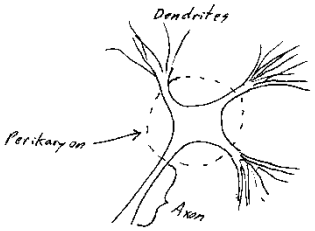
Neurons (nerve cells) - are the basic structural and functional units of the nervous system.

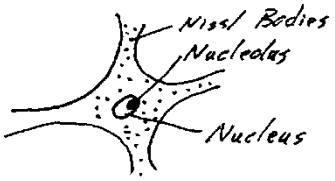
There are approximately 10 Billion neurons in the human body.

Neurons have the unique ability to transmit impulses (communicate).
Neurons that carry information into the central nervous system are termed afferent.
Neurons that carry information away from the central nervous system are termed efferent.

The makeup of a neuron. All neurons have three parts:

1. cell body (also known as the **soma** or perikaryon). This region has a centrally located prominent nucleus that usually has a prominent nucleolus. There are also Nissl Bodies present. Nissl Bodies are dense accumulations of RER and Polyribosomes for making proteins. The cell body also has Golgi, Mitochondria, some melanin pigment (substantia nigra), and some tubules and filaments.





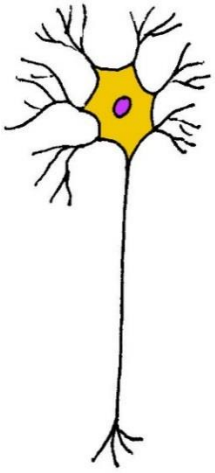
2. dendrites. Dendrites are essentially the antennae of a neuron. The contents of the dendrites are much the same as the soma. There will be some Nissl bodies in the dendrites. Dendrites also have dendritic spines or Gemules. These are spots where another neuron is contacting a dendrite. There may be as many as 100,000 other neurons synapsing on any given neuron. When new information is learned the dendrites usually grow more dendritic spines. This allows them to interact with even more neurons. It is estimated that for each new dendritic spine there may be up to 10,000 new synapses formed.

3. axon: The axon carries the outgoing information from the soma. The axon originates from an area of the some called the axon hillock. All neurons have an axon, but they only have one axon. This axon often has branches known as axon collaterals. Axons also typically branch profusely at their distal ends, known as axon terminals. Axons **may** be covered with an insulating sheath known as myelin. It is important to note that the dendrites and soma are **NEVER** myelinated. The cell membrane or plasmalemma of the axon is known as the axolemma and the cytoplasm is called axoplasm. The axon DOES NOT contain RER, Golgi or Nissl bodies but it DOES contain many neurofilaments and neurotubules as well as many membrane bound vesicles. These vesicles demonstrate axoplasmic flow. These vesicles transport neurotransmitter, made in the cell body, to the end of the axon. There is also flow back to the cell body. This is known as retrograde flow. This mechanism lets the neuron know that one of its processes is damaged. If remnants of the emptied vesicles do not return to the soma, the cell knows that they must have somehow leaked out along the way. The only way for them to leak out would be for the axon to be severed.

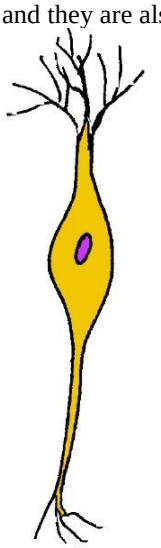
There are three types of neurons and they are classified by their number of cellular processes.

The Multipolar neuron has several dendrites and one axon. Most of the motor neurons of the body are this type of neuron. The motor neurons whose axons travel in peripheral nerves have their cell bodies (soma) in

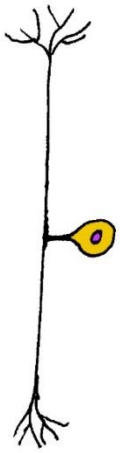
the ventral horn of gray matter in the spinal cord so they are often referred to as ventral horn cells.



The Bipolar neuron has a process at each end of the soma. One of these processes it the dendrite and the other, the axon. This type of neuron is relatively rare. They are found in acustic and vestibular nuclei associated with cranial nerve seven (CN VIII), they act as olfactory receptors in cranial nerve one (CN I), and they are also found in the retina.

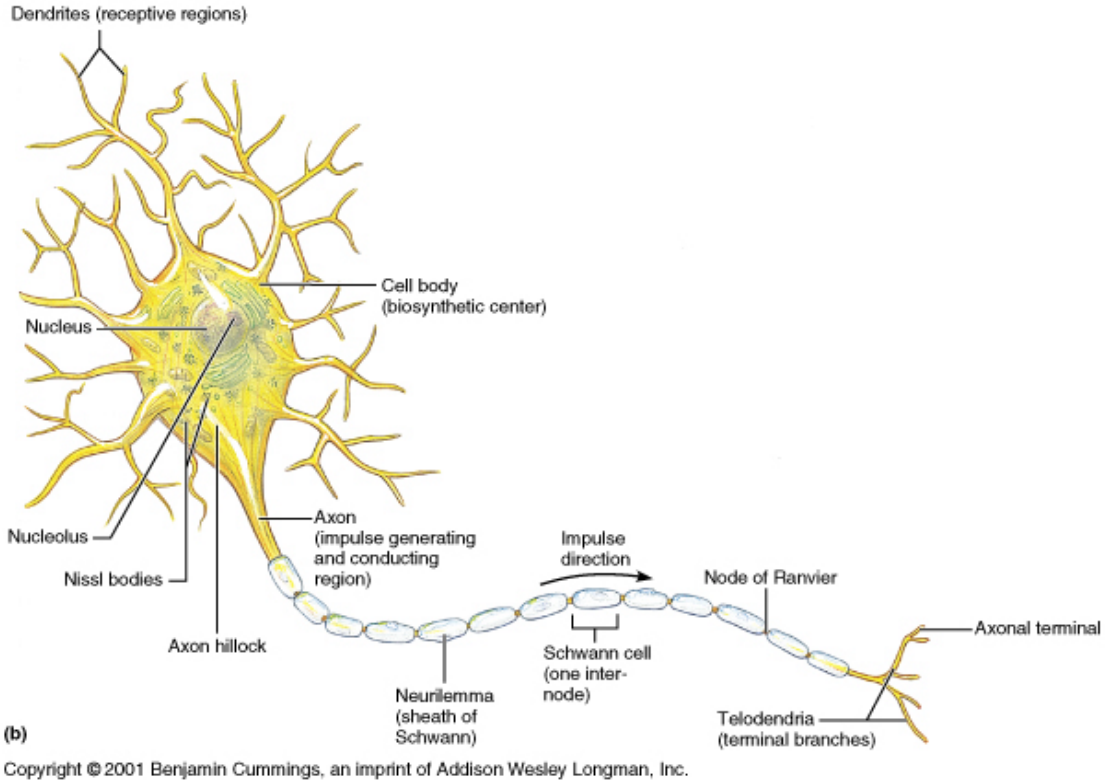


The Pseudounipolar neuron (often referred to as a unipolar neuron) has a single process extending from the soma. This process splits to form two extensions. All of the sensory neurons of our peripheral nervous system are of the psedounipolar variety.



Informational flow thought a neuron is unidirectional. Information is passed from one neuron to another via synapses. In a typical multipolar neuron most of the synapses will be on the dendrites, but there are also synapses directly on the soma. Information that enters into a dendrite will be passed along the dendrite to the soma. Information from synapses on the soma enters directly into the soma. However, not all information reaching the dendrites and/or soma will be passed on. Both the dendrites and the soma represent the receptive and integrational portions of the neuron. If the combined incoming signal/s are great enough, and outgoing signal will be generated at the axon hillock. To recap, information can enter the neuron at either the dendrites or the soma (or both) where this information can be summed up. If the combined information is great enough, and outgoing potential will be generated at the axon hillock.

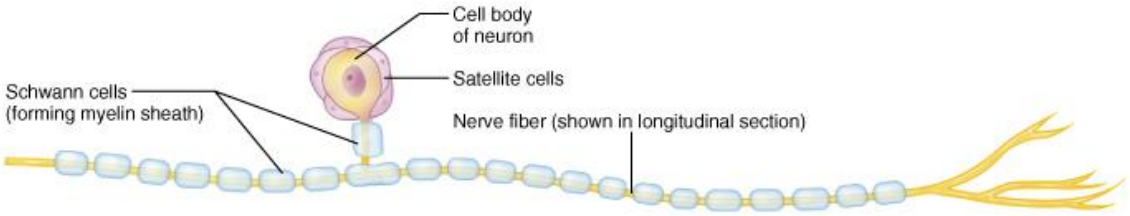
Under certain circumstances neurons (generally the axon) can be made to send an impulse that was not generated at the axon hillock. One of the principal rules in physics is that energy is neither created nor destroyed, but simply changes forms. If we apply this concept to a neuron, it is possible for external energy (energy from outside the neuron) to cause an axon to send an impulse. An example of this would be when neurons of a peripheral spinal nerve become pinched at an intervertebral foramen. Often times a patient with this condition will report excruciating pain in their lateral thigh of lateral leg. Examination shows no damage to that area but does show pinching (compression) of the sensory nerves from that area as they are nearing the spinal cord. This energy form this compression causes the axon of these sensory nerves to begin an impulse. When this impulse reaches the brain, the brain interprets that signal as one that started in the area where the neuron's sensory endings are located. After all, that is how the system is supposed to work. The brain has no way of knowing that the impulse was caused by compression energy entering the nerve somewhere along the pathway.



A typical Multipolar Neuron

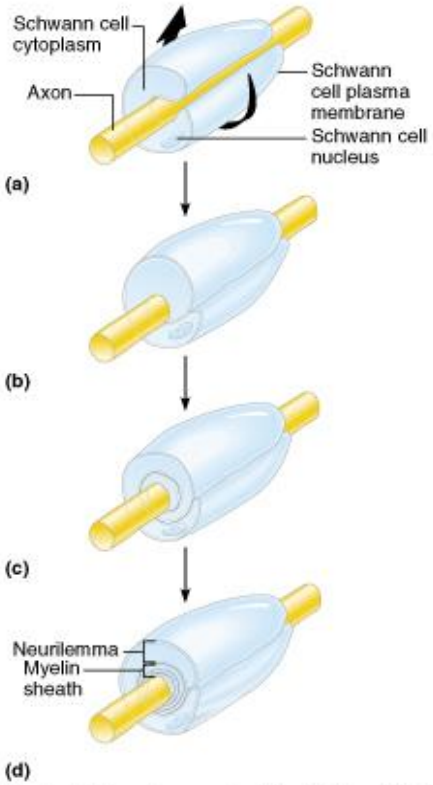
Neuroglia cells - are support cells for the neurons. There are 6 types of neuroglia cells:

1. neurolemmocytes (Schwann cells) - are responsible for the formation of myelin in the **peripheral nervous system**. Myelin is an insulating sheath that surrounds the axon. It functions to speed up the rate of impulse conduction.



(e) Sensory neuron with Schwann cells and satellite cells

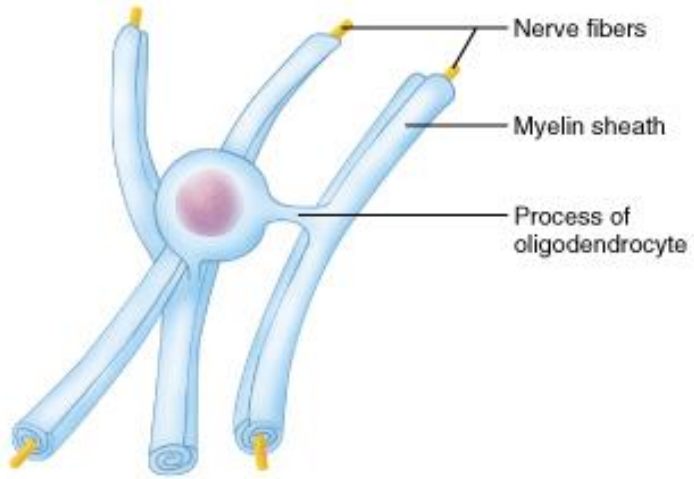
The process of myelination. During myelination in the peripheral nervous system, the neurolemmocyte (Schwann cell) tightly wraps itself around the axon. In this process, most of the cytoplasm is squeezed out and the actual insulation is the plasma membrane itself. The process of myelination in the central nervous system is similar. Its differences will be mentioned later. It is important to note that the neurolemmocyte is very short compared to the length of an axon therefor it takes many neurolemmocytes to myelinate a single axon. These neurolemmocytes do not actually touch each other, but rather leave bare areas along the axon (see the diagram above). These areas are referred to as axonal nodes (nodes of Ranvier).



As previously mentioned, myelination speeds up the rate of a nerve impulse. Let's take a brief look at nerve impulse conduction. As the width of an axon increases, the internal resistance to the flow of an impulse decreases. This means the wider the axon the faster the rate of impulse conduction. When myelin is added to the axon we can consider it to be part of the diameter of the axon. Based on this information alone it would seem that an axon of 5 µm and an axon of 2 µm in diameter but with 3 µm of insulating myelin (total diameter of 5 µm) would conduct an impulse at the same rate. However, there is another factor that we must consider. In a myelinated axon, charge only flows at the bare areas (the axonal nodes). The charge appears to jump from node to node. This process is called saltatory conduction. If you have a bare axon 1 meter long, the charge would have to flow that entire meter. By adding the myelin sheath the charge will

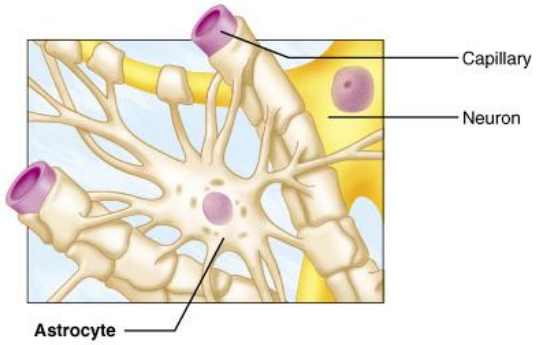
jump from node to node, and if we add up the total distance of the nodes along the axon, we find that it is only a fraction of the total axon length. Thus the charge has to flow over a shorter distance.

2. oligodendrocytes - are responsible for formation of myelin in the central nervous system. The process of myelination by oligodendrocytes is similar to that of the neurolemmocyte in that the cell wraps around the axon and the plasma membrane of the cell becomes that actual insulation. The main difference is that while a neurolemmocyte wrapped around a portion of a single axon, oligodendrocytes have cellular extensions that reach out and wrap around portions of many different axons.

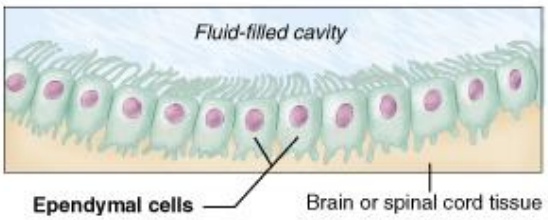


Oligodendrocyte

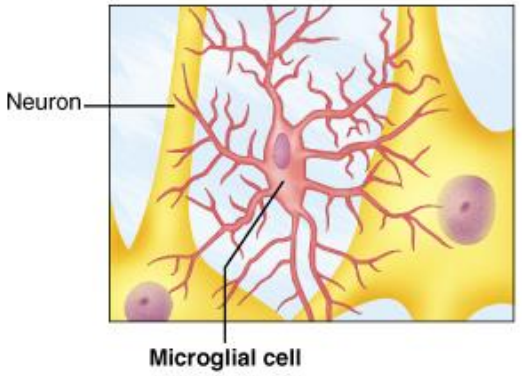
3. astrocytes - help form part of the blood-brain barrier. The brain does not have an immune system per se and therefore requires some other mechanism to protect it from pathogens that may be circulating in the blood stream. This is accomplished by the "blood-brain barrier." There are essentially two main components to the blood brain barrier. The first is a special type of capillary known as a continuous capillary. In this type of capillary, the endothelial cells that make up the wall of the capillary are held tightly together by "tight junctions." This means that any substance that passes from the blood to the brain from these capillaries must actually pass through the endothelial cells rather than between them. This allows for regulation of what passes through to the brain. The other component of the blood-brain barrier is made up of the astrocytes. These cells have extensions that wrap around the capillaries of the brain and around cellular processes of the neurons. The processes of the astrocytes also fit tightly together, thereby limiting the passage of substances from the capillary to the brain. Because the astrocyte forms a bond between capillaries and neurons, it is believed that it helps to provide structural support to the central nervous system. No other function has be ascribed to the astrocytes, however, a recent examination of a portion of Einstein's brain tissue revealed that he had approximately 10 times (10 X) more astrocytes that a normal brain. This finding suggests that astrocytes may play a role in intelligence.



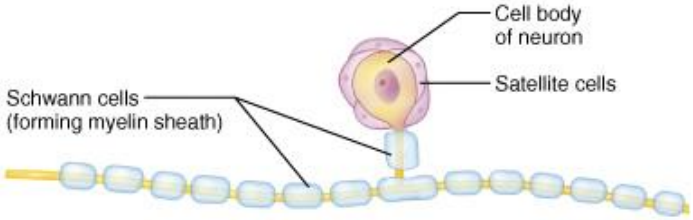
4. ependymal cells - cells that line the ventricles and the central canal of the spinal cord. Ependymal cells in the ventricles of the brain play an accessory role in the blood brain barrier in that they limit some movement of pathogens from the cerebrospinal fluid into the brain. Their role in this barrier is limited as is evidenced by conditions such as meningitis, where infections of the cerebrospinal fluid (bacterial, viral, and fungal) affect the surrounding neural tissue. Specialized collections of ependymal cells located in the ventricles of the brain are known as "choroid plexus." The choroid plexus functions to produce cerebrospinal fluid.



5. microglia - are phagocytic cells of the central nervous system. It is important to note that the brain does not have an immune system but rather relies on the blood-brain barrier for protection. Cells within the brain, both neurons and support cells, do occasionally die. The debris from these dead cells needs to be removed. It is the job of the microglia cells to phagocytize this debris.



6. satellite cells - provide structural support for neurons in the ganglia of the peripheral nervous system.



Sensory neuron with Schwann cells and satellite cells

The Synapse - The area where two (usually) neurons come into close contact (and communicate with each other) is called a **synapse**.

Functionally there are two types of synapses:

1. electrical synapse. These are found at gap junctions and are still poorly understood.

2. chemical synapse. Here the two neurons are separated by a space. A chemical messenger is released from one cell and traverses the space to exert an effect on the other cell. The messenger is called a **Neurotransmitter** and is usually Acetylcholine (Ach) or Epinephrine.

Structurally there are 4 types of synapses

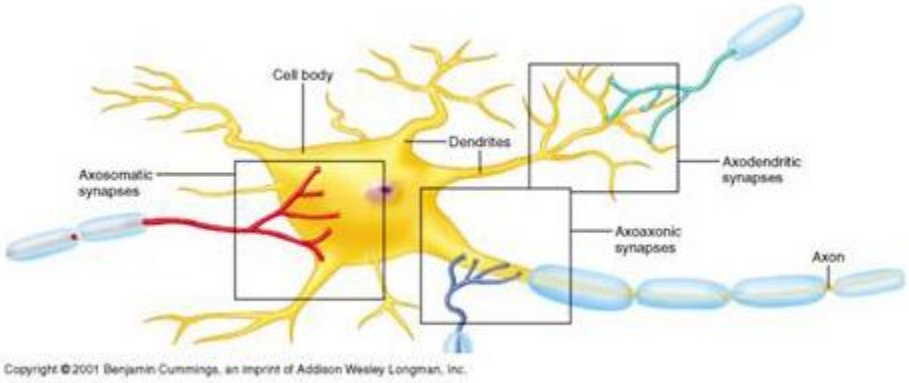
Four types of structural synapses

1. axodendritic synapse- axon of one cell to a dendrite of another cell. This is the most common type of synapse.

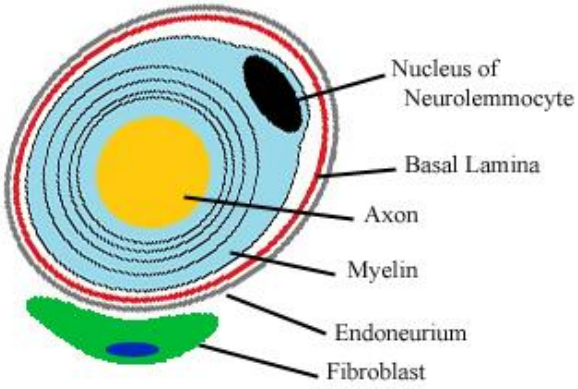
2. axosomatic - axon of one cell to the cell body of another cell. This is the second most common form of synapse.

3. axoaxonic - axon of one cell to the axon of another cell. Often this is an axon with a collateral that synapses with its own axon. This is used in a regulatory feedback loop.

4. dendodendritic - dendrite of one cell to a dendrite of another cell. This is the rarest of the synapses.



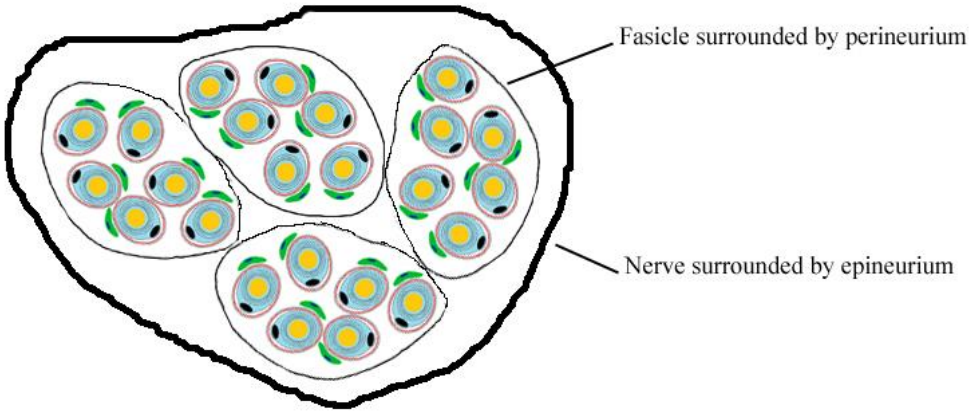
A typical neuron in cross section – A cross section through an axon shows that the axon is tightly wrapped in the myelin sheath created by the neurolemmocyte. Closer examination reveals the nucleus of the neurolemmocyte. This is surrounded by a thin layer known as the basal (or external) lamina. This in turn is surrounded by a layer of connective tissue known as the endoneurium. It is fairly common to find fibroblasts immediately outside the endoneurium.



The makeup of a nerve

So far we have looked at individual neurons, the functional units of the nervous system. Many neurons (thousands to hundreds of thousands) packaged together make up a nerve. There is an orderly arrangement to this process. Many of the axons, as shown above, are bundled together within a connective tissue wrapping known as perineurium. This structure is termed a fascicle. Many fascicles are bundled together within a connective tissue wrapping known as Epineurium. It is the epineurium that is the outermost wrapping of a nerve.

In recap: many neurons (axons) are bundles together to form a fascicle. And many fascicles are bundled together to make a nerve.



Clinical Issues

Multiple sclerosis is a demyelination disease. In this disease portions of the myelin sheath lose their ability to insulate the axon. They harden and form sclerotic plaques. Think about it. How would this condition affect an individual? What would be the effect near the onset of the disease versus later in the disease?

Severed Nerves: What happens if a nerve is severed? Recall that nerves are essentially bundles of axons and that axons are extensions of the neuron soma. That means that the distal portion of the severed axon is no longer connected to the cell. It is cut off from the metabolic and nutritional portion of the cell, therefore that distal portion of the axon dies. The neuron soma will soon know that the axon has been severed. How does it know? Think about it. We previously learned about axoplasmic and retrograde flow. How would this information be useful here? Also recall that the axon was surrounded by neurolemmocytes (Schwann cells) and a connective tissue known as the endoneurium. The neurolemmocytes are not a portion of the severed axon, and as such, are not cut off from their nutritional supply. As the distal portion of the severed axon dies, it leaves behind an endoneurial channel. The neurolemmocytes in the area then secrete factors that will draw macrophages into the area. These macrophages will clean up the cellular debris. At roughly the same time the proximal end of the severed axon begins to send out sprouts. If these sprouts find their way into an endoneurial channel they will follow that channel to its termination. That means that **IF** an axon were to sprout into the same endoneurial channel that it was originally following, the area would be reinnervated exactly as it was in its original condition. However, rarely is a single axon severed. Usually entire nerves are severed and if not the entire nerve, several of the fascicles within that nerve. What are the chances that each of those severed axons would find their original endoneurial channel? Not very good. The regenerating axons randomly find empty endoneurial channels and follow them to their termination. This means that the area will be reinnervated, but not exactly as it was, but relatively close. Through

physical therapy the brain can be retrained to know which neurons are now innervating the different areas. This is a slow process. Severed axons in the peripheral nervous system regenerate at a rate of approximately 2 mm per week. This means it can be months or even years before an area is reinnervated. Until recently nerve regeneration in the central nervous system was a very rare phenomenon. There are some drugs that have been shown to have limited success in getting neurons of the central nervous system to regenerate.