Ch 9
The Autonomic Nervous System
SLOs

• Review the organization of the ANS
• Describe how neural regulation of smooth and cardiac muscles differs from that of skeletal muscles
• Describe the structure and innervation pathways of the two branches of the ANS
• Explain the relationship between the sympathetic NS and the adrenal medulla.
• Identify the NTs of the sympathetic and parasympathetic divisions, and the hormones released by the adrenal medulla.
• Describe the effects of adrenergic stimulation on different organs, and identify the types of adrenergic receptors involved
• Describe the effects of cholinergic stimulation on different organs, and identify the types of cholinergic receptors involved
• Give examples and explain the principle of agonists and antagonists of the ANS
• Explain how β blockers and atropine affect the ANS
• Explain and give examples for dual innervation
9.1 Neural Control of Involuntary Effectors

visceral effector organs

- ANS regulates organs not under voluntary control
  - ES (Ch 11)
  - Smooth muscles (Ch 12)
  - Heart and circulatory system (Chs 13 & 14)

- Target organs not completely dependent on ANS innervation. Will not atrophy if nerve cut (unlike skeletal muscle)

- Cardiac muscle contracts independent of nerve stimulation. ANS speeds up or slows down intrinsic contractions.

- ANS stimulates or inhibits depending on ____________ present in organ
# Somatic vs. Autonomic System

## Table 9.1 | Comparison of the Somatic Motor System and the Autonomic Motor System

<table>
<thead>
<tr>
<th>Feature</th>
<th>Somatic Motor</th>
<th>Autonomic Motor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Effector organs</td>
<td>Skeletal muscles</td>
<td>Cardiac muscle, smooth muscle, and glands</td>
</tr>
<tr>
<td>Presence of ganglia</td>
<td>No ganglia</td>
<td>Cell bodies of postganglionic autonomic fibers located in paravertebral, prevertebral (collateral), and terminal ganglia</td>
</tr>
<tr>
<td>Number of neurons from CNS to effector</td>
<td>One</td>
<td>Two</td>
</tr>
<tr>
<td>Type of neuromuscular junction</td>
<td>Specialized motor end plate</td>
<td>No specialization of postsynaptic membrane; all areas of smooth muscle cells contain receptor proteins for neurotransmitters</td>
</tr>
<tr>
<td>Effect of nerve impulse on muscle</td>
<td>Excitatory only</td>
<td>Either excitatory or inhibitory</td>
</tr>
<tr>
<td>Type of nerve fibers</td>
<td>Fast-conducting, thick (9–13μm), and myelinated</td>
<td>Slow-conducting; preganglionic fibers lightly myelinated but thin (3μm); postganglionic fibers unmyelinated and very thin (about 1.0μm)</td>
</tr>
<tr>
<td>Effect of denervation</td>
<td>Flaccid paralysis and atrophy</td>
<td>Muscle tone and function persist; target cells show denervation hypersensitivity</td>
</tr>
</tbody>
</table>
Neurotransmitters

• **Somatic motor neurons** release only ________________ which is always excitatory.

• **Autonomic neurons** release ________________ and ________________. Response may be excitatory or inhibitory depending on ____________
Anatomical Differences between somatic NS and ANS

- **Somatic motor neurons** have cell bodies in ____________ of the spinal cord. One neuron travels from spinal cord to effector.
- **ANS** has two sets of neurons in the PNS.
Autonomic pathway: 2 Efferent Neurons in Series

Preganglionic neuron cell body in CNS

Synapsis in autonomic ganglion outside CNS ⇒ divergence

Postganglionic neurons

target cells?

Compare to Fig 9-1
Thoracolumbar division (T1 to L2)

- Preganglionic neurons from thoracolumbar region of spinal cord
- Paravertebral ganglia (Sympathetic chain of ganglia)
- Prevertebral (or collateral) ganglia
- Long postganglionic axons secrete NE onto adrenergic receptors

Compare to Fig 9-5
Division of the ANS

= Craniosacral Division

✿ Long preganglionic axons from brain & S2- S4

✿ Terminal or intramural ganglia

✿ Postganglionic neurons secrete Ach onto cholinergic muscarinic receptors

Compare to Fig 9-5
9.3 Functions of the ANS

- Responsible for homeostasis of BP, HR, Resp., H₂O balance, Temp. . .
- Mostly dual innervation; antagonistic
- **Tonic activity** (unlike somatic NS)
- **Sympathetic:** *fight-or-flight* through release of
  
  _________

- **Parasympathetic:** rest and digest
**Adrennergic and Cholinergic Synaptic Transmission**

**Acetylcholine (ACh) →** cholinergic (nicotinic or muscarinic) neurons and receptors

**Secreted from**

- preganglionic neurons of both divisions
- Postganglionic neurons of para-symp. division

**Norepinephrine (NE) →** adrenergic (α and β) neurons and receptors

**Secreted from**

- Postganglionic neurons of sympathetic division
Catecholamine Family of Molecules

Tyrosine derivatives

Tyrosine (an amino acid)

DOPA (dihydroxyphenylalanine)

Dopamine (a neurotransmitter)

Norepinephrine (a neurotransmitter and hormone)

Epinephrine (major hormone of adrenal medulla)

Adrenergic synapses

Fig 9-8
Adrenal Medulla

More similar to
a) anterior
b) posterior pituitary ???

Modified _____________

Adrenal gland subdivided into medulla and _____________
Neuroeffector Junction of ANS

= Synapse between postganglionic cell and target organ

Most are different from model synapse

⇒ Axon has varicosities containing NT

NT synthesized in axon

Compare to Fig 9.9
Varicosities of Sympathetic and Parasympathetic Division Release different NTs

- Form “synapses en passant” - in passing.

- Dual Innervation: Sympathetic and parasympathetic neurons innervate same tissue, releasing different NTs
Responses to Adrenergic Stimulation

- **E** in the blood or **NE** from sympathetic nerves
- Response depends on receptors
  - $\alpha_1$ and $\alpha_2$
  - $\beta_1$ and $\beta_2$
- All use **G-proteins** & 2nd messenger systems

**Stimulation:**
- heart,
- dilatory muscles of iris,
- vasoconstriction of many blood vessels

**Inhibition:**
- bronchodilation
Clinically more important even though not as abundant as $\alpha$ receptors

$-\beta_1$  $E = NE \implies$ Excitation heart

$-\beta_2$  not innervated! $E > NE! \implies$ usually inhibitory: smooth muscle relaxation of some blood vessels and bronchioles

Clinical Application: $\beta$ Blockers
Drugs that mimic adrenergic responses

- **Agonists**: Promote the process stimulated by the NT
- **Antagonists**: Block the NT action
- Agonists and antagonists are used for many medical applications
One more time:

Review of Location of NTs of ANS

Compare to Fig 9-7
Responses to Cholinergic Stimulation

• ACh released from preganglionic neurons of the sympathetic and parasympathetic division is stimulatory.

• ACh from postganglionic neurons of the parasympathetic division can be stimulatory or inhibitory, depending on __________.  

• 2 major subtypes of receptors:
  1)
  2)

• In general, sympathetic and parasympathetic effects are opposite → hence: **Dual innerervation**
Nicotinic cholinergic receptors

Outcome of opening monovalent Na⁺ / K⁺ channels?

- **Curare** inactivates this receptor ⇒

= ____________________________

*(see Table 11-3)*
Muscarinic cholinergic receptors

- Muscarine = ________

- G-protein coupled mechanisms

Clinical Application: Atropine

Atropin is __________ for these receptors
Comparison of Nicotinic & Muscarinic ACh Receptors

**Nicotinic ACh receptors**
- Postsynaptic membrane of
  - All autonomic ganglia
  - All neuromuscular junctions
  - Some CNS pathways
- Ligand-gated channels (ion channels are part of receptor)

**Muscarinic ACh receptors**
- Produces parasympathetic nerve effects in the heart, smooth muscles, and glands
- G-protein-coupled receptors (receptors influence ion channels by means of G-proteins)

Be able to explain what happens in each of the above situations
# Cholinergic Receptors & Responses to ACh

## Table 9.6  Cholinergic Receptors and Responses to Acetylcholine

<table>
<thead>
<tr>
<th>Receptor</th>
<th>Tissue</th>
<th>Response</th>
<th>Mechanisms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nicotinic</td>
<td>Skeletal muscle</td>
<td>Depolarization, producing action potentials and muscle contraction</td>
<td>ACh opens cation channel in receptor</td>
</tr>
<tr>
<td>Nicotinic</td>
<td>Autonomic ganglia</td>
<td>Depolarization, causing activation of postganglionic neurons</td>
<td>ACh opens cation channel in receptor</td>
</tr>
<tr>
<td>Muscarinic</td>
<td>Smooth muscle, glands</td>
<td>Depolarization and contraction of smooth muscle, secretion of glands</td>
<td>ACh activates G-protein coupled receptor, opening Ca^{2+} channels and increasing cytosolic Ca^{2+}</td>
</tr>
<tr>
<td>Muscarinic</td>
<td>Heart</td>
<td>Hyperpolarization, slowing rate of spontaneous depolarization</td>
<td>ACh activates G-protein coupled receptor, opening channels for K^{+}</td>
</tr>
</tbody>
</table>

Summary of Autonomic Functions

<table>
<thead>
<tr>
<th>Organ</th>
<th>Sympathetic</th>
<th>Parasympathetic</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Action</td>
<td>Action</td>
</tr>
<tr>
<td></td>
<td>Receptor*</td>
<td>Receptor*</td>
</tr>
<tr>
<td><strong>Eye</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Iris</td>
<td>Contracts (dilates pupil)</td>
<td>Contracts (constricts pupil)</td>
</tr>
<tr>
<td>Radial muscle</td>
<td>$\alpha_1$</td>
<td>$M$</td>
</tr>
<tr>
<td>Circular muscle</td>
<td>$-$</td>
<td>$-$</td>
</tr>
<tr>
<td><strong>Heart</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sinoatrial node</td>
<td>Increases heart rate</td>
<td>Decreases heart rate</td>
</tr>
<tr>
<td>Contractility</td>
<td>$\beta_1$</td>
<td>$M$</td>
</tr>
<tr>
<td><strong>Vascular Smooth Muscle</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Skin, splanchnic vessels</td>
<td>Contracts (vasoconstriction)</td>
<td>$\alpha, \beta$</td>
</tr>
<tr>
<td>Skeletal muscle vessels</td>
<td>Relaxes (vasodilation)</td>
<td>$\beta_2$</td>
</tr>
<tr>
<td></td>
<td>$M^{**}$</td>
<td></td>
</tr>
<tr>
<td><strong>Bronchiolar Smooth Muscle</strong></td>
<td>Relaxes (bronchodilation)</td>
<td>Contracts (bronchoconstriction)</td>
</tr>
<tr>
<td><strong>Gastrointestinal Tract</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Smooth muscle</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Walls</td>
<td>Relaxes</td>
<td>Contracts</td>
</tr>
<tr>
<td>Sphincters</td>
<td>Constricts</td>
<td>Relaxes</td>
</tr>
<tr>
<td>Secretion</td>
<td>Inhibits</td>
<td>Stimulates</td>
</tr>
<tr>
<td>Myenteric plexus</td>
<td>Inhibits</td>
<td>$\alpha$</td>
</tr>
<tr>
<td><strong>Genitourinary Smooth Muscle</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bladder wall (detrussor m.)</td>
<td>Relaxes slightly</td>
<td>Contracts</td>
</tr>
<tr>
<td>Urethral sphincter</td>
<td>Contracts</td>
<td>Relaxes</td>
</tr>
<tr>
<td>Uterus, pregnant</td>
<td>Relaxes</td>
<td>$\beta_2$</td>
</tr>
<tr>
<td></td>
<td>$\alpha_1$</td>
<td>$-$</td>
</tr>
<tr>
<td>Penis</td>
<td>Contracts</td>
<td>$\alpha_1$</td>
</tr>
<tr>
<td></td>
<td>Ejaculation</td>
<td>Erection</td>
</tr>
<tr>
<td><strong>Skin</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pilomotor smooth muscle</td>
<td>Contracts</td>
<td>$\alpha_1$</td>
</tr>
<tr>
<td>Sweat glands</td>
<td>$-$</td>
<td>$-$</td>
</tr>
</tbody>
</table>

* $\alpha$, $\beta$, $M$, $\alpha_1$, $\beta_2$ denote various types of receptors.
Organs with Dual Innervation

• Most visceral organs

• Mostly dual innervation is antagonistic. *E.g.*:
  
  a. Heart rate – sym increases, para decreases
  
  b. Digestive functions – sym decreases, para increases
  
  c. Pupil diameter – sym dilates, para constricts
Clinical Investigation: Sophia was nervous about her upcoming exam....