REVIEW OF THE AUTONOMIC NERVOUS SYSTEM

The nervous system is divided into two distinct, but interconnected systems. First is the central nervous system (CNS) which consists of the brain and spinal cord. The other is the peripheral nervous system (PNS) which can be subdivided into 3 parts. The first part of the PNS encompasses the cranial nerves (CN) which are numbered I through XII. The second part of the PNS includes the 31 pairs of spinal nerves. Spinal nerves are the dorsal primary rami that go to the back and ventral primary rami that go to the lateral and anterior body walls and to the limbs. The last part of the PNS is the autonomic nerves (or Autonomic Nervous System; ANS). The ANS is further subdivided into a sympathetic division and a parasympathetic division.

At this point in your education, you know about four functional types of fibers. The function of a nerve fiber describes what type of information it carries. The 4 functional types are somatic efferent (SE), somatic afferent (SA), visceral efferent (VE) and visceral afferent (VA). SE and SA fibers are considered somatic fibers in that they supply either skeletal muscles (SE) or conscious sensation from the skin, proprioception from the muscle spindles, etc. VE and VA fibers are associated with viscera or smooth muscles (ANS). VE fibers provide motor function to the smooth muscles of hollow organs (stomach, intestines, blood vessels, etc.), sweat glands and erector pili muscles (the little muscles that cause goose bumps). Since you have sympathetic and parasympathetic divisions of the ANS, you will have both parasympathetic and sympathetic VEs. Some literature consider the ANS as VE's. The sensory fibers associated with parasympathetic or sympathetic nerves, i.e., VAs, were overlooked and not included in the original classification of the ANS. This partly derives from the real lack of distinction between VA’s associated with either division of the ANS. In reality, generally where there is a VE, there will be a VA fiber. In other words, sympathetic VE nerves have VA fibers carrying unconscious sensation from viscera back to the CNS (the same goes for the parasympathetic division). Thus, while it makes more sense to say sympathetic or parasympathetic VA fibers, we will appease the old crusty anatomists (DLO'D) and refer to autonomic sensory nerves as either VA's associated with the sympathetics or VA's associated with the parasympathetics. One final important point to remember is that only the sympathetic division of the ANS is present in the limbs and body walls. The parasympathetic portion of the ANS is confined to viscera in the head, thorax, abdomen and pelvis. Parasympathetic nerves do not, and will not ever innervate structures (like blood vessels and sweat glands) in the body walls or limbs.

Realize that in gross anatomy, we call dissected structures "nerves", i.e., intercostal nerve, greater occipital nerve. These nerves, when viewed microscopically, are composed of thousands of nerve fibers. For example, the L5 spinal nerve contains over 15,000 nerve fibers. Each of these fibers will be either functionally a SA, SE, sympathetic VE or VA associated with sympathetics. By now you should understand why I said sympathetic VE (reread the above paragraph).

Before anything else gets described, lets go over the anatomy of the spinal cord and peripheral nerves. The legend is on the next page.
In the autonomic nerves I am going to discuss, remember that there are only VE and VA fibers. Never will a SA or SE fiber be found in any anatomical portion of the ANS. Also remember that a single VA, SA and SE neuron connects to (or from) its target structure all the way to the spinal cord. They only synapse at their axon terminals, no where else. VE neurons on the other hand, must synapse on a second neurons before reaching its target. In other words, THE VE SYSTEM IS A TWO NEURON SYSTEM AND IS THE ONLY TWO NEURON SYSTEM!! The first neuron has its cell body within the brainstem or spinal cord and is called preganglionic. The second neuron, which will be within a peripheral ganglion (outside the CNS), is called the postganglionic neuron.

**ORGANIZATION OF SYMPATHETIC VE NEURONS**

This is also called the thoracolumbar system. The name is derived from the location of the preganglionic sympathetic VE cell bodies. These cell bodies are located between T1 and L2 in the IML of the spinal cord. Remember that folks, **ALL** preganglionic sympathetic VE cell bodies are located in the IML between T1 and L2. These cells send their axons out the ventral roots, next through the white rami communicantes into the sympathetic chain ganglia. Now in the ganglia, the axons can do one of four things:

1. **Synapse at that chain and return to the segmental nerve to innervate the body wall.** Sweat glands, blood vessels and erector pili muscles in the body wall and limbs are innervated by sympathetic VE’s and associated VA’s. Since there are no ganglia in these places, the axons of VE preganglionic neurons must synapse in the chain ganglia before entering the spinal nerve. Therefore, preganglionic sympathetic VE fibers entering the sympathetic chain ganglia (through the “white” ramus) will synapse on a postganglionic neuron that will then send its axon out through the grey ramus communicantes into the segmental spinal nerve. Examples of this type of pathway include sympathetic supply through pre- and postganglionic fibers that get into intercostal nerves, ilioinguinal nerve, iliohypogastric nerve, etc.

2. **Project up or down the chain before synapsing and returning to the segmental nerve.** Another route for sympathetic VE’s is that the preganglionic fiber entering the chain ganglion to travel to another segmental level. In this case, it will enter (lie sympathetic chain and ascend or descend to reenter and synapse on a postganglionic sympathetic VE neuron at another level. The postganglionic fiber will then exit through the grey ramus to enter the spinal nerve. This is rather straight forward if changing levels occurs between T1 and L2.
However, realize that since the contribution of preganglionic fibers into the chain ganglia is confined to the T1 to L2 spinal cord segmental levels, white rami communicantes will only be found between T1 and L2. However, since the sympathetic chain and ganglia extend from the upper cervical to coccygeal vertebral levels, and since postganglionic sympathetic VE fibers must be able to get into all of the spinal nerves, grey rami must be present to connect the chain ganglia with the spinal nerves at all levels. Examples of this pathway include the sympathetic postganglionic VE fibers that enter the cervical plexus and innervates the neck and the brachial plexus and lumbosacral plexus and then innervate the arms and legs, respectively.

3. **By pass the ganglion to go to a splanchnic nerve destined for a preaortic ganglion.** The third route for sympathetic VE's is that the preganglionic fibers enter and leave the chain ganglia without synapsing. Examples of this pathway include the thoracic, lumbar and sacral splanchnic nerves. Remember that even through the preganglionic fibers have left the sympathetic chain, they still must find a postganglionic neuron before entering an organ. The postganglionic neuron is, of course, located in the preaortic (prevertebral) ganglia. Once the preganglionic fiber has synapsed on the postganglionic neuron, the Postganglionic axon will catch a ride on a blood vessel headed for an abdominal or pelvic organ. An example of this would be the innervation of the duodenum. The duodenal innervation would start with preganglionic neurons located between T1 and L2 (probably around T5). The preganglionic axon would pass through the chain ganglion, without synapsing, and go to form the greater thoracic splanchnic nerve. Then the greater splanchnic would then descend through the diaphragm and synapse on a postganglionic neuron located in the celiac ganglion. The postganglionic axon would then leave the celiac ganglion and travel with the common hepatic branch of the celiac artery to the gastroduodenal artery. The postganglionic fiber would then follow the branches of the gastroduodenal artery into the duodenum. And that, my friends, is how the duodenum is innervated. This is identical to the innervation of the kidney that is illustrated here.
VE Supply to the Abdominal Viscera

Preganglionic Fiber → Splanchnic Nerve

Diaphragm → Celiac Ganglion Synapse

Celiac A. → Adrenal Medulla

Kidney

No Synapse

4. The fiber may move up or down segments, synapse and the postganglionic leaves the chain ventrally like a splanchnic to innervate a target organ. The route for sympathetic VE’s is that the preganglionic axons enter the chain ganglia and synapse on postganglionic neurons. The postganglionic axon will then leave the ganglion ventrally (not through the chain) and head for an organ. This pathway occurs in the thorax where the cardiac nerves (postganglionic fibers) leave the chain ganglia, travel through the cardiac ganglionated plexus (without synapsing) to innervate the heart and or lungs.

VA NEURONS ASSOCIATED WITH THE SYMPATHETICS
The first rule is that wherever there is a sympathetic VE fiber, there will also be a VA fiber. The only exception is the grey rami communicantes. All viscera, including sweat glands and blood vessels are innervated by sensory nerves. The reason for this is that your nervous system needs to know if food is present in the GI tract, how dilated blood vessels are, how well viscera are being oxygenated, etc. VA fibers inform the nervous system of these conditions. VA fibers make their way back through spinal nerves, splanchnic nerves and cardiac nerves to the sympathetic chain ganglia. Remember that even if the VA fiber had to travel through a ganglion to get there, i.e., celiac and cardiac ganglia, it does not synapse in the chain ganglia. Once it reaches the sympathetic chain ganglion, it travels through it (without synapsing), then through the white ramus communicans and into the dorsal root. As a rule, all VA cell bodies from fibers, that have passed through the sympathetic chain, are located in the dorsal root ganglia. Now from the cell body, the central process travels through the dorsal root to enter the dorsal horn of the spinal cord. In the dorsal horn, it will synapse on other neurons that will relay the information throughout the CNS. Remember that for sensory information to get from an organ to the spinal cord, only one VA neuron is required.
ORGANIZATION OF THE PARASYMPATHETIC DIVISION OF THE ANS
As you know, the parasympathetics are also called the cranio-sacral division of the ANS. This name indicates the position of the parasympathetic preganglionic cell bodies. Some are in the brainstem associated with cranial nerves III, VII, IX and X, while others are in the IML of the S2 to S4 spinal cord levels. Remember, the parasympathetic innervation does not extend to the body wall or limbs.

THE VAGUS - VE
The vagus nerve innervates the heart, lungs and abdominal organs down to the left colic (splenic) flexure. Vagal parasympathetic preganglionic VE cell bodies are located bilaterally in the medulla of the brainstem. These preganglionic axons exit through the jugular foramen in the base of the skull as the right and left vagus nerve. They travel through the neck into the thorax where approximately three twigs from each vagal trunk head for the deep and superficial cardiac ganglia. Here they will synapse on postganglionic parasympathetic cell bodies innervating the heart and lungs. The vagal trunks will continue onto the surface of the esophagus where they split into a plexus. At the caudal end of the esophagus, the vagal trunks reform into an anterior trunk (which is derived from the left vagus) and a posterior vagal trunk (derived from the right vagus). The anterior and posterior vagal trunks pierce the diaphragm and pass through the celiac ganglia where they help form the celiac plexus. Remember that the celiac ganglion contains postganglionic cell bodies for the sympathetic nervous system only. There are no postganglionic parasympathetic cell bodies in the celiac or any other preaortic ganglia. The preganglionic parasympathetic fibers continue on through

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the celiac ganglia, without synapsing, and catch a ride on all the branches of the celiac artery. They travel to organs with the arteries; i.e. preganglionic parasympathetic fibers to the spleen will wrap around and travel with the splenic artery. Once the preganglionic fiber reaches its organ, it will synapse on a postganglionic parasympathetic cell body which will lie in or on the organ itself. The postganglionic parasympathetic axon will then trail off and innervate the smooth musculature of the organ.

VA’s WITH THE VAGUS
As in the case with the sympathetics, VA fibers also travel with the vagus nerves. As a matter of fact, approximately 90% of the fibers within the vagi are VA. Therefore, the sensory component of the vagus must be somewhat important, it is. Parasympathetic VA’s from the heart and lungs are involved with reflexogenic regulation of heart rate and bronchodilation. In the abdomen, parasympathetic VA fibers inform the CNS of the presence of food in the bowel. This contributes to reflex mechanisms that propel the food bolus into the next bowel segment.

VA of CN X - Vagus

No Synapses
In the
Cardiac Ganglion
VA Fiber pass
Through,
No Synapses
in Celiac Ganglion

Esophageal Plexus

VA Nerve Endings
In wall of Gut

Remember that only one VA neuron is required to get an impulse from the target to the CNS. The processes of vagal afferents travel back up through the preaortic ganglia, through the thoracic vagal trunks into the vagus nerve in the neck. Just before the vagus enters the cranium, there is a large swelling on the nerve. Within this swelling, called the nodose ganglion, are ALL of the pseudounipolar cell bodies of VA vagal afferents.

SACRAL 2 to S4 - VE
To understand the reason why you need parasympathetics at S2-4, consider this. If you pulled the intestines out, all 30 something feet of them, and held them up by the esophagus and then you put the vagus next to them and said, "Okay, go innervate!" The vagus would start innervating with glee. However, there is a finite number of vagal VE fibers. So by the time everything, down to the left colic flexure, gets innervated there are simply no more vagal VE fibers left to do anymore innervating. Therefore, to provide parasympathetic VE fibers to the descending and sigmoid colon, rectum and, pelvic viscera, you need another source of VE parasympathetic fibers. That is where the parasympathetics at S2-S4 come in.

Parasympathetic preganglionic cell bodies to the lower GI tract (the hindgut) are located in the intermediolateral (IML) cell column between S2-S4. Now don’t get these confused with (i.e. SYMPATHETIC PRE-GANGLIONIC cell bodies located in the IML between T1 and L2! Anyway, these cell bodies send their preganglionic axons out the ventral root into the spinal nerve. Remember, that in the sacrum, the dorsal primary rami exit the dorsal foramina of the sacrum while the ventral primary rami exit the ventral sacral foramina.
As the spinal nerve branches into dorsal and ventral primary rami, the preganglionic parasympathetic fibers stay in the ventral primary ramus. Once out of the ventral sacral foramina, the preganglionic parasympathetic fibers, branch off the S2-S4 ventral primary rami as the pelvic splanchnic nerves (get it Pelvic splanchnics – Parasympathetic).

Understand that these pelvic splanchnic nerves have absolutely nothing to do with the sympathetic chain. Sacral splanchnics (Sympathetic) leave the sympathetic chain to join the pelvic (hypogastric) plexus.

The pelvic splanchnics then either travel to a pelvic organ (bladder, uterus, prostate, etc.) or enter the hypogastric plexus (which is just a continuation of the preaortic plexus into the pelvis). Once in the hypogastric plexus, the preganglionic parasympathetic fibers ascend to the inferior mesenteric artery. The fibers will then follow the branches of the inferior mesenteric artery out to the descending and sigmoid colon and the rectum.

VA's WITH S2 - S4 NERVES (See Fig. 4)
There are also VA fibers associated with the parasympathetics at S2-S4. These fibers travel back along the inferior mesenteric artery, through the hypogastric plexus, through the pelvic splanchnics, through the ventral primary rami, to the spinal nerve and into the dorsal root. The cell bodies (pseudounipolar) of sacral VA neurons are located in the dorsal root ganglia. The proximal process leaves the dorsal root ganglia and travels through to the dorsal horn of the spinal cord where it participates in visceral reflexes or is perceived as pain.