscular spindle

Longitudinal section

Transverse section
EM of a muscular spindle in the equatorial region
Sensory mechanoreceptor at the tendon-muscle junction:

**Organ of Golgi or neurotendinous spindle**

This organ of Golgi is an encapsulated stretch receptor. The capsule contains collagen fibers and endings of a single nerve fiber that is connected with interneurons in the spinal cord. Stretching forces will result in a depolarization of the axon and an inhibitory muscle reflex to protect muscles and tendons from excessive force.
Cross section of the spinal cord
Somatic sensory neurons also have components in both CNS and PNS

pseudounipolar sensory neuron in a dorsal root (spinal) ganglion

Wheater’s Functional Histology; 5th edition, 2006, Young, Lowe, Stevens and Heath; Churchill Livingstone Elsevier, Fig 20.2a
Neuromuscular spindles are stretch receptors that regulate muscle tone via the spinal stretch reflex.
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Slide 10: Neuron to Brain, 3rd edition, 1992, Nicholls, Martin and Wallace, Sinauer, Fig 6
Slide 11: Human Histology, 2nd edition, Stevens and Lowe, Mosby, Fig. 6-1
Slide 14: Human Histology, 2nd edition, Stevens and Lowe, Mosby, Fig. 6-1
Slide 24: Photograph by AK Christensen from slide by Ray Truex, Dept of Anatomy, Temple Univ. School of Medicine