Autonomic Nervous System (ANS)

The stability of our internal environment depends largely on the autonomic nervous system (ANS), the system of motor neurons that innervates smooth and cardiac muscle and glands. The ANS makes adjustments as necessary to ensure optimal support for body activities and operates via subconscious control. The ANS is also called the involuntary nervous system or general visceral motor system.

The motor division is divided into the somatic and autonomic nervous system. Higher brain centers regulate both the SNS and ANS and nearly all spinal nerves and many cranial nerves contain both somatic and autonomic fibers. Most of our body adaptations to the changing internal and external environment involve both skeletal muscle activity and enhanced responses of certain visceral organs.

Both the somatic nervous system (SNS) and autonomic nervous system (ANS) have motor fibers, but they differ in:
1. In their effectors
2. In their effector pathways
3. Target organs responses to their neurotransmitters

<table>
<thead>
<tr>
<th>SNS</th>
<th>ANS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Innervates skeletal muscle</td>
<td>Innervates cardiac muscle, smooth muscle and glands</td>
</tr>
</tbody>
</table>
| Cell body in CNS; thick, myelinated, group A fiber extends in spinal or cranial nerve to skeletal muscle | Uses two-neuron chain -
  - Preganglionic neuron (in CNS) has a thin, lightly myelinated preganglionic axon.
  - Postganglionic (ganglionic) neuron in autonomic ganglion outside CNS has nonmyelinated postganglionic axon that extends to effector organ |
| - All somatic motor neurons release acetylcholine (ACh) | - Preganglionic fibers release ACh
  - Postganglionic fibers release norepinephrine or ACh at effectors
  - Effects always stimulatory
  - Effect is either stimulatory or inhibitory, depending on receptors |
Divisions of the ANS – Sympathetic and Parasympathetic

The sympathetic and parasympathetic divisions exhibit dual innervation – the two divisions counterbalance each other’s activities. All visceral organs are served by both divisions, but cause opposite effects. There is a dynamic antagonism between the two divisions to maintain homeostasis.

<table>
<thead>
<tr>
<th>Parasympathetic</th>
<th>Sympathetic</th>
</tr>
</thead>
<tbody>
<tr>
<td>✴ Promotes maintenance activities and conserves body energy -- directs digestion, diuresis, defecation</td>
<td>✴ Mobilizes body during activity; “fight-or-flight” system</td>
</tr>
<tr>
<td>✴ As in person relaxing and reading after a meal -- blood pressure, heart rate, and respiratory rates are low; gastrointestinal tract activity high; pupils constricted; lenses accommodated for close vision</td>
<td>✴ Exercise, excitement, emergency, embarrassment -- increased heart rate; dry mouth; cold, sweaty skin; dilated pupils</td>
</tr>
<tr>
<td>“D” division – digestion, defecation, diuresis</td>
<td>✴ During vigorous physical activity -- shunts blood to skeletal muscles and heart; dilates bronchioles; causes liver to release glucose</td>
</tr>
<tr>
<td></td>
<td>“E” division – exercise, emergency, excitement</td>
</tr>
</tbody>
</table>
ANS Anatomy

<table>
<thead>
<tr>
<th>Parasympathetic</th>
<th>Sympathetic</th>
</tr>
</thead>
<tbody>
<tr>
<td>✷ Origin site – fibers emerge from brain and sacral spinal cord (craniosacral)</td>
<td>✷ Origin site – fibers originate in the thoracolumbar region of spinal cord</td>
</tr>
<tr>
<td>✷ Length of fibers – long preganglionic and short postganglionic fibers</td>
<td>✷ Length of fibers – short preganglionic and long postganglionic fibers</td>
</tr>
<tr>
<td>✷ Location of ganglia – located in visceral effector organs</td>
<td>✷ Location of ganglia – located close to the spinal cord; within a few cm of CNS</td>
</tr>
<tr>
<td>✷ All fibers release ACh</td>
<td>✷ All preganglionic fibers release ACh; most postganglionic fibers release norepinephrine</td>
</tr>
</tbody>
</table>

![Diagram of the autonomic nervous system showing parasympathetic and sympathetic pathways](image)
Parasympathetic (Craniosacral) Division

- Long preganglionic fibers from brain stem and sacrum
- Extend from CNS almost to target organs
- Synapse with postganglionic neurons in terminal ganglia close to/within target organs
- Short postganglionic fibers synapse with effectors

<table>
<thead>
<tr>
<th>Cranial part</th>
<th>Sacral Part</th>
</tr>
</thead>
<tbody>
<tr>
<td>o Cell bodies in brain stem</td>
<td>o Serves pelvic organs and distal half of large intestine</td>
</tr>
<tr>
<td>o Preganglionic fibers in oculomotor, facial, glossopharyngeal, and vagus nerves</td>
<td>o From neurons in lateral gray matter of S&lt;sub&gt;2&lt;/sub&gt;-S&lt;sub&gt;4&lt;/sub&gt;</td>
</tr>
<tr>
<td>o Oculomotor nerves – innervates smooth muscle of eye</td>
<td>o Axons travel in ventral root of spinal nerves</td>
</tr>
<tr>
<td>o Facial nerves – stimulate large glands in head</td>
<td>o Synapse with -- ganglia in pelvic floor; intramural ganglia in walls of distal half of large intestine, urinary bladder, ureters, and reproductive organs</td>
</tr>
<tr>
<td>o Glossopharyngeal nerves – stimulates parotid salivary glands</td>
<td></td>
</tr>
<tr>
<td>o Vagus nerves – neck and nerve plexuses for ~ all thoracic and abdominal viscera</td>
<td></td>
</tr>
</tbody>
</table>

![Diagram of the parasympathetic system](image)
**Sympathetic (Thoracolumbar) Division**

- Innervates visceral organs in the internal body cavities and all visceral structures in the somatic part of the body – some glands in the smooth muscle structures in the soma require autonomic innervation and are served only by sympathetic fibers (ex. sweat glands, arrector pili)
- Preganglionic neurons are in spinal cord segments T₁ – L₂ --- form lateral horns of spinal cord
- Preganglionic fibers pass through white rami communicantes and enter sympathetic trunk (chain or paravertebral) ganglia

**Trunks and pathways**

- Paravertebral ganglia vary in size, position, and number
- There are 23 paravertebral ganglia in the sympathetic trunk (chain) – 3 cervical, 11 thoracic, 4 lumbar, 4 sacral, 1 coccygeal.
- Upon entering sympathetic trunk ganglion, short preganglionic fiber may do one of these:
  1. Synapse with ganglionic neuron in same trunk ganglion
  2. Ascend or descend sympathetic trunk to synapse in another trunk ganglion
  3. Pass through trunk ganglion and emerge without synapsing (only in abdomen and pelvis)

**Pathways with synapse in Trunk Ganglia**

- Postganglionic axons enter ventral rami via gray rami communicantes
- These fibers innervate sweat glands, arrector pili muscles and vascular smooth muscle.

**Pathways to the Head**

- Fibers emerge from T₁ – T₄ and synapse in the superior cervical ganglion
- These fibers innervate skin & blood vessels of the head, stimulate dilator muscles of the iris, inhibit nasal & salivary glands, innervate smooth muscle of upper eyelid and branch to the heart.

**Pathways to the Thorax**

- Preganglionic fibers emerge from T₁ – T₆ and synapse in cervical trunk ganglia
- Postganglionic fibers emerge from middle and inferior cervical ganglia and enter nerves C₄ – C₈
- These fibers innervates: the heart via the cardiac plexus; thyroid gland and the skin; lungs and esophagus.

**Pathways with Synapses in Collateral Ganglia**

- Most fibers from T₅ – L₂ synapse in collateral ganglia
- They form thoracic, lumbar, and sacral splanchnic nerves
- Their ganglia include the celiac and the superior and inferior mesenteric

**Pathways to the Abdomen**

- Preganglionic fibers from T₅ – L₂ travel through thoracic splanchnic nerves
- Synapses occur in celiac and superior mesenteric ganglia
- Postganglionic fibers serve the stomach, intestines, liver, spleen, and kidneys

**Pathways to the Pelvis**

- Preganglionic fibers from T₁₀ – L₂ travel via lumbar and sacral splanchnic nerves
- Synapses occur in the inferior mesenteric and hypogastric ganglia
- Postganglionic fibers serve the distal half of the large intestine, the urinary bladder, and the reproductive organs
- Primarily inhibit activity of muscles and glands in abdominopelvic visceral organs
Pathways with Synapses in the Adrenal Medulla

- Some preganglionic fibers pass directly to adrenal medulla without synapsing.
- Upon stimulation, medullary cells secrete norepinephrine and epinephrine into blood.
- Sympathetic ganglia and adrenal medulla arise from same tissue -- adrenal medulla is "misplaced" sympathetic ganglion.
Visceral Reflexes

* Visceral reflex arcs have same components as somatic reflex arcs, but visceral reflex arc has two neurons in motor pathway.
* Visceral pain afferents travel along same pathways as somatic pain fibers, contributing to phenomenon of referred pain

Neurotransmitters & Receptors

Acetylcholine and norepinephrine are the major neurotransmitters released by ANS neurons. ACh is released by all ANS preganglionic axons and all parasympathetic post ganglionic axons at synapses with their effectors. ACh releasing fibers are called Cholinergic fibers. Most sympathetic post ganglionic axons release NE and are called Adrenergic fibers. Exceptions are sympathetic postganglionic fibers innervating sweat glands --- these fibers secrete ACh.

Cholinergic Receptors for ACh

Two types of receptors that bind ACh are named for drugs that bind and mimic ACh effects.
(1) Nicotinic – found on sarcolemma of skeletal muscle cells, all postganglionic neurons (sympathetic and parasympathetic) and hormone-producing cells of adrenal medulla. Effects of ACh at nicotinic receptors is always stimulatory – opens ion channels, depolarizing postsynaptic cell
(2) Muscarinic – found on all effector cells stimulated by postganglionic cholinergic fibers. Effects of ACh at muscarinic receptors can either be inhibitory or excitatory – depends on receptor type.

Adrenergic Receptors for NE

There are two major classes of receptors -- Alpha (\( \alpha \)) (subtypes \( \alpha_1, \alpha_2 \)) and Beta (\( \beta \)) (subtypes \( \beta_1, \beta_2, \beta_3 \)). Effects of NE depend on which subclass of receptor predominates on target organ.
(1) Alpha – found in blood vessels serving skin, mucosae, abdominal viscera, kidneys and salivary glands; in virtually all sympathetic target organs except heart; in membrane of adrenergic axon terminals; in pancreas; blood platelets
- Effects of binding – constricts blood vessels and visceral organ sphincters; dilates pupils of eyes; inhibits NE release from adrenergic terminals, inhibits insulin secretion by pancreas; promotes blood clotting
(2) Beta – predominantly found in heart, but also kidneys and adipose tissue; in lungs and most other sympathetic target organs; abundant on blood vessels serving the heart, liver and skeletal muscle
- Effects of binding – increase heart rate and force of contraction; stimulates kidneys to release renin; dilates blood vessels and bronchioles; relaxes smooth muscle walls of digestive and urinary visceral organs; relaxes uterus, stimulates lipolysis by fat cell.
### Effects of Drugs on ANS

**Table 14.3** Selected Drug Classes That Influence the Autonomic Nervous System

<table>
<thead>
<tr>
<th>DRUG CLASS</th>
<th>RECEPTOR BOUND</th>
<th>EFFECTS</th>
<th>EXAMPLE</th>
<th>CLINICAL APPLICATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nicotinic agents (little therapeutic value, but important for public health because tobacco contains nicotine)</td>
<td>Nicotinic ACh receptors on all postganglionic neurons and in CNS</td>
<td>Typically stimulates sympathetic effects; blood pressure rises</td>
<td>Nicotine</td>
<td>Smoking cessation products</td>
</tr>
<tr>
<td>Parasympathomimetic agents (muscarinic agents)</td>
<td>Muscarinic ACh receptors</td>
<td>Enhance parasympathetic activity by mimicking effects of ACh</td>
<td>Pilocarpine</td>
<td>Glaucoma (opens aqueous humor drainage pores)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Bethanechol</td>
<td>Difficulty urinating (increases bladder contraction)</td>
</tr>
<tr>
<td>Acetylcholinesterase inhibitors</td>
<td>None; bind to the enzyme (AChE) that degrades ACh</td>
<td>Indirect effect at all ACh receptors; prolong the effect of ACh</td>
<td>Neostigmine</td>
<td>Myasthenia gravis (increases availability of ACh)</td>
</tr>
<tr>
<td>Sympathomimetic agents</td>
<td>Adrenergic receptors</td>
<td>Enhance sympathetic activity by binding to adrenergic receptors or increasing NE release</td>
<td>Albuterol (Ventolin)</td>
<td>Asthma (dilates bronchioles by binding to β2 receptors)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Phenylephrine</td>
<td>Colds (nasal decongestant, binds to α1 receptors)</td>
</tr>
<tr>
<td>Sympathectolytic agents</td>
<td>Adrenergic receptors</td>
<td>Decrease sympathetic activity by blocking adrenergic receptors or inhibiting NE release</td>
<td>Propranolol</td>
<td>Hypertension (member of a class of drugs called beta-blockers that block β receptors, decreasing blood pressure)</td>
</tr>
</tbody>
</table>

### Interaction of the ANS – dual innervation

**Table 14.4** Effects of the Parasympathetic and Sympathetic Divisions on Various Organs

<table>
<thead>
<tr>
<th>TARGET ORGAN OR SYSTEM</th>
<th>PARASYMPATHETIC EFFECTS</th>
<th>SYMPATHETIC EFFECTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eye (iris)</td>
<td>Stimulates sphincter pupillae muscles; constricts pupils</td>
<td>Stimulates dilator pupillae muscles; dilates pupils</td>
</tr>
<tr>
<td>Eye (ciliary muscle)</td>
<td>Stimulates muscle, which makes lens bulge for close vision</td>
<td>Weakly inhibits muscle, which flattens lens for far vision</td>
</tr>
<tr>
<td>Glands (nasal, lacrimal, gastric, pancreas)</td>
<td>Stimulates secretory activity</td>
<td>Inhibits secretory activity; constricts blood vessels supplying the glands</td>
</tr>
<tr>
<td>Salivary glands</td>
<td>Stimulates secretion of watery saliva</td>
<td>Stimulates secretion of thick, viscous saliva</td>
</tr>
<tr>
<td>Sweat glands</td>
<td>No effect (no innervation)</td>
<td>Stimulates copious sweating (cholinergic fibers)</td>
</tr>
<tr>
<td>Adrenal medulla</td>
<td>No effect (no innervation)</td>
<td>Stimulates medulla cells to secrete epinephrine and norepinephrine</td>
</tr>
<tr>
<td>Arrector pili muscles attached to hair follicles</td>
<td>No effect (no innervation)</td>
<td>Stimulates contraction (erects hairs and produces “goosebumps”)</td>
</tr>
<tr>
<td>Heart (muscle)</td>
<td>Decreases rate; slows heart</td>
<td>Increases rate and force of heartbeat</td>
</tr>
<tr>
<td>Heart (coronary blood vessels)</td>
<td>No effect (no innervation)</td>
<td>Dilates blood vessels (vasodilation)*</td>
</tr>
<tr>
<td>Urinary bladder/urethra</td>
<td>Contracts smooth muscle of bladder wall; relaxes urethral sphincter; promotes voiding</td>
<td>Relaxes smooth muscle of bladder wall; constricts urethral sphincter; inhibits voiding</td>
</tr>
<tr>
<td>Lungs</td>
<td>Constricts bronchioles</td>
<td>Dilates bronchioles*</td>
</tr>
</tbody>
</table>

*Effects are mediated by epinephrine release into the bloodstream from the adrenal medulla.*
Sympathetic Tone

• Sympathetic division controls blood pressure, even at rest
• Vascular system ~ entirely innervated by sympathetic fibers
• Sympathetic tone (vasomotor tone) - keeps blood vessels in continual state of partial constriction
• Sympathetic fibers fire more rapidly to constrict blood vessels and cause blood pressure to rise
• Sympathetic fibers fire less rapidly to prompt vessels to dilate to decrease blood pressure
• Alpha-blocker drugs interfere with vasomotor fibers -- used to treat hypertension

Parasympathetic Tone

• Parasympathetic division normally dominates heart, smooth muscle of digestive and urinary tract organs, activate most glands except for adrenal and sweat glands -- Slows the heart and dictates normal activity levels of digestive and urinary tracts
• The sympathetic division can override these effects during times of stress
• Drugs that block parasympathetic responses increase heart rate and cause fecal and urinary retention

Cooperative Effects

• Best seen in control of external genitalia
• Parasympathetic fibers cause vasodilation; are responsible for erection of penis or clitoris
• Sympathetic fibers cause ejaculation of semen in males and reflex contraction of a vagina

Unique role of Sympathetic Division

• Adrenal medulla, sweat glands, arrector pili muscles, kidneys, and most blood vessels receive only sympathetic fibers.
• Sympathetic division controls: thermoregulatory responses to heat; release of renin from kidneys; metabolic effects – increase metabolic rates of cells, raise blood glucose levels and mobilizes fats for use as fuels.

*Effects are mediated by epinephrine release into the bloodstream from the adrenal medulla.
**Localized vs. Diffused Effects**

- Parasympathetic division: short-lived, highly localized control over effectors – ACh quickly destroyed by acetylcholinesterase.
- Sympathetic division: longer-lasting, body-wide effects
  - NE inactivated more slowly than ACh
  - NE and epinephrine hormones from adrenal medulla prolong effects

**Controls of ANS**

- Hypothalamus—main integrative center of ANS activity; control may be direct or indirect (through reticular system). Centers of hypothalamus control:
  - Heart activity and blood pressure
  - Body temperature, water balance, and endocrine activity
  - Emotional stages (rage, pleasure) and biological drives (hunger, thirst, sex)
  - Reactions to fear and "fight-or-flight" system
- Subconscious cerebral input via limbic system structures on hypothalamic centers and other controls come from cerebral cortex, reticular formation, and spinal cord
  - Connections of hypothalamus to limbic lobe allow cortical influence on ANS
  - Voluntary cortical control of visceral activities is possible by biofeedback: awareness of physiological conditions with goal of consciously influencing them and biofeedback training allows some to control migraines and manage stress

**Developmental Aspects of ANS**

- Nerve growth factor and signaling chemicals aid axonal pathfinding to target organs
- During youth, ANS impairments usually due to injury
- ANS efficiency declines in old age, partially due to structural changes at preganglionic axon terminals
- Effects of age on ANS – constipation, dry eyes, frequent eye infections, orthostatic hypotension, low blood pressure after position change, pressure receptors less responsive to blood pressure changes and cardiovascular centers fail to maintain healthy blood pressure