Autonomic Nervous System (ANS)

- The ANS consists of motor neurons that:
  - Innervate smooth and cardiac muscle and glands
  - Make adjustments to ensure optimal support for body activities
  - Operate via subconscious control (involuntary nervous system or general visceral motor system)
  - Have viscera as most of their effectors
ANS Versus Somatic Nervous System (SNS)

- The ANS differs from the SNS in the following three areas
  - Effectors
  - Efferent pathways
  - Target organ responses
Effectors

- The effectors of the SNS are skeletal muscles
- The effectors of the ANS are cardiac muscle, smooth muscle, and glands
Efferent Pathways & Ganglia

- Somatic Nervous System:
  - Motor neuron cell bodies are in the CNS and axons extend in spinal or cranial nerves all the way to the skeletal muscles they activate
  - Somatic motor fibers are typically thicker, heavily myelinated fibers that conduct impulses rapidly

- Autonomic Nervous System:
  - Use a 2-neuron chain to its effectors; cell body of 1\textsuperscript{st} neuron (preganglion neuron) resides in the brain or spinal cord. The axon of the 1\textsuperscript{st} neuron (preganglionic axon) synapses w/ the 2\textsuperscript{nd} motor neuron (ganglionic neuron) in an autonomic ganglion outside of the CNS.
  - The axon of the ganglionic neuron (postsynaptic axon) extends to the effector organ
Comparison of Somatic and Autonomic Systems

Figure 14.2

Preganglionic axons are lightly myelinated, thin fibers

Postganglionic axons are even thinner and unmyelinated fibers

Thus, conduction thru the autonomic efferent chain is slower than conduction thru the somatic motor system
Neurotransmitter Effects

- All somatic motor neurons release Acetylcholine (ACh) at synapses w/ skeletal muscle, which always has an excitatory effect

- In the ANS:
  - Preganglionic fibers release ACh
  - Postganglionic fibers release norepinephrine (NE) or ACh and the effect is either stimulatory or inhibitory
  - ANS effect on the target organ is dependent upon the neurotransmitter released and the receptor type of the effector
Divisions of the ANS

- Sympathetic and Parasympathetic
  - Serve the same visceral organs but cause opposite effects
  - Help maintain homeostasis
- Sympathetic division mobilizes the body during activity
- Parasympathetic division conserves body energy
Role of the Parasympathetic Division

- Concerned with keeping body energy use as low as possible
- Its activity is illustrated in a person who relaxes after a meal
  - Blood pressure, heart rate, and respiratory rates are low
  - Gastrointestinal tract activity is high
  - The skin is warm and the pupils are constricted
Al Bundy’s Parasympathetic Division…

- Working just fine!
Role of the Sympathetic Division

- The sympathetic division is the “fight-or-flight” system
- Promotes adjustments during exercise – blood flow to organs is reduced, flow to muscles is increased
- Its activity is illustrated by a person who is threatened
  - Heart rate increases, and breathing is rapid and deep
  - Glucose is released from the liver to the blood
  - The skin is cold and sweaty, and the pupils dilate
And the person looks something like this
Anatomy of ANS

- Sympathetic and parasympathetic are distinguished by:
  - Origin sites: PS are craniosacral; S are in the thoracolumbar region
  - Relative lengths of their fibers: PS has long preganglionic and short postganglionic fibers; S has the opposite
  - Location of their ganglia: PS ganglia are located in the visceral effector organs; S ganglia lie close to the spinal cord
    - E.g. sympathetic chain ganglia seen in lab
### Anatomy of ANS

<table>
<thead>
<tr>
<th>Division</th>
<th>Origin of Fibers</th>
<th>Length of Fibers</th>
<th>Location of Ganglia</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sympathetic</td>
<td>Thoracolumbar region of the spinal cord</td>
<td>Short preganglionic and long postganglionic</td>
<td>Close to the spinal cord</td>
</tr>
<tr>
<td>Parasympathetic</td>
<td>Brain and sacral spinal cord</td>
<td>Long preganglionic and short postganglionic</td>
<td>In the visceral effector organs</td>
</tr>
</tbody>
</table>
Parasympathetic Division Outflow

- Anatomically simpler than the sympathetic division
- Preganglionic fibers arise from opposite ends of the CNS
- Preganglionic axons extend from the CNS nearly all the way to the organs to be innervated
- There, the axons synapse w/ ganglionic neurons located in terminal ganglia that lie close to (or w/i) the target organs
- Very short postganglionic axons issue from the terminal ganglia and synapse w/ effector cells in their immediate area
# Parasympathetic Division Outflow

<table>
<thead>
<tr>
<th>Cranial Outflow: Preganglionic fibers run <em>in</em> the following cranial nerves:</th>
<th>Cranial Nerve</th>
<th>Ganglion</th>
<th>Effector Organ(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Occulomotor (III)</td>
<td>Ciliary</td>
<td>Eye</td>
</tr>
<tr>
<td></td>
<td>Facial (VII)</td>
<td>Pterygopalatin Submandibular</td>
<td>Salivary, nasal, and lacrimal glands</td>
</tr>
<tr>
<td></td>
<td>Glossopharyngeal (IX)</td>
<td>Otic</td>
<td>Parotid salivary glands</td>
</tr>
<tr>
<td></td>
<td>Vagus (X)</td>
<td>Located within the walls of target organs</td>
<td>Heart, lungs, and most visceral organs</td>
</tr>
<tr>
<td>Sacral Outflow</td>
<td>$S_2$-$S_4$</td>
<td>Located within the walls of the target organs</td>
<td>Large intestine, urinary bladder, ureters, and reproductive organs</td>
</tr>
</tbody>
</table>
Parasympathetic Division Outflow

- **Occulomotor:**
  - Parasympathetic fibers of the oculomotor nerves innervate smooth muscles in the eye that cause the pupils to constrict & the lenses to “unflatten” to focus on near objects.
  - Cell bodies of the ganglionic neurons are in the ciliary ganglia w/i the orbits

- **Facial:**
  - Stimulate large glands in the head
  - E.g. nasal glands, lacrimal glands, submandibular & sublingual salivary glands

- **Glossopharyngeal:**
  - Activate the parotid salivary gland
  - The distal ends synapse with branches of the trigeminal nerves and these postsynaptic fibers travel in the trigeminal nerves to reach the face
Parasympathetic Division Outflow

- **Vagus:**
  - The 2 vagus nerves account for 90% of all preganglionic parasympathetic fibers in the body
  - Serve every organ in the thoracic & abdominal cavities
  - As the vagus nerves pass into the thorax, they send branches to the cardiac plexuses supplying fibers to the heart slowing heart rate
  - Pulmonary plexus: lungs & bronchi
  - Esophageal plexus: supply the esophagus
  - When the main fibers reach the esophagus, they intermingle then “ride” the esophagus down to the abdominal cavity and innervate the liver, gall bladder, stomach, small intestine, kidneys, pancreas, and proximal half of the large intestine
Parasympathetic Division Outflow

- Sacral Outflow:
  - S2-S4 (location)
  - Serve the distal half of the large intestine, urinary bladder, ureters, and reproductive organs
  - Ventral roots to ventral rami then branch to form the pelvic splanchnic nerves
Sympathetic (Thoracolumbar) Outflow

- More complex than the Parasympathetic division
- Innervates more organs
- Innervates visceral and superficial regions
- Arises from spinal cord segments $T_1$ through $L_2$
- Sympathetic neurons produce the lateral horns in the gray matter of the spinal cord
- Preganglionic fibers pass through the white rami communicans and synapse in the chain (paravertebral) ganglia
- Fibers from $T_5$-$L_2$ form splanchnic nerves and synapse with collateral ganglia
- Postganglionic fibers innervate the numerous organs of the body
Figure 14.5
Sympathetic Trunks and Pathways

- The paravertebral ganglia form part of the sympathetic trunk or chain
- Typically there are 23 ganglia – 3 cervical, 11 thoracic, 4 lumbar, 4 sacral, and 1 coccygeal
Sympathetic Trunks and Pathways

Figure 14.6

- Spinal cord
- Sympathetic trunk ganglion
- Body of a vertebra
- Thoracic splanchnic nerves
- Intercostal nerve
- Intercostal muscle of thorax
- Blood vessels
- Skin (arrector pili muscles and sweat glands)
- Dorsal root
- Ventral root
- Sympathetic trunk (chain) ganglion
- Lateral horn (visceral motor zone)
- Dorsal root ganglion
- Sympathetic trunk
- Ventral ramus of spinal nerve
- Gray ramus communicans
- White ramus communicans
- Ventral root
- Dorsal ramus of spinal nerve
- Splanchnic nerve
- Collateral (prevertebral) ganglion such as the celiac
- To effector
- Target organ (in abdomen)
A preganglionic fiber follows one of three pathways upon entering the paravertebral ganglia

1) Synapse with the ganglionic neuron within the same chain ganglion

2) Ascend or descend the sympathetic chain to synapse in another chain ganglion

3) Pass through the chain ganglion and emerge without synapsing.

These help form the splanchnic nerves that synapse in collateral (prevertebral) ganglia located anterior to the vertebral column (fig. 14.6a)
Pathways with Synapses in Chain Ganglia

- Postganglionic axons enter the ventral or dorsal rami of the adjoining spinal nerves via the gray rami communicans
- From the GRC, axons travel to their effectors
  - Gray rami are found from cervical to sacral regions
- White rami carry preganglionic axons to the sympathetic chains and are found only in the T1-L2 cord segments
- White, gray rami reflect their appearance (myelinated or unmyelinated)
Pathways to the Head

- Preganglionic fibers emerge from T₁-T₄ and synapse in the superior cervical ganglion

- These fibers:
  - Serve the skin and blood vessels of the head
  - Stimulate dilator muscles of the iris
  - Stimulate the tarsus muscle of the eye
  - Inhibit nasal and salivary glands (dry mouth)
Pathways to the Thorax

- Preganglionic fibers emerge from T₁-T₆ and synapse in the cervical chain ganglia.
- Postganglionic fibers emerge from the middle and inferior cervical ganglia and enter nerves C₄-C₈.
- These fibers innervate the heart via the cardiac plexus, as well as innervating the thyroid.
- But most service the skin.
Pathways with Synapses in Collateral Ganglia

- Preganglionic fibers from T5 down synapse in collateral ganglia and form splanchnic nerves including:
  - Greater/lesser thoracic splanchnic nerves
  - Sacral splanchnic nerves
    - These form the abdominal aortic plexus which cling to the abdominal aorta
- Most important ganglia from top to bottom are:
  - Celiac
  - Superior/inferior mesenteric
  - Inferior hypogastric
  - Travel to their organs by means of the arteries servicing the organs
  - Named for the arteries to which they are most associated
Pathways with Synapses in Collateral Ganglia
Pathways to the Abdomen

- Sympathetic nerves innervating the abdomen have preganglionic fibers from T_5-L_2
- They travel through the thoracic splanchnic nerves and synapse at the celiac and superior mesenteric ganglia
- Postganglionic fibers serve the stomach, intestines, liver, spleen, and kidneys (but not the distal half of the large intestine)
Pathways to the Pelvis

- Preganglionic fibers originate from T_{10}-L_{2}.

- Most travel via the lumbar and sacral splanchnic nerves to the inferior mesenteric and hypogastric ganglia.

- Postganglionic fibers serve the distal half of the large intestine, the urinary bladder, and the reproductive organs (where they have inhibitory effects).
Pathways with Synapses in the Adrenal Medulla

- Fibers of the thoracic splanchnic nerve pass directly to the hormone-producing medullary cells of the adrenal gland which sit atop the kidney

- Upon stimulation, medullary cells secrete norepinephrine and epinephrine (adrenaline) into the blood
## Segmental Sympathetic Supplies

<table>
<thead>
<tr>
<th>SPINAL CORD SEGMENT</th>
<th>ORGANS SERVED</th>
</tr>
</thead>
<tbody>
<tr>
<td>T₁–T₅</td>
<td>Head and neck, heart</td>
</tr>
<tr>
<td>T₂–T₄</td>
<td>Bronchi and lungs</td>
</tr>
<tr>
<td>T₂–T₅</td>
<td>Upper limb</td>
</tr>
<tr>
<td>T₅–T₆</td>
<td>Esophagus</td>
</tr>
<tr>
<td>T₆–T₁₀</td>
<td>Stomach, spleen, pancreas</td>
</tr>
<tr>
<td>T₇–T₉</td>
<td>Liver</td>
</tr>
<tr>
<td>T₉–T₁₀</td>
<td>Small intestine</td>
</tr>
<tr>
<td>T₁₀–L₁</td>
<td>Kidney, reproductive organs (uterus, testis, ovary, etc.)</td>
</tr>
<tr>
<td>T₁₀–L₂</td>
<td>Lower limb</td>
</tr>
<tr>
<td>T₁₁–L₂</td>
<td>Large intestine, ureter, urinary bladder</td>
</tr>
</tbody>
</table>

Table 14.2
Visceral Reflexes

- Visceral sensory neurons send information concerning chemical changes, stretch, and irritation

- Visceral reflex arcs have the same elements as somatic reflex arcs

- EXCEPT, a visceral reflex arc has 2 neurons in its motor component
Visceral Reflexes

- **Stimulus**
  - Sensory receptor in viscera
  - Dorsal root ganglion

- **Visceral reflex arc**
  - (Autonomic reflex)
  - Postganglionic axon
  - Visceral effector

- **Response**
  - Visceral effector
  - Ganglionic neuron
  - Autonomic ganglion
  - Integration center (may be preganglionic neuron)
  - Preganglionic axon

- **Central nervous system**
Referred Pain

- Visceral pain afferents travel along the same pathways as somatic pain fibers
- Pain stimuli arising in the viscera are perceived as somatic in origin
  - E.g. heart attack produces sensation of pain in the superior thoracic wall and the medial aspect of the left arm
  - The same spinal segments (T1-5) innervate both the heart and the somatic regions, the brain perceives pain from the more common somatic regions.
Referred Pain

- Lungs and diaphragm
- Liver
- Gallbladder
- Heart
- Liver
- Stomach
- Pancreas
- Small intestine
- Ovaries
- Colon
- Kidneys
- Urinary bladder
- Ureters

Radiation is usually to the neck, spine, jaw, shoulder, or arm.

If heart attack patients are treated immediately, most recover to eventually return to work and other activities they enjoy.
Neurotransmitters and Receptors

- Acetylcholine (ACh) and norepinephrine (NE) are the two major neurotransmitters of the ANS.

- ACh is released by:
  - 1) All preganglionic axons
  - 2) All parasympathetic postganglionic axons
    - Referred to as cholinergic fibers – ACh-releasing fibers

- Adrenergic fibers – sympathetic postganglionic axons that release NE

- Neurotransmitter effects can be excitatory or inhibitory depending upon the receptor type.
Cholinergic Receptors

- The two types of receptors that bind ACh are nicotinic and muscarinic receptors.
- These are named after drugs that bind to them and mimic ACh effects.
Nicotinic Receptors (Nicotine)

- Nicotinic receptors are found on:
  - Motor end plates (somatic targets)
  - All ganglionic neurons of both sympathetic and parasympathetic divisions
  - The hormone-producing cells of the adrenal medulla
- Ach binding opens ion channels resulting in depolarization
- The effect of ACh binding to nicotinic receptors is always stimulatory
Muscarinic Receptors (Mushroom Poison)

- Muscarinic receptors occur on all effector cells stimulated by postganglionic cholinergic fibers

- The effect of ACh binding:
  - Can be either inhibitory or excitatory
  - Depends on the receptor type of the target organ
Adrenergic Receptors

- The two types of adrenergic receptors are alpha and beta

- Each type has two or three subclasses (α1, α2, β1, β2, β3)

- Effects of NE binding to:
  - α receptors is generally stimulatory
  - β receptors is generally inhibitory

- A notable exception – NE binding to β receptors of the heart is stimulatory
# Drugs that Influence the ANS

## Table 14.4 Selected Drug Classes That Influence the Activity of the Autonomic Nervous System

<table>
<thead>
<tr>
<th>DRUG CLASS</th>
<th>RECEPTOR BOUND</th>
<th>EFFECTS</th>
<th>EXAMPLE</th>
<th>CLINICAL USE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nicotinic agents (little therapeutic value, but important because of presence of nicotine in tobacco)</td>
<td>Nicotinic ACh receptors on all ganglionic neurons and in CNS</td>
<td>Typically stimulation of sympathetic effects; heart rhythm becomes less regular; blood pressure increases</td>
<td>Nicotine</td>
<td>Used in smoking cessation products</td>
</tr>
<tr>
<td>Parasympathomimetic agents (muscarinic agents)</td>
<td>Muscarinic ACh receptors</td>
<td>Mimics effects of ACh, enhances PNS effects</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; binds to the enzyme (AChE) that degrades ACh</td>
<td>Indirect effect at all ACh receptors; prolongs the effect of ACh</td>
<td>Neostigmine</td>
<td>Myasthenia gravis, (increases availability of ACh)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Sarin</td>
<td>Used as chemical warfare agent (similar to widely used insecticides)</td>
</tr>
<tr>
<td>Sympathomimetic agents</td>
<td>Adrenergic receptors</td>
<td>Enhances sympathetic activity by increasing NE release or binding to adrenergic receptors</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>Sympatholytic agents</td>
<td>Adrenergic receptors</td>
<td>Decreases sympathetic activity by blocking adrenergic receptors or inhibiting NE release</td>
<td>Propranolol</td>
<td>Hypertension (member of a class of drugs called β blockers that decrease heart rate and blood pressure)</td>
</tr>
</tbody>
</table>
Interactions of the Autonomic Divisions

- Most visceral organs are innervated by both sympathetic and parasympathetic fibers.

- This results in dynamic antagonisms that precisely control visceral activity.

- Sympathetic fibers increase heart and respiratory rates, and inhibit digestion and elimination.

- Parasympathetic fibers decrease heart and respiratory rates, and allow for digestion and the discarding of wastes.
Sympathetic Tone

- The sympathetic division controls blood pressure and keeps the blood vessels in a continual state of partial constriction.

- This sympathetic tone (vasomotor tone):
  - Constricts blood vessels and causes blood pressure to rise as needed by firing the fibers more rapidly.
  - Prompts vessels to dilate if blood pressure is to be decreased.

- Alpha-blocker drugs interfere with vasomotor fibers and are used to treat hypertension.

- Also involved with blood shunting.
Parasympathetic Tone

- Parasympathetic tone:
  - Slows the heart
  - Dictates normal activity levels of the digestive and urinary systems
- The sympathetic division can override these effects during times of stress
- Drugs that block parasympathetic responses increase heart rate and block fecal and urinary retention
Cooperative Effects

- ANS cooperation is best seen in control of the external genitalia
- Parasympathetic fibers cause vasodilation and are responsible for erection of the penis and clitoris
- Sympathetic fibers cause ejaculation of semen in males and reflex peristalsis in females
Unique Roles of the Sympathetic Division

- Regulates many functions not subject to parasympathetic influence
- These include the activity of the adrenal medulla, sweat glands, arrector pili muscles, kidneys, and most blood vessels
- The sympathetic division controls:
  - Thermoregulatory responses to heat
  - Release of renin from the kidneys
  - Metabolic effects
Thermoregulatory Responses to Heat

- Applying heat to the skin causes reflex dilation of blood vessels
- Systemic body temperature elevation results in widespread dilation of blood vessels
- This dilation brings warm blood to the surface and activates sweat glands to cool the body
- When temperature falls, blood vessels constrict and blood is retained in deeper vital organs
Release of Renin from the Kidneys

- Sympathetic impulses activate the kidneys to release renin
- Renin is an enzyme that promotes increased blood pressure
Metabolic Effects

- The sympathetic division promotes metabolic effects that are not reversed by the parasympathetic division
  - Increases the metabolic rate of body cells
  - Raises blood glucose levels
  - Mobilizes fat as an energy source
Localized Versus Diffuse Effects

- The parasympathetic division exerts short-lived, highly localized control
- The sympathetic division exerts long-lasting, diffuse effects
Effects of Sympathetic Activation

- Sympathetic activation is long-lasting because NE:
  - Is inactivated more slowly than ACh
  - Is an indirectly acting neurotransmitter, using a second-messenger system
  - NE and Epinephrine are released into the blood and remain there until destroyed by the liver
Levels of ANS Control

- The hypothalamus is the main integration center of ANS activity
- Subconscious cerebral input via limbic lobe connections influences hypothalamic function
- Other controls come from the cerebral cortex, the reticular formation, and the spinal cord
Hypothalamic Control

- Centers of the 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 the “fight-or-flight” system
- You have now completed A&P I
  - How does it feel?