The Nervous System

The nervous system receives information from the external environment and the interior of the body, processes and interprets this input and causes a response in the various organ systems. It is the chief controlling and communicating system in the body and it does this by generating electrical signals.

The nervous system is generally organized into two parts – the Central Nervous System (CNS) that includes the brain and spinal cord, and the Peripheral Nervous System (PNS) that includes the nerves going to and from the CNS. The PNS itself is divided into the sensory (or afferent) division in which nerve fibers convey impulses to the CNS and the motor (or efferent) division in which nerve fibers convey impulses from the CNS to effector organs such as muscles and glands. The motor division can be further broken down into the somatic nervous system that controls skeletal muscles and the autonomic nervous system that controls cardiac muscle, smooth muscle and glands. Lastly, the autonomic nervous system is broken down into the sympathetic and parasympathetic divisions which we will treat later.

Histology
In addition to neurons, the cells that actually transmit the electrical impulses, there are also smaller cells generally called neuroglia which have a number of supporting functions. Neuroglia in the CNS include:

- Astrocytes are the most abundant type and make up about half the mass of the brain. Their numerous processes wrap around both neurons and brain capillaries, delivering nutrients to the neurons. They also absorb excess ions around the neurons.
- Microglia phagocytize microorganisms and dead neurons in the CNS. Normal white blood cells are unable to get into the CNS as they are into other parts of the body because of the tight junctions of brain capillaries (part of the blood-brain barrier).
- Ependymal cells are found in the lining of certain cavities in the CNS and may be ciliated. They help form Cerebrospinal Fluid from blood plasma and help to circulate the CSF.
- Oligodendrocytes wrap around neurons of the CNS forming a fatty myelin sheath. This insulates the neuron speeds the transmission of impulses.

In the PNS there is one important supporting cell that we will consider – the Schwann cell. These form a myelin sheath around the axons of neurons, insulating them and speeding the transmission of the impulse.

Neurons are the structural units of the nervous system. They have a high requirement for O_2 and nutrients. As adults, we have very little regeneration of nerve tissue. Basicly, the neurons we have entering adulthood must last the rest of our lives. Neurons have a cell body which contains the nucleus and a varying number of cytoplasmic processes of two types – dendrites (usually multiple) which receive impulses and convey them toward the cell body, and one axon which arises from a part of the cell body called the axon hillock and continues as a long process called a nerve fiber conveying impulses away from the cell body.

Although there is but one axon per neuron, it may branch at right angles. These branches, called axon collaterals are usually rare. At the end, however, the axon branches many times, typically thousands of times, into telodendria. The distal ends of the telodendria are enlarged into synaptic knobs. (pp 391 – 393)

Neurons may be structurally classified as

- Multipolar neurons. These have 3 or more (usually many more) processes. They are by far the most common type of neuron.
- Bipolar neurons. These have two processes – a dendrite and an axon. They are relatively rare but may be found in sense organs.
- Unipolar neurons. These have one process that emerges from the cell body and it quickly divides into a long process called an axon with branches at both ends. They are mostly sensory nerves found in the spinal cord.

Neurons may also be classified functionally as sensory (afferent) neurons that transmit impulses toward the CNS, motor (efferent) neurons that direct impulses away from the CNS, and association neurons that lie between sensory and motor neurons and function in areas where integration occurs. These last make up the bulk of the CNS and are mostly multipolar. (pp 395 – 396)

The Action Potential

When the membrane of an axon is at rest and no impulses are being conducted, there is a difference in electrical charge between the inside of the cell and the outside. A difference in electrical potential is measured in volts and the difference between the inside and outside of the membrane is typically –70 millivolts (1 millivolt = 1/1000 volt), the outside being more positively charged than the inside. The cell keeps it this way by maintaining a certain balance of positive and negative ions. Two ions, both positively charged are particularly important: Na^+ and K^+. At rest more Na^+ ions are found outside the cell and more K^+ ions are found inside the cell. An electrical impulse, or action potential, is generated when sodium channels open within the cell membrane. Because there are more Na^+ ions on the outside, there will be a rush of Na^+ into the cell. This is called depolarization. The electrical potential changes and becomes 0 and finally the inside becomes more positive the outside because of this influx of positive ions. Depolarization occurs quickly (fractions of a second). As the Na^+ channels close, K^+ channels begin to open and the process of repolarization begins. Since there are more K^+ ions inside than outside, there is a rush K^+ out of the cell until the electrical potential is back to where it was. (Because the K^+ channels are a little slow in closing, hyperpolarization actually occurs.) Although repolarization returns the electrical potential to where it was, there are now more K^+ outside and more Na^+ inside, a situation that must be reversed if the neuron is to fire again. This reversal is quickly accomplished by the sodium-potassium pump. The sodium and potassium channels do not open and close all at once but do so consecutively along the length of the axon. The effect is a wave of change in membrane potential toward the distal end of the axon. So there is a wave of depolarization followed by a wave of reporarization. (pp 361 – 363)

There must be enough stimulation of the neuron in order for the depolarization to produce an action potential, i.e. a certain threshold point must be reached for the nerve to fire. An action potential is an all or none phenomenon – either it happens or it doesn't. (p 365)

On unmyelinated axons the action potentials generate continuous conduction and are relatively slow. On myelinated fibers the conduction is called saltatory conduction. Myelination of a fiber occurs when Schwann cells wrap themselves around and around the axon. There may be thousands of these Schwann cells along the length of the axon but they do not overlap. There are small spaces between them called the Nodes of Ranvier. Sodium channels are concentrated at these nodes and the result is that the action potential "jumps" from node to node, increasing the speed of transmission significantly. Multiple sclerosis is an autoimmune disease affecting mostly young adults in which the myelin sheath is attacked by the person's own antibodies. The deterioration of the myelin may result in muscle weakness, speech difficulties, urinary incontinence among other symptoms. The speed of nerve transmission is slowed considerably and much of the insulation properties of myelin are lost so that "short circuits" occur. (p 366)

Synaptic Transmission

At the end of the axon, at the synaptic knob of the telodendrion, the electrical impulse may be transferred to another neuron (often to the dendrites of that neuron) or to a muscle or a gland across a synapse. The membrane of the first neuron (presynaptic neuron) does not directly touch the membrane of the receiving neuron (postsynaptic neuron). The membranes are always separated by a small space, the synaptic cleft. When the action potential reaches the distal end of the axon, each of the telodendria branches depolarize. Depolarization of the synaptic knob causes calcium channels to open in the knob's membrane allowing an influx of Ca^{++} ions. The Ca^{++}binds to vesicles with in the synaptic knob causing them to bind to the cell membrane and release their product into the synaptic cleft. The chemical that is released is called a neurotransmitter. This neurotransmitter diffuses across the synaptic cleft and binds to receptors which are sodium channels on the post synaptic membrane. This causes the Na^+ channels to open and depolarization continues down the postsynaptic neuron. The neurotransmitter cannot remain bound to the sodium channel keeping it open. The neurotransmitter is degraded by enzymes. The most common neurotransmitter in the body is called Acetylcholine. It is the one released into the synaptic cleft between motor neurons and muscle cells. The enzyme that breaks acetylcholine down is called acetylcholinesterase. A number of insecticides work by inhibiting acetylcholinesterase forcing the sodium channels on the muscle membrane to remain open and preventing further stimulation. (pp 367 – 370)

There are a number of different neurotransmitters exist in the body. Some are excitatory and some are inhibitory depending on the receptors involved. For example, dopamine is a neurotransmitter found in part of the brain. A deficiency of dopamine may lead to Parkinson's disease. Endorphins inhibit pain and are mimicked by narcotics. Epinephrine (adrenaline) may act as a neurotransmitter.

The Central Nervous System

The Brain
The brain may be divided into four regions: the cerebrum, the cerebellum, the diencephalon and the brainstem.
The **cerebrum** is the largest of these comprising about 80% of the volume of the brain. It is divided into two (R&L) cerebral hemispheres separated by the longitudinal fissure. The cerebrum as a whole is separated from the cerebellum by the transverse fissure. Each of the hemispheres has a superficial layer of gray matter (unmyelinated) referred to as the cortex. Deep to the cortex is the myelinated white matter and within the white matter are islands of gray matter called the basal nuclei. Most of the surface of the cerebrum is made up of raised ridges called gyri. These are separated by shallow grooves called sulci. Several sulci further divide the cerebrum into 5 lobes: frontal, parietal, temporal, occipital and insula. The first four are named for their overlying skull bones. The insula is not visible from the surface but is tucked up underneath the temporal lobe. The deeper central sulcus divides the frontal from the parietal lobe. The lateral sulcus separates the temporal from the frontal and parietal lobes. (pp387 – 391)

Just anterior to the central sulcus is the primary motor cortex located in the precentral gyrus of the frontal lobes. The primary motor cortex allows the conscious control of our voluntary movements. Anterior to this is the premotor cortex, important in controlling motor skills of a repetitive nature. The most anterior part is the prefrontal cortex. This region controls higher brain functions such as personality, judgement, planning, reasoning and abstract reasoning. Another area of the frontal lobe is Brocca's area. It lies, usually, within the left hemisphere and controls the motor aspects of speech.

Just posterior to the central sulcus is the primary somatosensory area that receives information from the various regions of the body. Posterior to this is somatosensory association area which allows an understanding of what it is we have sensed. The primary visual cortex is in the very posterior part of the occipital lobe and receives information from the eye. The primary visual cortex allows an understanding of what we have seen. Similarly, the primary auditory cortex of the temporal lobe interprets sound stimuli as pitch and loudness and the auditory association area allows us to make sense of what we have heard. Olfaction and gustation cortices are also found in the temporal lobe. (393 – 395)

Although each of the hemispheres is similar in appearance, it is often the case that one side performs functions not shared by the opposite side. This is called lateralization. The term cerebral dominance refers to the side of the brain that is most responsible for language, math and logic. In 90% of the population this is the left side. The opposite side is more creative, intuitive and emotional. Most (but not all) left dominant people are right-handed and right dominated people are left-handed.

Below the cortex is the white matter. These myelinated fibers are bundled into tracts and allow communication of the various parts of the brain and also with the lower parts of the CNS. Some tracts connect the two hemispheres. The largest of these connections is the corpus collosum. (p 398)

The **cerebellum** is also divided into two hemispheres. The white matter inside has the appearance of a branched tree and is called the arbor vitae. The function of the cerebellum is to provide for the smooth, coordinated movement of the skeletal muscles. It receives information from the cerebral motor cortex (via the brainstem) and at the same time it receives information from the muscles and tendons (from sensory receptors called proprioceptors) and then calculates the best way to coordinate the movement. (pp 407 – 408)

Within the **diencephalon** we will consider two important structures. The thalamus consists of two, egg shaped collections of nuclei connected by a structure called the intermediate mass of the thalamus. Virtually all sensory input to the cerebral cortex is sorted out, edited and directed first by the thalamus. It acts as a “switching station” directing impulses to the appropriate part of the cerebrum.

The hypothalamus is situated inferiorly to the anterior thalamus. Its functions are many despite its small size:

- It is involved in emotional perception such as fear, pleasure, rage nad the sensation of orgasm.
- It is the body’s thermostat, regulating temperature by initiating sweating and shivering.
- It regulates hunger and thirst and water balance within the body.
- It is an endocrine gland that produces hormones.
- It controls the brain stem and thus influences heart and lung activity and other visceral functions.

On either ends of the diencephalon are two endocrine glands, the pituitary and the pineal gland which will be discussed at a later time in the course. (pp 398 – 401)

There are three regions in the **brain stem**: the midbrain, the pons and the medulla oblongata (or simply medulla). It has a number of regulatory, coordinating and reflexive functions. For example, with the medulla is the cardiovascular center that regulates heartbeat and blood pressure. Also here is the respiratory center that controls the rate and depth of breathing. Such reflexive activities as coughing and vomiting are controlled in the brain stem.

On the medulla are two longitudinal ridges called pyramids. The fibers within cross to the opposite side just before exiting the cranium. This is referred to as the decussation of the pyramids. This results in each of the cerebral hemispheres controlling the voluntary movements on the opposite side of the body. (pp 402 – 406)

Ventricles

The brain ventricles (pp 433 – 434 and 464 - 465) are large spaces within the brain filled with cerebrospinal fluid (CSF) and lined with ependymal cells. The two large C-shaped ventricle in the cerebrum are called the R&L lateral ventricles. They approach each other anteriorly and there are separated by a thin membrane. The third ventricle flattened laterally and connects to the lateral ventricles via the two interventricular foramina. The third ventricle is in the diencephalon - the intermediate mass of the thalamus passes through the middle of the third ventricle. The fourth ventrical lies in the brain stem and is connected to the third ventricle via the cerebral aqueduct. The fourth ventricle is dorsoventrally flattened and has several small openings (apertures) in it that allow the CFS to connect to the subarachnoid space, a fluid-filled space surrounding the brain. Ependymal cells and capillaries form structures called choroid plexuses that are found on the roof of each ventricle. The ependymal cells take fluid from the plasma in the capillaries and secrete it as CSF. Many ependymal cells are ciliated and this helps to circulate the CSF.

Meninges

There are three connective tissue membranes that cover and protect the brain and spinal cord called the meninges. The most superficial menix is the dura mater. In the brain (but not the spinal cord) there is an outer periosteal layer of the dura comprised of the inner periosteum of the skull. Attached to this is the inner meningeal layer covering the brain and spinal cord. Deep to the dura mater is a very small space called the subdural space. Deep to this is the arachnoid mater, the middle menix. Below it is the larger subarachnoid space containing CSF and blood vessles. Web-like extensions support the arachnoid mater and attach to the underlying pia mater. The pia mater is a thin membrane that clings tightly to the surface of the brain. Knob-like projections of the arachnoid mater extend through the dura mater into a large vein called the sagittal sinus. Here CSF is absorbed back into the blood. (pp 463 – 464)

Disorders and Diseases

Cerebrovascular accidents, or strokes, occur because of ischemias in the brain. The deprevation of oxygen may be because of a blockage in the vessel, a hemorrhage (bleeding) or edema (swelling caused by fluid accumulation). Damaged neurons cause ion disruptions in other neurons and the subsequent inflammatory response continue to damage and destroy neurons.

Alzheimer's Disease is a chronic degenerative disease of unknown etiology. Memory loss, disorientation, shortened attention span and confusion are symptoms of this type of dementia. Tangles of degenerated fibers occur in association with β amyloid plaques. There is, over time, an actual shrinkage of the brain with the loss of many neurons. (pp 467 – 468)

The Spinal Cord

Once the medulla passes through the foramen magnum it becomes the spinal cord. It is covered with dura mater but not attached to the bone in the way the brain is. Between the bones of the vertebral column and the dura is a layer of adipose tissue that fills the epidural space. The spinal cord typically ends at L1 but the dura and arachnoid membranes extend down to S2. The subarachnoid space is filled with CSF. The very end of the cord tapers to a cone-shaped structure called the conus medularis. A continuation of the pia mater called the filum terminale anchors the conus to the coccyx . Thirty-one pairs of spinal nerves are attached to the cord and pass between the vertebrae. The nerves of the sacral and most of the lumbar nerves are attached to the very end of the cord forming the cauda equina. (pp 469 – 471)

A cross section of the spinal cord reveals a butterfly-shaped mass of gray matter surrounding a central canal filled with CSF. The posterior projections are called the dorsal horns and the anterior projections are called the ventral horns. (There are also lateral horns in the thoracic region.) The ventral horns contain the cell bodies of somatic motor nerves and their axons exit the spinal cord via the ventral roots. Sensory nerve axons enter the spinal cord via the dorsal roots and synapse with association nerves in the dorsal horns. The cell bodies of the sensory nerves are contained within the dorsal root ganglion. (A ganglion is a collection of neuron cell bodies outside of the CNS.) The ventral and dorsal roots fuse laterally to form the spinal nerves. The white matter of the spinal cord contains ascending, descending and transverse fibers that connect one part of the cord to another and the cord to the brain. (pp 471 – 473)

Damage to the ventral horns and roots results in paralysis of skeletal muscles. Damage to the dorsal horns and roots results in sensory loss. Because the more superior spinal nerves serve muscles of the upper body and as you proceed down the cord, the lower the spinal nerve the lower the muscles being served. If a spinal cord injury occurs in the cervical region, all four limbs may be paralyzed (quadriplegia). If the damage occurs between T_1 and L_1, the lower limbs may be paralyzed (paraplegia). Quadriplegia and paraplegia should not be confused with hemiplegia in which the right or left side of parts of the body become paralyzed. This may occur as a result of a stroke in the brain. (p 479)

Poliomyelitis is a viral disease which is transmitted by fecal contamination of water or food. In a relatively low percentage of cases the virus invades the ventral horns of the spinal cord (sometimes the medulla) and destroys motor neurons resulting in paralysis. Death could occur if , for example, the nerves innervating the respiratory muscles were destroyed. The World Health Organization has eliminated polio from most of the world by using the live virus Sabin oral vaccine. This is not used in the U.S. – only the killed virus Salk vaccine is used here. (p 479)

Spina bifida is caused by an incomplete closure during fetal development of the vertebral bone surrounding the spinal cord. There are various degrees of severity but in the most severe, a spinal cyst (called a myelomeningocele) forms containing meninges and parts of the spinal cord itself. Paralysis of the lower limbs and of visceral smooth muscle may result. Most cases are caused by a deficiency of the B vitamin folate during pregnancy. (p 481)

Spinal Reflexes

A reflex is a rapid, predictable, motor response to a stimulus. Some are intrinsic (inborn) and some are acquired (learned). Reflexes occur over specific neural pathways called reflex arcs. There are five basic components:

- receptor
- sensory neuron
- integration center in the CNS
- motor neuron
- effector organ (muscle or gland

Some reflexes involve the spinal cord. Many of these spinal reflexes do not directly involve higher brain functions, although the brain may receive information about the reflex simultaneously. For example, the patellar reflex, in which the knee is reflexively extended when the quadriceps tendon is reflexively over-stretched, involves the reception of the stimulus, a sensory nerve that synapses directly with a motor nerve in the spinal cord, and the quadriceps muscle which contracts. Such a reflex is called monosynaptic because it involves but one synapse, that between the sensory and the motor nerve. If more than two nerves are involved, as in those requiring an association neuron, the reflex is called polysynaptic. Some reflexes, such as the one just described are termed ipsilateral because the stimulus and response occur on the same side of the body. If the response occurs on the side of the body opposite to where the stimulus is received, it is termed contralateral. For example, if something causes one of your knees to buckle while you're standing, you may reflexively shift your weight to the opposite leg. A consensual reflex occurs when one side of the body is stimulated and both sides react. For example, when a bright light is shone in one eye, both the right and left eye pupils constrict. (pp 505 – 509)

The Peripheral Nervous System

The peripheral nervous system refers to neural structures outside of the CNS. A ganglion is a collection of nerve cell bodies outside of the CNS. Nerves are bundles of peripheral axons and almost always contain both sensory and motor nerves. Each axon, in addition to its myelin sheath, is covered with a connective tissue layer called an endoneurium. Groups of axons are bundled together with another connective tissue covering called the perineurium. Such bundles are called fascicles. Bundles of fascicles are covered with yet another connective tissue covering called an epineurium. Also within the epineurium may be blood and lymphatic vessels. This whole structure, then, is the nerve. (p 481)

Motor nerves control skeletal muscles, smooth muscles and glands. Sensory nerves may be classified according to what it is that activates them:

- Mechanoreceptors react to touch, pressure, vibration and stretch. Receptors to stretch and position are found in muscles and tendons and are called proprioceptors. Certain receptors sensitive to changes in blood pressure are called baroreceptors.
- Thermoreceptors respond to heat and cold.
- Photoreceptors respond to light.
- Chemoreceptors react to various chemicals and are important in taste and smell and also O_2 and CO_2.
- Nociceptors respond to painful stimuli.

There are twelve pairs of peripheral nerves called **cranial nerves** that are associated directly with the brain. They are numbered I through XII. I and II attach to the forebrain, III through XII to the brain stem. (pp 483 – 491)

I. Olfactory. This is our sensory nerve of olfaction (sense of smell).

II. Optic. This is our sensory nerve of vision.

III. Oculomotor. This is primarily a motor nerve that controls four of the six extrinsic eye muscles (the muscles used to control the direction of the eyeball.) It also innervates involuntary muscles in the eye that control pupil size and lens shape.

IV. Trochlear. This has primarily motor nerves that controls one of the intrinsic eye muscles.

V. Trigeminal. This is the largest of the cranial nerves and contains both sensory and motor nerves. It conveys sensations of touch, temperature and pain from the cornea, part of the face and teeth. Its motor nerves innervate our chewing muscles.

VI. Abducens. This has primarily motor nerves that controls one of the extrinsic eye muscles.

VII. Facial. It contains both sensory and motor nerves. It innervates the muscles of facial expression, the smooth muscle around the lacrimal gland and some of the salivary glands. Its sensory receptors are the taste receptors found on the outer 2/3 of the tongue.

VIII. Auditory (or Vestibulocochlear). This has primarily sensory nerves of hearing and balance.

IX. Glossopharyngeal. This has both motor and sensory nerves. Taste on the back of the tongue and control of pharyngeal muscles are among its functions.

X. Vagus. This is the only cranial nerve to extend beyond the head and neck. Its motor nerves extend to virtually every major visceral organ and to certain muscles of the throat used in swallowing. Sensory receptors include some that detect changes in blood pressure and CO_2.

XI. Accessory. This has primarily motor nerves supplying the muscles that move the head and neck.

XII. Hypoglossal. These are mostly motor nerves that control muscles of the tongue used in speech and swallowing.

The **spinal nerves**, containing both sensory and motor fibers, supply the rest of the body. They issue from the spinal cord in pairs and emerge between the bones of the vertebral column. They are named as follows: (p 492)

- the first 7 spinal nerves are named for the vertebra immediately inferior to the nerve. Thus spinal nerve C_1 emerges superior to vertebra C_1, spinal nerve C_4 emerges superior to vertebra C_4, etc.
- spinal nerve C_8 emerges below vertebra C_7, i.e. between C_7 and T_1.
- All of the other spinal nerves are named for the vertebra immediately superior to it. So, spinal nerve T_1 emerges between T_1 and T_2. Spinal nerve L_1 emerges between L_1 and L_2, etc.
- There is one small pair of coccygeal nerves called C_0.

Except for the thoracic nerves, parts of the other spinal nerves are interconnected with one another forming a lacework of nerves called a plexus. (p 492, fig.13.29 and p 494, fig. 13.31) These interconnections assure that each branch of a plexus contains fibers from several spinal nerves and that the fibers from one spinal nerve supply the body via several routes. There are four such plexuses: (494 – 499)

- the cervical plexus. A major nerve arising from the cervical plexus is the phrenic nerve supplying the diaphragm.
- the brachial plexus. Major nerves arising from the brachial plexus are the radial, medial and ulnar nerves that supply the arms and hands.
- the lumbar plexus. Major nerves arising from the lumbar plexus are the femoral and obdurator nerves supplying the anterior leg and medial thigh.
- the sacral plexus. The largest nerve arising from the sacral plexus is the sciatic nerve supplying the posterior leg. Two of the major branches of the sciatic nerve are the tibial nerve and the common fibular nerve.

The thoracic nerves supply abdominal and thoracic areas without forming plexuses.

Areas of the skin innervated by the cutaneous branches of a single spinal nerve are called dermatomes. (All spinal nerves except C_1 innervate dermatomes.) Because of overlaps, the destruction of a single spinal nerve does not result in total numbness anywhere. (pp 500 – 501 and fig. 13.35)

The Autonomic Nervous System

The ANS are motor nerves that innervate smooth and cardiac muscles and glands. The ANS almost always consists of a two-neuron chain: the preganglionic neuron resides in the brain or spinal cord; its preganglionic axon synapses with the ganglionic neuron; the postganglionic axon extends to the effector organ.

There are two divisions of the ANS: Sympathetic (fight or flight) and Parasympathetic (restin' and digestin'). There is usually (but not always) dual innervation of an organ by both divisions (Example: pupil dilation by sympathetic, pupil constriction by parasympathetic). All somatic motor neurons (not part of the ANS) release acetylcholine at their synapses with skeletal muscle fibers. Preganglionic axons also release acetylcholine as do postganglionic axons of the parasympathetic division. Postganglionic axons of the sympathetic division release the neurotransmitter norepinephrine. (pp 514 – 515)

Anatomy of the Parasympathetic
Preganglionic axons extend from several cranial nerves (particularly the vagus) and from neurons located in the spinal cord and extending through the sacral region. These are generally long axons that synapse with neurons located in ganglia near, on, or in the organ being supplied.
Vagal innervation includes the heart, lungs, esophagus, liver, gall bladder, stomach small intestine, kidneys, pancreas and parts of large intestine. Sacral innervation includes pelvic organs, genitals, parts of large intestine. (pp517 – 518)

Anatomy of the Sympathetic
Preganglionic neurons are located in spinal cord segments T1 through L2. The upper sympathetic nerves synapse with neurons of the sympathetic chain ganglia lying on either side of the vertebral column. The lower ones pass through the chain ganglia without synapsing and synapse with neurons in ganglia located outside the chain.
The effects of acetylcholine and norepinephrine may be stimulatory or inhibitory. The response of the effectors depends not only on the neurotransmitter but also on the receptor to which it attaches. (Example: β receptors to norepinephrine on the heart are stimulatory) (pp 519 – 521)