Vegetative nervous system

1. General characteristic of the VNS

2. Peculiarities of the vegetative reflex arch

3. Sympathetic nervous system

4. Parasympathetic nervous system

5. Types of reflexes, referred pain

6. Development of the vegetative nervous system
NERVOUS SYSTEM
(MORPHOLOGICAL CLASSIFICATION)

CENTRAL

Brain + Spinal cord

PERIPHERAL

12 pairs of cranial nerves + 31 pairs of spinal nerve
NERVOUS SYSTEM
(MORPHOFUNCTIONAL CLASSIFICATION)

VEGETATIVE (AUTONOMIC)

Region of supply: smooth muscles, glands
Action: slow
Duration: permanent
Functions: metabolism, growth, homeostasis

SOMATIC (ANIMAL)

Action: fast
duration during the action of excitant motion

Functional differences

Structural differences

*has not segmental structure
*ascending part does not form visible nerves
*vegetative nerves form plexuses around blood vessels

*has segmental structure
*ascending & descending fibers form visible nerves
I neuron: *in the spinal ganglion

II neuron: *posterior horn of the spinal cord

III neuron: *anterior horn
* the II neuron finishes in the spinal cord
* descending part is unineuronal
I neuron: *in the spinal ganglion

II neuron: * lateral horn of the spinal cord

III neuron: *outside of the spinal cord, in the vegetative ganglion
* the II neuron doesn’t finish in the spinal cord
* descending part is bineuronal
* postganglionic fibers form the visceral and somatic parts
* preganglionic fibers form the white communicating branch
* postganglionic fibers form the gray communicating branch
- There are 2 neurons of efferent way. The second neuron is located in ganglion.
- Preganglionic fibers are myelin – associated.
- Postganglionic fibers are without myelin.

**Differential features:**

- **Mediator**
  - Sympathetic nervous system – adrenalin, noradrenalin
  - Parasympathetic nervous system – acetylcholine

- **The length of fibers**
  - Sympathetic nervous system – short pre- and long postganglionic fibers
  - Parasympathetic nervous system – long pre – and short postganglionic fibers
somatic NS

1 - visceral part of the VNS
2 - somatic part of the VNS
to the glands of the skin, blood vessels of the skin and muscles/

skeletal muscle

preganglionic fibers

paravertebral ganglion

spinal ganglion

prevertebral ganglion

post-ganglionic fibers

glands

smooth muscles

internal organ

vegetative NS
Course of spinal nerve fibres and their communications with sympathetic trunk (diagram).
**White Rami**

Connecting the spinal nerves to each sympathetic trunk are rami communicantes. Carry preganglionic sympathetic axons from the C8–L2 spinal nerves to the sympathetic trunk. **Associated only with the C8–L2 spinal nerves.**

Preganglionic axons are *myelinated.*

The white ramus has a whitish appearance.

**Gray Rami**

Carry postganglionic sympathetic axons from the sympathetic trunk to the spinal nerve. Axons are **unmyelinated.**

gray rami have a grayish appearance

Similar to “exit ramps” on a highway.

**Connect to all spinal nerves.**

Sympathetic information that starts in the thoracolumbar region can be dispersed to all parts of the body.
Divisions of the ANS

• Two divisions
  – Parasympathetic division
  – Sympathetic division

• Divisions are similar:
  – both use a preganglionic neuron (cell body in the CNS)
  – Both use a postganglionic neuron (cell body in the ganglion)
    • innervates muscles or glands.
    – Both are involuntary
    – Both are concerned with the body’s internal environment (homeostasis)

• Divisions perform dramatically different functions.
DIVISIONS OF THE VNS

Parasympathetic
“rest-and-digest” division

Sympathetic
“fight-or-flight” division

Functions: Regulates body temperature. Coordinates CV, respiratory, excretory & reproductive activities.
COMPONENTS OF AUTONOMIC NERVOUS SYSTEM

Parasympathetic (craniosacral) division

*Origin:* preganglionic neurons located in brainstem nuclei & lateral horns of S2-S4 segments of the spinal cord.

*Functions:* rest & digest response, brings body to homeostasis.

Sympathetic (thoracolumbar) division

*Origin:* preganglionic neurons located in lateral horns of C8-L2 of the spinal cord.

*Functions:* emergency stimulation, fight or flight response, involves with homeostasis.
Structural differences of the sympathetic and parasympathetic nervous systems

SNS
- central fiber
- peripheral fibers
- preganglionic, postganglionic ganglia
- paravertebral, prevertebral

PSNS
- central fiber
- peripheral fibers
- preganglionic, postganglionic ganglia
- terminal, preterminal

Sympathetic division
- Salivary glands
- Trachea
- Bronchi
- Postganglionic fibers
- Proganglionic fibers

Parasympathetic division
- Heart
- Liver
- Gallbladder
- Stomach
- Kidney
- Alimentary tract
- Urinary bladder
The Sympathetic Division

- Also termed the thoracolumbar division
- Primarily concerned with preparing the body for emergencies.
  - referred to as the “fight-or-flight” division
- Increased sympathetic activity results in:
  - increased alertness
  - Increased metabolic activity
Sympathetic division

Preganglionic neurons

- located within the lateral horn of the C8-L2 spinal segments
- their axons enter ventral roots of the C8-L2 spinal nerves
- axons synapse in sympathetic ganglia /para- or prevertebral/
- all preganglionic fibers are stimulatory
- fibers are divergent
- 1 preganglionic fiber can synapse with 1 of ganglionic neurons
Vegetative component of the spinal nerves

**SYMPATHETIC CHAIN**
- 3 cervical, 11-12 thoracic, 2-5 lumbar, 4-5 sacral & 1 coccygeal sympathetic ganglia

- common spinal nerve branches to **white ramus communicans**
  - myelinated, preganglionic fibers
- common spinal nerve receives **gray rami communicans** from ganglia
  - unmyelinated, postganglionic fibers

**NOTE:**
- preganglionic fibers only from C8-L2
- every spinal nerve receives postganglionic fiber
Left and Right Sympathetic Trunks

- Immediately anterior to the paired spinal nerves are the left and right sympathetic trunks.
- Each is located immediately lateral to the vertebral column.
- A sympathetic trunk is like a pearl necklace:
  - the “string” of the “necklace” is composed of bundles of axons
  - the “pearls” are the sympathetic trunk (or paravertebral) ganglia
    - house sympathetic ganglionic neuron cell bodies
- One sympathetic trunk ganglion is approximately associated with each spinal nerve.
- Cervical portions
  - three sympathetic trunk ganglia
    - superior, middle, and inferior cervical ganglia
    - opposed to the eight cervical spinal nerves.
Nerves and plexuses of thoracic organs; right aspect (1/4).
BRANCHES OF THE SYMPATHETIC CHAIN

- carotid nerves (ext., int)
  - jugular nerve
- C1 g. - the larynx and pharynx
  - superior cervical nerve of the heart
- C2 g. - middle cervical nerve of the heart
  - subclavian branches
- C3 g. - branches to the vagus and phrenicus nerves
  - inferior cervical nerve of the heart
- C3 + Th1 = g. stelatum
  - rr. bronchiales - plexus pulmonaris
  - rr. esophagei
- Th1-Th4-5 — plexus aorticus thoracicus
  - nervi cardiaci thoracici
- Th5-9 — n. splanchnicus major
- Th10-12 — n. splanchnicus minor
- L1-5 — plexus aorticus abdominalis
  - rectalis
  - vesicalis
- S1-Co — plexus cavernosus penis
  - ductus deferentis
  - prostaticus
  - uterovaginalis
Lower thoracic and lumbar ganglia:

- Visceral and autonomic disorders of the organs of abdominal cavity.

Solar(celiac) plexus:

- Dull pain in the abdomen
- Increased aorta pulsation
- Instable AP
- Instable stool
- Poli – oligouria
- Glucosuria
Differ from the sympathetic trunk ganglia.
Are single structures, rather than paired.
Are anterior to the vertebral column, on the anterior surface of the aorta.
Located only in the abdominopelvic cavity.

Prevertebral ganglia include:
the celiac ganglion
superior mesenteric ganglion
interior mesenteric ganglion.
• Composed of preganglionic sympathetic axons.
• Run anteriorly from the sympathetic trunk to most of the viscera.
• Should not be confused with the pelvic splanchnic nerves associated with the parasympathetic division.
• Larger splanchnic nerves have specific names:
  - greater thoracic splanchnic nerves
  - lesser thoracic splanchnic nerves
  - least thoracic splanchnic nerves
  - lumbar splanchnic nerves
  - sacral splanchnic nerves
• Terminate in prevertebral (or collateral) ganglia called “prevertebral” because they are immediately anterior to the vertebral column.
• Prevertebral ganglia typically cluster around the major abdominal arteries and are named for these arteries.
Parasympathetic division is also termed the craniosacral division because its preganglionic neurons are housed within nuclei in the brainstem, within the lateral gray regions of the S2–S4 spinal cord segments. Postganglionic neurons in the parasympathetic division are found in terminal ganglia: are located close to the target organ & intramural ganglia: located within the wall of the target organ.
Nerves associated with the parasympathetic division:

- the oculomotor (CN III)
- facial (CN VII)
- glossopharyngeal (CN IX)
- vagus (CN X)

First three of these nerves convey parasympathetic innervation to the head.

Vagus nerve is the source of parasympathetic stimulation for:

- organs of the neck,
- thoracic organs,
- most abdominal organs.
# Parasympathetic nervous system

## Cerebral part

<table>
<thead>
<tr>
<th>Nuclei</th>
<th>Nerve</th>
<th>Neuron-effector</th>
<th>Region of the supply</th>
</tr>
</thead>
<tbody>
<tr>
<td>V. Iacubovich</td>
<td>III /oculomotorius/</td>
<td>g.ciliare /in the orbit/</td>
<td>m.constrictor pupillae m.ciliaris</td>
</tr>
<tr>
<td>n.Perl</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>n.salivatorius superior</td>
<td>VII /facial/</td>
<td>g.sphenopalatinum /fossa pterygopalatina/ g.submandibulare /fossa glandae submandibularis/</td>
<td>gl. lacrimalis + glandulae mucosae /nose + mouth/ gl.submandibularis gl.sublingualis</td>
</tr>
<tr>
<td>n.salivatorius inferior</td>
<td>IX /glossopharyngeus/</td>
<td>g.oticum /foramen ovale/</td>
<td>gl.parotidea</td>
</tr>
<tr>
<td>n.dorsalis</td>
<td>X /vagus/</td>
<td>g.g. terminales</td>
<td>Internal organs of the neck, thorax, abdominal cavity /to the level of the descendens colon/</td>
</tr>
<tr>
<td></td>
<td></td>
<td>g.g. intramurales</td>
<td></td>
</tr>
</tbody>
</table>

## Sacral part:

* supplies the descendens colon, sigmoid colon, organs of the pelvis
Parasympathetic division is also termed the craniosacral division because its preganglionic neurons are: housed within nuclei in the brainstem, within the lateral gray regions of the S2–S4 spinal cord segments. Postganglionic neurons in the parasympathetic division are found in terminal ganglia: are located close to the target organ & intramural ganglia: located within the wall of the target organ.
Dual Innervation of the organs by the ANS

Innervate organs through specific axon bundles called autonomic plexuses.

Communication by chemical messengers, called neurotransmitters, specific in each division of the autonomic nervous system.

Usually all organs are innervated by both divisions of the autonomic nervous system.

Maintains homeostasis through autonomic reflexes that occur in the innervated organs.
Two neurotransmitters are used in the ANS: acetylcholine (ACh) and norepinephrine (NE).

Neurotransmitters are released by the presynaptic cell. They bind to specific receptors in the postsynaptic cell membrane. Binding has either an excitatory or an inhibitory effect on the effector, depending on the specific receptor.

Both the preganglionic and postganglionic axons in the parasympathetic division release acetylcholine and thus are called cholinergic.

The preganglionic axon and a few postganglionic axons in the sympathetic division are also cholinergic.

Most of the postganglionic axons of the sympathetic division release norepinephrine and are called adrenergic.
Sympathetic Nervous System

- Also called thoracolumbar system (T1-L2)
- Preganglionic cell bodies in lateral horn
- Preganglionic fibers leave spinal cord with ventral roots
- Leave spinal nerve via white rami communicans
- Postganglionic cell bodies in ganglia
  - Sympathetic chain (paravertebral)
  - Collateral (prevertebral)
• Sympathetic fibers may:
  – Synapse at that level, re-enter spinal nerve via gray ramus communicans
  – Go up the chain before (or after) synapse
  – Go down the chain before (or after) synapse
  – Go through without synapse in chain (as splanchnic nerves)
• Splanchnic nerves
• Postganglionic fibers go to effector organs
• Preganglionic fibers are relatively short; postganglionic relatively long
Sympathetic nervous system

- Consists of the cells of lateral horn of spinal cord from C8 to L2
- The axons within the anterior roots leave the spinal cord
- Some of them are finished in sympathetic trunk (it consists of 20 – 23 ganglia) – 3 cervical, 10 – 12 thoracic, 3 – 4 lumbar, 4 pelvic.
- The rest fibers are going to the prevertebral ganglia or plexuses
Parasympathetic nervous system

- **Mesencephalic level** (nuclei of Perlea and Yakubovich), the fibers are going within the III CN and provide innervating of m. Sphincter pupillae, m. Ciliaris

- **Bulbar** (n. salivatorius superior et inferior, n. dorsalis nervi Vagi) within VII, IX, X CN’s innervate parotid, sublingual, submandibular glands and internal organs (except the pelvic organs)

- **Sacral part** – the cells of lateral horn S2 – S4 – innervating of pelvic organs
Two sources of parasympathetic preganglionic fibers

1) the brain stem via cranial nerves III, VII, IX, X
2) sacral part of spinal cord via spinal nerves S2 through S4

Parasympathetic ganglia lie in body close to organ or body part innervated, thus preganglionic parasympathetic fibers tend to be long.

Preganglionic fibers remain in cranial or sacral nerve in which they exited CNS until they reach target.

All organs of body except liver receive parasympathetic input, but skin and blood vessels generally not innervated.

**Function:**
When stimulated, heart rate decreases, blood pressure falls, blood is directed away from skeletal muscles to viscera
Generally relaxes body, although increases activity in digestive system and a few other organs
Cervical ganglia, nerves of the heart

Nerves and plexuses of thoracic organs; right aspect (34).

Nerves and plexuses of abdominal and pelvic cavities
Enteric nervous system
Two arrays of ganglia and nerves distributed along the gut

Myenteric plexus
Ganglia and nerves located between the longitudinal and circular muscles of the intestines

Submucosal plexus
Ganglia and nerves within the submucosa (layer of fibrous connective tissue that attaches a mucus membrane to its subadjacent parts)

Enteric ganglia receive input from both sympathetic and parasympathetic systems
Ganglia contain many local neurons that allow enteric system to function semiautomously
VEGETATIVE PLEXUSES

Collections of sympathetic postganglionic axons and parasympathetic preganglionic axons, as well as some visceral sensory axons. Close to one another, but they do not interact or synapse with one another. Provide a complex innervation pattern to their target organs.

Cardiac plexus
increased sympathetic activity increases heart rate and blood pressure, while increased parasympathetic activity decreases heart rate

Pulmonary Plexus
parasympathetic pathway causes bronchoconstriction and increased secretion from mucous glands of the bronchial tree. sympathetic innervation causes bronchodilation

Esophageal Plexus
parasympathetic axons control the swallowing reflex

Abdominal aortic plexus
consists of the celiac plexus, superior mesenteric plexus, and inferior mesenteric plexus

Hypogastric plexuses
Autonomic plexuses of abdomen

**The celiac plexus:** - It lies around the celiac trunk
* it has 5 sympathetic nodules /2 coeliac, 2 aortorenal, 1 superior mesenteric ganglion/
*Formation:*
a) sympathetic postganglionary fibers
b) parasympathetic preganglionary fibers from nn.vagi /mainly the right/

**Branches:**
around the celiac trunk and its branches /gastric, splenic, hepatic/
---- the superior mesenteric artery, the renal and gonadal arteries
4) to the suprarenal gland

**The intermesenteric plexus** – it lies between the superior and inferior mesenteric arteries
*Formation:*
a) sympathetic fibers - from the celiac plexus as well as the first and second lumbar splanchnic nerves /of both sides/
b) parasympathetic fibers – from the pelvic splanchnic nerves of both sides

**Branches:**
around the inferior mesenteric artery, gonadal artery, iliac arteries
branches to **the superior hypogastric plexus** - lies just below aortic bifurcation /in front of L5/
divides below into R and L divisions which join the R and L inferior hypogastric plexuses
*Formation:*
a) sympathetic fibers – from the aortic plexus, the third and fourth lumbar splanchnic nerves of both sides
b) parasympathetic fibers from the pelvic splanchnic nerves of both sides /S2,3,4/

**Branches:**
a) It divides inferiorly to the R and L hypogastric nerves which descend into the pelvis to form the R and L inferior hypogastric plexuses
b) it also gives branches to the ureteric, gonadal and common iliac plexuses

**Inferior hypogastric plexuses**
* lying in the extraperitoneal tissue of the pelvis on each side of the rectum and base of the urinary bladder /or cervix of the uterus/
*Formation:*
a) sympathetic fibers – from the superior hypogastric plexus
the upper 2 sacral sympathetic ganglia
parasympathetic fibers - from the pelvic splanchnic nerves of both sides /S2,3,4/

**Branches:**
middle rectal plexus to the rectum
vesical plexus: to the urinary bladder, seminal vesicles and vas deferens
prostatic: to the prostate and penis
uterovaginal: to the uterus and vagina
Vegetative plexuses:

_of the neck and head_
common carotid
internal carotid
external carotid

_of the thorax_
cardiac
bronchial – pulmonary
oesophageal
aortic

_of the abdomen_
coeliac  - lienal
  - gastric
  - hepatic
  - pancreatic
upper mesenteric
lower mesenteric
Intermesenteric
renalis – uretericus

_of the pelvis_
upper hypogastric
2 lower hypogastric
  - rectal
  - prostatic
  - uro vaginal
Summary of reflex types

There are a number of ways of classifying reflexes.

One is in terms of the systems that receive the stimulus and give the response.

There are *somato-somatic reflexes*, like the knee jerk that follows tapping the patellar tendon;

*Somato-visceral reflexes*, such as the vasoconstriction that results from cooling the skin;

*Viscero-visceral reflexes*, for example the decrease in heart rate that follows distention of the carotid sinus;

and *viscero-somatic reflexes*, like the abdominal cramping that accompanies rupture of the appendix.
Regulation of the VNS depends on the highest vegetative centers:

- thalamus
- hypothalamus
- cerebellum
- basal nuclei of the brain
- reticular formation
- cortex of the brain
- grey matter surrounding the aqueduct of the midbrain
CNS Control of Autonomic Function

Autonomic function is influenced by the cerebrum, hypothalamus, brainstem, and spinal cord.

Sensory processing in the thalamus and emotional states controlled in the limbic system directly affect the hypothalamus.

The integration and command center for autonomic functions contains nuclei that control visceral functions in both divisions of the ANS communicates with other CNS regions, including the cerebral cortex, thalamus, brainstem, cerebellum, and spinal cord.

The hypothalamus is the central brain structure involved in emotions and drives that act through the ANS.

The brainstem nuclei in the mesencephalon, pons, and medulla oblongata mediate visceral reflexes.

Reflex centers control accommodation of the lens, blood pressure changes, blood vessel diameter changes, digestive activities, heart rate changes, and pupil size.

The centers for cardiac, digestive, and vasomotor functions are housed within the brainstem.

Some responses (defecation and urination), are processed and controlled at the level of the spinal cord without the involvement of the brain.

Higher centers in the brain may consciously inhibit these reflex activities.
Many visceral effectors are innervated by postganglionic axons from both ANS divisions. Actions of the divisions usually oppose each other.

Exert antagonistic effects on the same organ.

Opposing effects are also achieved by increasing or decreasing activity in one division.
The relevance of the ANS

The autonomic nervous system is so important in regulation of a vast number of body processes that one could say “it's relevant in almost every disease state”! However, autonomic dysfunction plays a particularly prominent role in certain diseases, including:

- diabetes mellitus
- other conditions where there is autonomic neuropathy
- heart failure
- tetanus
- Guillain-Barré syndrome
- porphyria
- organophosphate poisoning
- ischaemic heart disease and arrhythmias
What does the ANS control?

Resisting the temptation to say 'everything', we note the important functions of the ANS:

- Control of heart rate;
- Control of exocrine glands;
- Influence on certain endocrine glands;
- Altered tone in almost all smooth muscle, wherever it's found;
- Effects on metabolism.
The Roles of Reflexes

- Communication, Integration, Homeostasis
- Senses
- Proprioception
- Positive & Negative Feedback
Viscero-Visceral Reflexes

- Found in all of the body’s systems and may be local (influencing the structure which generated the impulses) or systemic (influencing other structures in response to a given stimuli)
Somato-Visceral & Viscero-Somatic Reflexes

- Somato-Visceral influences via the nervous (central, peripheral, and autonomic) systems
- Viscero-Somatic influences via the nervous (central, peripheral, and autonomic) systems
Psycho-Somato-Visceral Reflexes

- The mind influences the body and vice versa via complex interconnections and interactions.
Psycho-Somato-Visceral Reflexes

The mind influences the body and vice versa via complex interconnections and interactions.
The pain is referred to a cutaneous site remote from the site of the lesion.

The referred cutaneous site may be tender and painfull to touch.

Examples:

1) pain in the right shoulder region in cholecystitis;

2) pain caused by the stretching and irritation of the liver capsule may be referred to the right side of the neck, shoulder or scapula;

3) compression of the lower end of the spine causes pain to the pelvic region or upper leg;

4) pain in the left shoulder region or arm in heart diseases

What Is Referred Pain?

Referred pain has its source in one place but is felt in another.

For example, pain behind the eyes may actually be caused by tense muscles in the neck and shoulders.

This means that the place that hurts may not be the part of the head that needs treatment.
When a person has a heart attack where do they have pain? The pain usually manifests in the left arm, chest, neck - Zakharyin-Head’s areas.
**A. Zakharyin-Head’s areas regions :**
1 — lungs; 2 — capsule of the liver; 3 — stomach; pancreas; 4 — liver; 5 — kidney; 6 — intestine; 7 — ureter; 8 — heart; 9 — urinary bladder; 10 — urogenital organs; 11 — uterus.

**B. Scheme of the viscerocutaneus reflex :**
12 — affected internal organ; 13 — interoreceptor; 14 — spinal ganglion; 15 — vegetative cell of the lateral horn; 16 — sympathetic chain; 17 — Zharin-head region (hyperesthesia and muscle tension); 18 — exteroreceptor; 19 — sensory neuron of the posterior horn; 20 — lateral spino-thalamic pathway.
TRIGGER POINTS & REFERRED PAIN

Myofascial trigger points are irritable tight spots in taut bands of muscle that are painful when pressed and may feel knotty to the touch.

Myofascial refers to the body's soft tissue, comprised of muscles and the muscle fascia (or skin), which covers bones, muscle fibers and groups of muscles. Myofascial pain is often misdiagnosed and mistreated because the cause is typically not located in the same place where the pain is felt - this is called referred pain.

Once myofascial trigger points are activated, they may causereferred pain and dysfunction in various and disparate parts of the body unless treated by myofascial trigger point therapy."

Here are a few of the most common conditions caused by trigger points and myofascial dysfunction:
The Trapezius is a major source of headache pain, typically the type of pain experienced as a “tension headache.”

It can also be a cause of dizziness, jaw, and toothache pain.

Tightness felt in the neck and back of the skull often comes from Trigger Points in the Trapezius.

If neck massage does not relieve the sensation of tightness in the neck, Trigger Points in the Trapezius are the most likely culprit.

Computer users and others who use their arms for extended periods of time will recognize the burning pain between the shoulder blades.

Referred pain from the Trapezius can be found in such a wide variety of locations, that it commonly leads to misdiagnosis, including shoulder bursitis, headaches, disc compression, or a “pinched nerve.” Using the Pressure Pointer may help alleviate symptoms.
Development of the vegetative ganglia

The ganglion cells of the sympathetic system are derived from the cells of the neural crests.

As these crests move forward along the sides of the neural tube and become segmented off to form the spinal ganglia, certain cells detach themselves from the ventral margins of the crests and migrate toward the sides of the aorta, where some of them are grouped to form the ganglia of the sympathetic trunks, while others undergo a further migration and form the ganglia of the prevertebral and visceral plexuses.

The ciliary, sphenopalatine, otic, and submaxillary ganglia which are found on the branches of the trigeminal nerve are formed by groups of cells which have migrated from the part of the neural crest which gives rise to the semilunar or Gasser's ganglion.

Some of the cells of the ciliary ganglion are said to migrate from the neural tube along the oculomotor nerve.
End
Principles of ANS function

As is often done when dealing with any fairly complex system, people have tried to extract simplifying principles. Here are a few (after Rang, Dale & Ritter):

Dale's principle is a gross oversimplification. This principle is that a mature neuron releases the same transmitter(s) at all of its synapses. Although generally true, we now know that not only is release of a 'cocktail' of neurotransmitters the rule rather than the exception, but also that the 'mix' may vary depending on stimulation frequency, and so on. (As an aside, neurones may during their lifetime also change the transmitters they release).

Cannon's law of denervation tells us that if a post-ganglionic neurone has its pre-ganglionic input removed, then it will become super-sensitive to the normal neurotransmitters that mediate that pre-ganglionic input. There is a variety of reasons for this, including up-regulation of receptors for the neurotransmitter(s), post-receptor effects, and impaired removal of neurotransmitters from the synapse.

The modulation of transmission ('neuromodulation') at a synapse may be either at a presynaptic or postsynaptic level. Presynaptic modulation is discussed within the next section, and post-synaptic effects a bit later.