Autonomic Nervous System, Visceral Sensation and Visceral Reflexes
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OBJECTIVES
After studying the material of this lecture, the student should know the:
1. basic divisions of the autonomic nervous system
2. cells of origin and projections of sympathetic and parasympathetic divisions
3. relationship between the autonomic nervous system and the General Visceral Afferents
4. structures and pathways that convey GVA sensation
5. structural basis of referred pain
6. connections related to visceral reflexes

I. AUTONOMIC NERVOUS SYSTEM

The autonomic nervous system is a general visceral efferent (GVE) system that constitutes the “efferent limb” of a visceral reflex, orchestrating responses to visceral afferent (GVA) signals. It consists of the sympathetic and parasympathetic divisions. A chain of two neurons, preganglionic and postganglionic neurons, connect the CNS to the target tissue (smooth muscle, cardiac muscle, or viscera). The sympathetic division is thoracolumbar in origin with short preganglionic and long postganglionic axons; the parasympathetic division is craniosacral in origin with long preganglionic and short postganglionic axons.

A. Sympathetic Division

The sympathetic division of the autonomic nervous system stimulates activities related to stress—“fight or flight” (e.g. increased heart rate, blood vessel constriction, adrenal gland stimulation and increased sweat gland secretion).

1. Preganglionic Neurons
   a) originate from the intermediolateral cell column (T1-L2)
   b) exit the spinal cord thru the ventral root, pass through the white communicating rami to enter the sympathetic chain
   c) synapse in sympathetic chain ganglia within the sympathetic chain (either after ascending, descending or remaining at the same thoracic or lumbar level) or pass through the sympathetic chain (without synapsing) to form splanchnic nerves that synapse on peripheral (pre-aortic) sympathetic ganglia (e.g. celiac, superior mesenteric and inferior mesenteric ganglia).

2. Post-ganglionic Neurons
   -are located either in sympathetic chain ganglia or peripheral sympathetic ganglia
   a) sympathetic chain ganglia
      -axons exit via gray communicating rami and project to blood vessels, arrector pili muscles and sweat glands
      -“piggy-back” blood vessels to target organs; thus vascular damage may be accompanied by sympathetic nerve deficits.
   b) peripheral sympathetic ganglia
      -axons terminate on smooth muscle in the walls of thoracic or abdominal viscera.
B. **Parasympathetic Division**

The parasympathetic division is associated with activities that maintain homeostasis and promotes relaxation—"rest and digest" (reduced heart rate, arterial dilation and digestion).

1. **Pre-ganglionic Neurons**
   - originate in brainstem parasympathetic cranial nerve nuclei or the sacral parasympathetic cell column in the sacral spinal cord (cranio-sacral in origin)

   a) brainstem parasympathetic (GVE) cranial nerve nuclei (Edinger-Westphal, superior and inferior salivatory nuclei, nucleus ambiguus, dorsal vagal nucleus)
      - axons follow cranial nerves to terminal ganglia in the walls of target organs (listed below)

   b) sacral spinal cord (S2-S4)
      - axons project to peripheral parasympathetic ganglia near or within the walls of pelvic organs (e.g. lower portion of the large intestine, bladder and genitalia.

2. **Post-ganglionic Neurons**
   - short post-ganglionics in the walls of target organs are listed in Table I.
TABLE I

<table>
<thead>
<tr>
<th>Pre-ganglionic Neuron</th>
<th>Ganglion</th>
<th>Target(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Edinger-Westphal (CN III)</td>
<td>ciliary ganglion</td>
<td>sphincter pupillae m. (iris) ciliary m. (accommodation)</td>
</tr>
<tr>
<td>Sup. Salivatory (CN VII)</td>
<td>pterygopalatine</td>
<td>lacrimal gland</td>
</tr>
<tr>
<td>Sup. Salivatory (CN VII)</td>
<td>submandibular</td>
<td>submandibular and sublingual glands</td>
</tr>
<tr>
<td>Inf. Salivatory (CN IX)</td>
<td>otic</td>
<td>parotid gland</td>
</tr>
<tr>
<td>Nucleus ambiguus (CN X)</td>
<td>peripheral</td>
<td>sinoatrial &amp; atrioventricular nodes</td>
</tr>
<tr>
<td>Dorsal motor (CN X)</td>
<td>peripheral</td>
<td>visceral organs</td>
</tr>
<tr>
<td>Sacral spinal cord (S2-S4)</td>
<td>terminal ganglia</td>
<td>colon distal to left colic flexure, bladder and genital viscera</td>
</tr>
</tbody>
</table>

II. GENERAL VISCERAL AFFERENT SYSTEM

General visceral afferent (GVA) fibers are responsible for conveying sensory input from the visceral tissues. GVA stimuli include visceral inflammation, organ distension, hunger, blood pressure, blood gases, and fullness of bowel and bladder.

Pain that is conveyed via GVA axons is usually dull, difficult to pin-point a precise origin and often described as a “burning” or “aching” sensation. In contrast, GSA sensation is frequently depicted as sharp, acute pain.

A. Primary GVA Afferents: Cells of Origin

1. Dorsal Root Ganglia

-Pseudo-unipolar dorsal root ganglion neurons convey GVA sensations toward the CNS. These GVA fibers accompany the thoracolumbar sympathetic and sacral parasympathetic fibers.
2. Cranial Nerve Sensory Ganglia: VII, IX and X

a) Facial nerve (C.N. VII): GVA component of the facial nerve is controversial. GVA sensation of the nose, palate, and pharynx may be conveyed by neurons located in the geniculate ganglion.

b) Glossopharyngeal nerve (C.N. IX): Neurons in the inferior (petrosal) ganglion convey GVA impulses from the mucous membranes of the posterior tongue, tonsil, posterior pharyngeal wall, eustachian tube, and carotid sinus and body.

c) Vagus nerve (C.N.X): Neurons in the inferior (nodose) ganglion provide GVA innervation to the pharynx, larynx, trachea, esophagus and thoracic and abdominal viscera.

Primary afferents, both from spinal and cranial nerves, that convey GVA sensation are unipolar neurons which have a peripheral process that extends out to the visceral receptor, and a central process that conveys GVA impulses into the CNS.

B. Peripheral Processes of First-Order GVA Neurons

1. The peripheral projections of the first order neurons extend to receptors that are distributed throughout the viscera (blood vessels and internal organs) particularly to the smooth muscle of the muscular tunic. Visceral (GVA) pain is returned to the CNS through fibers that travel with sympathetics to the spinal cord.
2. GVA receptors include mechanoreceptors in the gut (e.g. Pacinian corpuscles) and large blood vessels (e.g. baroreceptors of the carotid sinus and aortic arch) and chemoreceptors (carotid and aortic bodies), and are innervated by the glossopharyngeal and vagus nerves (C.N. IX and X)

   a) **mechanoreceptors**
      (1) specialized sensory end organ that responds to mechanical stimuli such as tension, pressure, or displacement.

      (2) located in the mesentery, along blood vessels, and in various tissue layers of the gastrointestinal tract that respond to over distention (stones in ureter or biliary ducts), abnormal contraction (spasm), inflammation (appendicitis) and movement of the viscera.

      (3) specialized type of mechanoreceptors are baroreceptors, which are located in the carotid sinus and the aortic arch. Baroreceptors detect pulsatile variations in blood pressure

   b) **chemoreceptors**
      (1) unique visceral receptor associated with general visceral and special visceral (taste and smell) afferents but not associated with somatic afferents

      (2) measures chemical changes such as pH in the stomach and partial pressure of oxygen and carbon dioxide

The peripheral processes of primary GVA neurons accompany both sympathetic and parasympathetic nerve fibers. These peripheral processes pass through, but DO NOT form synaptic connections, in peripheral sympathetic or parasympathetic ganglia and traverse white communicating rami to join the spinal nerve and then the dorsal root to enter the dorsal root ganglia. There are no synapses in the DRG. Central processes of GVA neurons follow the dorsal root to enter the CNS.

C. **Central Connections of the First-Order GVA Neurons**

1. **Dorsal root ganglion: central connections**
   a) Upon entering the spinal cord, the central projections of the GVA fibers terminate on second-order neurons in the dorsal horn of the spinal cord.
   b) The second order neurons extend ascending projections to the reticular formation, hypothalamus and thalamus via the lateral and anterior spinothalamic tracts. The second order neurons ascend both contralateral and ipsilateral

Most of the visceral afferent activity that enters the spinal cord does not reach the level of consciousness and ascends to the reticular formation, and the hypothalamus, which functions as an integrator for the central visceral control of neural and endocrine activities.
Visceral afferent activity that does reach the level of consciousness is related to pain. This nociceptive input is relayed to neurons in the thalamus, which send projections to the postcentral gyrus and insular cortex. Irritation, torsion, traction, strong contractions, or distension of viscera are perceived as pain. Both visceral and somatic primary afferent axons can terminate on the same spinothalamic tract neurons within the dorsal horn of the spinal cord. The overlap in the central termination of visceral and somatic afferents in the dorsal horn of the spinal cord provides one basis for the concept of referred pain (to be discussed in more detail later in the lecture).

2. Cranial Sensory Ganglia: Central Connections

The central projections of the glossopharyngeal and vagus nerves (CN IX and CN X) enter the brainstem and join the solitary tract and terminate in the caudal (GVA) portion of the solitary nucleus. Second-order neurons in the solitary nucleus are strategically located in close proximity to visceral and somatic motor nuclei with which connections are established for visceral reflexes (pharyngeal and laryngeal) and the central regulation of respiratory, cardiovascular, and emetic functions.

Second-order neurons in the solitary nucleus give rise to ascending projections (that travel adjacent to the medial lemniscus) to the hypothalamus and ventral posteromedial nucleus (VPM) of the thalamus.

IV. GENERAL VISCERALAFFERENT REFLEXES

A. Spinal nerves

In addition to their termination in the dorsal horn of the spinal cord, GVA fibers establish reflex synaptic connections with visceral efferent neurons in the intermediolateral cell column (preganglionic sympathetic) and sacral autonomic (preganglionic parasympathetic) nuclei or somatic motor neurons in the ventral horn. For example, spasms of abdominal muscles often associated with abdominal disease is mediated by such connections.

B. Cranial nerves

1. Glossopharyngeal nerve (C.N. IX):
   - peripheral projection extends to the carotid body, carotid sinus and the posterior wall of the pharynx
   - cells of origin for afferent limb of visceral reflexes is the inferior (petrosal) ganglion of CN IX.

   a) Carotid Body Reflex- blood gases
   - chemoreceptors in the carotid body are sensitive to changes in blood levels of oxygen and carbon dioxide

   Carotid body (chemoreceptors) ➤ petrosal ganglion ➤ solitary tract ➤ solitary nucleus
medullary “respiratory center” ➔ ventral horn spinal cord (C3-C5 for diaphragm contraction; intercostal motoneurons)

b) Carotid Sinus Reflex- blood pressure
- baroreceptors of carotid sinus are sensitive to changes in arterial pressure
- to a lesser extent, C.N. X (nodose ganglion) also provides primary afferents

Carotid sinus (baroreceptors) ➔ petrosal ganglion ➔ solitary tract ➔ solitary nucleus

dorsal motor nucleus of C.N. X (parasymp)
medullary “vasomotor center” with projections to intermediolateral column (symp)

c) Gag Reflex

Pharynx ➔ petrosal ganglion ➔ solitary tract ➔ solitary nucleus ➔ nucleus ambiguus pharyngeal muscles (C.N. X)

2. Vagus nerve (C.N. X):
- peripheral projections extend to the mucous membrane of the epiglottis, base of the tongue, aryepiglottic folds, larynx, trachea, heart and lungs project to the inferior (nodose) ganglion.
- cells of origin for afferent limb of visceral reflexes is the inferior (nodose) ganglion of C.N. X.

a) cough reflex
Respiratory pathways ➔ nodose ganglion ➔ solitary tract ➔ solitary nucleus

somatic motoneurons in the nucleus ambiguus ➔ pharyngeal muscles (C.N. X)
neurons in the medullary “respiratory center” ➔ phrenic/intercostal motoneurons

b) vomiting reflex
Gastrointestinal tract ➔ nodose ganglion ➔ solitary tract ➔ solitary nucleus

medullary “vomiting center”
-the “vomiting center” coordinates a series of complicated somatic and visceral motor mechanisms that cause contraction of the abdominal and diaphragmatic muscles coupled with relaxation of the cardiac sphincter and esophagus, contraction of the pylorus, and closure of the glottis.

V. REFERRED PAIN

Visceral pain, which originates from an internal organ, is frequently felt in a location remote to that organ. The remote location corresponds with the dermatome(s) of the dorsal roots
supplying GVA innervation of the organ. This phenomenon is known as **referred pain**. The precise mechanism that facilitates referred pain is not fully understood. It appears that referred pain results from the central projections of visceral sensory axons terminating in the spinal cord on the same neurons that receive somatic sensory input.

**Common Examples of Referred Pain:**

**Angina pectoris**: Pain impulses generated from the heart are conveyed via T1 GVA fibers to sensory dorsal horn neurons of the thoracic region. These sensory dorsal horn neurons also receive cutaneous input from the corresponding dermatome. Frequently, the GVA pain is confused for the GSA pain as “mixing” occurs at the level of spinal cord neurons and the pain is perceived as cutaneous left arm pain. (See figure below)

**Gall bladder**: Pain originating from gall bladder is conveyed back to the spinal cord through a peripheral extension of dorsal root ganglion neurons. The central projection synapses on dorsal horn neurons that also receive cutaneous innervation (GSA) from corresponding dermatomes. Pain can thus be perceived as somatic pain from the right side and back, radiating toward the scapula.