THE AUTONOMIC NERVOUS SYSTEM
Divisions of the Nervous System
**Autonomic nervous system - introduction**

Autonomic nervous system is an involuntary system that primarily controls and modulates the functions of the visceral organs.

**Autonomic nervous system inervates:**
- smooth muscles of the vessels
- smooth muscles of the digestive system
- smooth muscles of the urine bladder and urethra
- smooth muscles of the lower airways
- cardiac muscle
- sweet, digestive and lacrimal glands
- adrenal medulla

Similarly as the control of the somatic functions, the relative large part of the autonomic regulations is controlled through reflex arc.
Autonomic nervous system – distribution

- Sympathetic branches
  - thoracolumbal part of the autonomic nervous system

- Parasympathetic branches
  - craniosacral part of the autonomic nervous system
Autonomic nervous system – characteristics of the single parts

Parasympathetic part is dominant in the rest conditions and especially at the passing of organism from energetic exacting stress states to the rest state.

„Fight-or-flight“ – sympathetic activity dominates.
Sympathetic part is dominant in stressful situations and usually at the preparing of organism for situations connected with probably high energy output.
Efferent pathway consists of two neurons:

- the first is stored in the brain stem, or spinal cord, and is referred to as preganglionic neuron.

- the second neuron is stored in ganglia, or in the body itself and is referred to as postganglionic neuron.
Comparison of Somatic and Autonomic Nervous Systems

- Effectors
- Effector pathways and ganglia
- Neurotransmitter used
- Amount of myelination
Comparison of Somatic and Autonomic Nervous Systems

<table>
<thead>
<tr>
<th>Comparison of Somatic and Autonomic Nervous Systems</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>SOMATIC NERVOUS SYSTEM</strong></td>
</tr>
<tr>
<td>Single neuron from CNS to effector organs</td>
</tr>
<tr>
<td>Heavily myelinated axon</td>
</tr>
<tr>
<td></td>
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</table>

**Acetylcholine (ACh)** | **Norepinephrine (NE)**

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Comparison of Somatic and Autonomic Nervous Systems

A schematic of the somatic nervous system (SNS), which provides conscious and subconscious control over skeletal muscles.

Somatic motor nuclei of brain stem

Upper motor neurons in primary motor cortex

Visceral motor nuclei in hypothalamus

Somatic motor nuclei of spinal cord

A schematic of the autonomic nervous system (ANS), which controls visceral functions largely outside our awareness.
# Autonomic nervous system – comparison of somatic and autonomic divisions

<table>
<thead>
<tr>
<th></th>
<th>Somatic division of CNS</th>
<th>Autonomic division of CNS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of neurons in efferent path</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Neurotransmitter/receptor at neuron-target synapse</td>
<td>acetylcholine/nicotinic receptor</td>
<td>acetylcholine/muscarinic receptor or noradrenaline/α- or β-adrenergic receptor</td>
</tr>
<tr>
<td>Target tissue</td>
<td>skeletal muscle</td>
<td>smooth and cardiac muscle; some endocrine and exocrine glands; some adipose tissue</td>
</tr>
<tr>
<td>Neurotransmitter released from</td>
<td>axon terminals</td>
<td>varicosities and axon terminals</td>
</tr>
<tr>
<td>Effects on target tissue</td>
<td>excitatory only: muscle contracts</td>
<td>excitatory or inhibitory</td>
</tr>
<tr>
<td>Peripheral components found outside the CNS</td>
<td>axons only</td>
<td>preganglionic axons, ganglia, postganglionic neurons</td>
</tr>
<tr>
<td>Summary of function</td>
<td>posture and movement</td>
<td>visceral function, including movement in internal organs and secretion; control of metabolism</td>
</tr>
</tbody>
</table>
Sympathetic Nervous System
The innervation of the sympathetic division: at left, the distribution of nerves to the skin, skeletal muscles, and tissues of the body wall; at right, the distribution of nerves to visceral organs.

**NOTE 1**

Every spinal nerve has a gray ramus that carries sympathetic postganglionic fibers for distribution in the body wall and limbs. In the head and neck, postganglionic sympathetic fibers leaving the superior cervical sympathetic ganglia supply the regions innervated by cranial nerves III, VII, IX, and X.

**NOTE 2**

Preganglionic fibers on their way to the collateral ganglia form the splanchnic (SPLANK-nik) nerves. Postganglionic fibers innervating structures in the thoracic cavity, such as the heart and lungs, form bundles known as sympathetic nerves.
Sympathetic Nervous System

- Greater splanchnic nerve
- Lesser splanchnic nerve
- Celiac ganglion
- Superior mesenteric ganglion
- Lumbar splanchnic nerves
- Inferior mesenteric ganglion
- Small intestine
- Large intestine
- Rectum
- Genitalia (uterus, vagina, and penis) and urinary bladder

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Figure 61-1  Sympathetic nervous system. The black lines represent postganglionic fibers, and the red lines show preganglionic fibers.
Figure 61-2 Nerve connections among the spinal cord, spinal nerves, sympathetic chain, and peripheral sympathetic nerves.
**SYMPATHETIC DIVISION – thoracolumbal part**

Axons of neurons C8-L3 (ncl.intermedial and ncl.intermediolateralis) leave the spinal cord by ventral roots of *rami communicantes albi* and enter the sympathetic trunk. Here are most of the neuron connects.

Only a part of neurons is interconnected in prevertebral ganglia.
**SYMPATHETIC DIVISION – thoracolumbal part**

Ganglionic fibers to proceed to the organs either through *rami viscerales* (from the sympathetic trunk) or through *rami communicantae griseae* and further by sensitive neuron to the periphery (especially the skin).

The fibers from *rami viscerales* to proceed the most often periarteriolarly.
Sympathetic Nervous System

**Organization of the sympathetic division of the ANS**

- **Preganglionic Neurons**
  - Lateral gray horns of spinal segments $T_1 - L_2$

- **Ganglionic Neurons**
  - Each sympathetic chain consists of a series of interconnected ganglia located on either side of the vertebral column.
  - The collateral ganglia, located within the abdominopelvic cavity, include the celiac, superior mesenteric, and inferior mesenteric ganglia.
  - The center of each adrenal gland contains a sympathetic ganglion, the adrenal medulla, that acts as an endocrine organ.

- **Target Organs**
  - Visceral effectors in thoracic cavity, head, body wall, and limbs
  - Visceral effectors in abdominopelvic cavity
  - Organs and systems throughout the body

Ganglionic neurons in the sympathetic chain and collateral ganglia exert their effects through innervation of peripheral target organs. Ganglionic neurons in the adrenal medullae affect target organs throughout the body through the release of hormones into the general circulation.
PARASYMPATHETIC DIVISION
Figure 61-3 The parasympathetic nervous system. The blue lines represent preganglionic fibers and the black lines show postganglionic fibers.
Autonomic nervous system – anatomy of peripheral part

**PARASYMPATHETIC DIVISION – cranial part**

- **ncl.Edinger-Westphal**
  - n. oculomotorius (III. cranial nerve) and its *ramus inferior*

- **ncl.salivatorius superior**
  - n. facialis (VII. cranial nerve) and branch of n. petrosus maior

**ggl.ciliare**
- nn. ciliares breves

**m. sphincter pupillae (miosis)**
**m. ciliaris (accomodation)**

**ggl.pterygopalatinum**
- nn. pterygopalatini n. zygomaticus
- n. lacrimalis

**tear gland**

**ggl.submandibulare**
- nn. lingualis

**submandibularis and sublingual salivary glands**

- n. facialis (VII. cranial nerve), chorda tympani and n. lingualis
Autonomic nervous system – anatomy of peripheral part

PARASYMPATHETIC DIVISION – cranial part

- ncl.salivatorius inferior
  - n.glossopharyngeus (IX cranial nerve) and branches of n.petrosus minor and n.tympanicus
  - ggl.oticum
  - n.auriculotemporalis
    - parotid gland
  - n.vagi (X cranial nerve)
    - intramural ganglia in heart, in respiratory and digestive systems

ncl.dorsalis n.vagi
Autonomic nervous system – anatomy of peripheral part

PARASYMPATHETIC DIVISION – sacral part

It starts in ncll.intermediolateralis, where axons leave the spinal cord through anterior roots and after a short course by the sacral nerves create plexus hypogastricus inferior.
Parasympathetic Nervous System (cranial outflow)
Parasympathetic Nervous System (cranial outflow)
### Parasympathetic Nervous System (cranial outflow)

**Organization of the parasympathetic division of the ANS**

<table>
<thead>
<tr>
<th>Preganglionic Neurons</th>
<th>Ganglionic Neurons</th>
<th>Target Organs</th>
</tr>
</thead>
<tbody>
<tr>
<td>The midbrain, pons, and medulla oblongata contain parasympathetic nuclei associated with cranial nerves III, VII, IX, and X.</td>
<td>Ciliary ganglion</td>
<td>Intrinsic eye muscles (pupil and lens shape)</td>
</tr>
<tr>
<td></td>
<td>Pterygopalatine and submandibular ganglia</td>
<td>Nasal glands, tear glands, and salivary glands</td>
</tr>
<tr>
<td></td>
<td>Otic ganglion</td>
<td>Parotid salivary gland</td>
</tr>
<tr>
<td></td>
<td>Intramural ganglia</td>
<td>Visceral organs of neck, thoracic cavity, and most of abdominal cavity</td>
</tr>
<tr>
<td></td>
<td>Pelvic nerves</td>
<td>Visceral organs in inferior portion of abdominopelvic cavity</td>
</tr>
</tbody>
</table>

In sacral segments of the spinal cord, parasympathetic nuclei lie in the lateral gray horns of spinal segments S₂–S₄.
Parasympathetic Nervous System (sacral outflow)
Parasympathetic Nervous System (sacral outflow)
Comparison of Sympathetic and Parasympathetic Divisions

- Origins
- Length of fibers
- Location of ganglia and synapse
Comparison of Sympathetic and Parasympathetic Divisions
Parasympathetic versus Sympathetic

Autonomic Nervous System

**Sympathetic Division**
In the sympathetic division, or thoracolumbar (thor-ə-kō-LUM-bar) division, axons emerge from the thoracic and superior lumbar segments of the spinal cord and innervate ganglia relatively close to the spinal cord.

**Parasympathetic Division**
In the parasympathetic division, or craniosacral (krā-nē-ō-SÄ-kral) division, axons emerge from the brain stem and the sacral segments of the spinal cord, and they innervate ganglia very close to (or within) target organs.

The two main divisions of the ANS: the sympathetic and parasympathetic divisions

- **Thoracic nerves**
- **Lumbar nerves** ($L_1, L_2$ only)
- **Sacral nerves** ($S_2, S_3, S_4$ only)
- **Cranial nerves** (III, VII, IX, and X)
# Comparison of Parasympathetic and Sympathetic Nervous Systems

## Table 14.4

<table>
<thead>
<tr>
<th>Target Organ or System</th>
<th>Parasympathetic Effects</th>
<th>Sympathetic Effects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Digestive tract organs</td>
<td>Increases motility (peristalsis) and amount of secretion by digestive organs; relaxes sphincters to allow movement of foodstuffs along tract</td>
<td>Decreases activity of glands and muscles of digestive system and constricts sphincters (e.g., anal sphincter)</td>
</tr>
<tr>
<td>Liver</td>
<td>Increases glucose uptake from blood</td>
<td>Stimulates release of glucose to blood*</td>
</tr>
<tr>
<td>Gallbladder</td>
<td>Excites (gallbladder contracts to expel bile)</td>
<td>Inhibits (gallbladder is relaxed)</td>
</tr>
<tr>
<td>Kidney</td>
<td>No effect (no innervation)</td>
<td>Promotes renin release; causes vasoconstriction; decreases urine output</td>
</tr>
<tr>
<td>Penis</td>
<td>Causes erection (vasodilation)</td>
<td>Causes ejaculation</td>
</tr>
<tr>
<td>Vagina/clitoris</td>
<td>Causes erection (vasodilation) of clitoris; increases vaginal lubrication</td>
<td>Causes contraction of vagina</td>
</tr>
<tr>
<td>Blood vessels</td>
<td>Little or no effect</td>
<td>Constricts most vessels and increases blood pressure; constricts vessels of abdominal viscera and skin to divert blood to muscles, brain, and heart when necessary; NE constricts most vessels; epinephrine dilates vessels of the skeletal muscles during exercise*</td>
</tr>
<tr>
<td>Blood coagulation</td>
<td>No effect (no innervation)</td>
<td>Increases coagulation*</td>
</tr>
<tr>
<td>Cellular metabolism</td>
<td>No effect (no innervation)</td>
<td>Increases metabolic rate*</td>
</tr>
<tr>
<td>Adipose tissue</td>
<td>No effect (no innervation)</td>
<td>Stimulates lipolysis (fat breakdown)</td>
</tr>
</tbody>
</table>

*Effects are mediated by epinephrine release into the bloodstream from the adrenal medulla.
### 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 results in bulging of the lens for close vision</td>
<td>Weakly inhibits muscle, which results in flattening of the lens for far vision</td>
</tr>
<tr>
<td>Glands (nasal, lacrimal, gastric, pancreas)</td>
<td>Stimulates secretory activity</td>
<td>Inhibits secretory activity; causes vasoconstriction of 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>Causes vasodilation*</td>
</tr>
<tr>
<td>Urinary bladder/urethra</td>
<td>Causes contraction of smooth muscle of bladder wall; relaxes urethral sphincter; promotes voiding</td>
<td>Causes relaxation of 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.
## Anatomical and Physiological Differences Between the Parasympathetic and Sympathetic Divisions

<table>
<thead>
<tr>
<th>CHARACTERISTIC</th>
<th>PARASYMPATHETIC</th>
<th>SYMPATHETIC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location of ganglia</td>
<td>Ganglia (terminal ganglia) are within the visceral organ (intramural) or close to the organ served.</td>
<td>Ganglia are within a few centimeters of CNS: alongside vertebral column (sympathetic trunk ganglia) and anterior to vertebral column (collateral, or prevertebral, ganglia).</td>
</tr>
<tr>
<td>Relative length of pre- and postganglionic fibers</td>
<td>Long preganglionic; short postganglionic.</td>
<td>Short preganglionic; long postganglionic.</td>
</tr>
<tr>
<td>Rami communicantes</td>
<td>None.</td>
<td>Gray and white rami communicantes. White rami contain myelinated preganglionic fibers; gray contain unmyelinated postganglionic fibers.</td>
</tr>
<tr>
<td>Degree of branching of preganglionic fibers</td>
<td>Minimal.</td>
<td>Extensive.</td>
</tr>
<tr>
<td>Functional role</td>
<td>Maintenance functions; conserves and stores energy; “rest and digest.”</td>
<td>Prepares body for activity; “fight-or-flight.”</td>
</tr>
<tr>
<td>Neurotransmitters</td>
<td>All preganglionic and postganglionic fibers release ACh (are cholinergic fibers).</td>
<td>All preganglionic fibers release ACh. Most postganglionic fibers release norepinephrine (are adrenergic fibers); postganglionic fibers serving sweat glands and some blood vessels of skeletal muscles release ACh. Neurotransmitter activity is augmented by release of adrenal medullary hormones (norepinephrine and epinephrine).</td>
</tr>
</tbody>
</table>
Neurotransmitters and Receptors

- Cholinergic
  - Nicotinic
  - Muscarinic

- Adrenergic
  - Alpha
  - Beta
Autonomic nervous system - mediators

ACETYLCHOLINE
- binds on two types of the membrane receptors – muscarinic and nicotinic

Muscarinic receptors – they are on membranes of the effector cells, between terminals of the postganglionic parasympathetic and sympathetic cholinergic fibers and effector organs. Their activation show slower excitatory effect.

Nicotinic receptors – they are placed on the membranes of the ganglionic parasympathetic and sympathetic neurons and their activation shows rapid depolarization – excitatory effect to the ganglionic neurons.

NORADRENALINE
- is neurotransmitter of the sympathetic part of the autonomic nervous system.
- combines with two types of the membrane receptors - \( \alpha \)-receptors and \( \beta \)-receptors
- the result of combinations are different responses of the effector organs (for example, stimulation of \( \alpha \)-receptors on the the vessel smooth muscle produces vasoconstriction, stimulation of \( \beta \)-receptors of the bronchial smooth muscle bronchodilatation).
Autonomic nervous system - acetylcholine

Terminal fiber with varicosity
Extracellular space
Cell membrane
Effector cell
Receptor place for ACh

Acetylation process:

- Acetyl-coA + cholin → Acetylcholine (ACh)
- ACh acts on the receptor place for ACh
Autonomic nervous system - noradrenaline

- noradrenaline (NA)
- dopamine
- DOPA
- tyrosine

Reactions:
- monoaminooxidasis (MAO)
- catechol-O-methyltransferasis (COMT)

Processes:
- inactivation
- terminal fiber with varicosity
- extracellular space
- cell membrane
- effector cell

Part of NA is transported to blood and is eliminated from tissue.
Adrenoreceptors are found in target tissue of the sympathetic nervous system and are activated by the catecholamines – noradrenaline and adrenaline.

Noradrenaline is released from postganglionic neurons of the sympathetic nervous system. Adrenaline is secreted by the adrenal medulla and reaches the target tissues via the circulation.

Each of the receptor types has a different mechanism of action (except the $\beta_1$ and $\beta_2$ receptors, which have the same mechanism of action), resulting in different physiological effects.
Cholinergic Receptors

The effects of the binding of ACh to nicotinic and muscarinic receptors of the parasympathetic division.

The action of nicotinic receptors of the parasympathetic division:

- ACh binds to the nicotinic receptor, allowing Na+ ions to enter the cell, which activates the receptor.

The action of muscarinic receptors of the parasympathetic division:

- ACh binds to the muscarinic receptor, activating a G protein.
- The G protein activates specific enzymes, leading to metabolic effects.
Adrenergic Receptors

The effects of sympathetic stimulation, which result primarily from the interactions of NE and E with adrenergic receptors in the target cell's plasma membrane.

The stimulation of alpha receptors by norepinephrine, which activates enzymes on the inside of the target cell's plasma membrane.

The stimulation of beta receptors by epinephrine, which triggers changes in the metabolic activity of the target cell.

- **Alpha receptors**
  - Activation of second messengers
  - Reduction of cAMP levels
  - Release of Ca²⁺ from ER
  - Smooth muscle contraction
  - Gland cell secretion

- **Beta receptors**
  - Activation of adenylate cyclase
  - cAMP
  - ATP
  - Cardiac muscle stimulation and increased tissue metabolism
  - Relaxation of smooth muscle in respiratory passages and in the blood vessels of skeletal muscle
  - Release of fatty acids by adipose tissue for metabolic use in other tissues
Autonomic nervous system – noradrenergic neurons

Effects mediated by $\alpha_1$-adrenergic receptor activation:

- Vasoconstriction of smooth muscles in vessels in the skin, sphincter of GIT and brain. During the fight-or-flight response, vasoconstriction results in decreased blood flow to these organs.

- Smooth muscle are contraction in renal system (ureter, uterus, urethral sphincter)

- Smooth muscle are contraction in bronchioles

- Dilatation of iris

- Seminal tract resulting in ejaculation

- Produces anorexia by inhibition in the olfactory system

- Both positive and negative inotropic effects on heart muscle
**Autonomic nervous system – noradrenergic neurons**

**Effects mediated by $\alpha_1$-adrenergic receptor activation:**

- Saline secretion is affected by increase of K+ levels in saliva
- In liver – increase in glycogenolysis and gluconeogenesis
- Secretion from sweat glands
- Support of Na+ reabsorption from kidney
- Activate mitogenic responses and regulate growth and proliferation of many cells
- Involved in the detection of mechanical feedback on the hypoglossal motor neurons which allow a long-term facilitation in respiration in response to repeated apnea
Autonomic nervous system – noradrenergic neurons

**Effects mediated by $\alpha_2$-adrenergic receptor:**

The $\alpha_2$-adrenergic receptor binds both noradrenaline released by sympathetic postganglionic fibers and adrenaline released by the adrenal medulla.

It has several general functions in common with the $\alpha_1$-adrenergic receptor, but also has specific effects as:

- suppression of release of noradrenaline by negative feedback
- transient hypertension, followed by a sustained hypotension
- vasoconstriction of certain arteries and veins
- vasoconstriction of coronary arteries; however, the extent of this effect may be limited and may be negated by the vasodilatory effect from $\beta_2$ receptors
- decrease motility of smooth muscle in GIT
Autonomic nervous system – noradrenergic neurons

Effects mediated by $\alpha_2$-adrenergic receptor activation:

Individual actions of the $\alpha_2$ receptor include:

- mediates synaptic transmission in pre- and postsynaptic nerve terminals by decrease of release of acetylcholine and noradrenaline
- inhibition of noradrenergic system in brain
- inhibition of lipolysis in adipose tissue
- inhibition of insulin release in pancreas
- induction of glucagon release from pancreas
- support of platelet aggregation
- contraction of sphincter of the GIT
- decreased secretion from salivary gland
- relaxation of GIT (presynaptic effect)
# Cholinergic and Adrenergic Receptors

## Table 14.2: Cholinergic and Adrenergic Receptors

<table>
<thead>
<tr>
<th>NEUROTRANSMITTER</th>
<th>RECEPTOR TYPE</th>
<th>MAJOR LOCATIONS*</th>
<th>EFFECT OF BINDING</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acetylcholine</td>
<td>Cholinergic</td>
<td>All ganglionic neurons; adrenal medullary cells (also neuromuscular junctions of skeletal muscle)</td>
<td>Excitation</td>
</tr>
<tr>
<td></td>
<td>Nicotinic</td>
<td>All parasympathetic target organs</td>
<td>Excitation in most cases; inhibition of cardiac muscle</td>
</tr>
</tbody>
</table>
|                  | Muscarinic    | Limited sympathetic targets:  
- Eccrine sweat glands  
- Blood vessels in skeletal muscles | Activation |
| Norepinephrine (and epinephrine released by adrenal medulla) | Adrenergic | Heart predominantly, but also kidneys and adipose tissue | Increases heart rate and strength; stimulates renin release by kidneys |
|                  | $\beta_1$     | Lungs and most other sympathetic target organs; abundant on blood vessels serving the heart, liver and skeletal muscle | Effects mostly inhibitory; dilates blood vessels and bronchioles; relaxes smooth muscle walls of digestive and urinary visceral organs; relaxes uterus |
|                  | $\beta_2$     | Adipose tissue | Stimulates lipolysis by fat cells |
|                  | $\beta_3$     | Most importantly blood vessels serving the skin, mucosae, abdominal viscera, kidneys, and salivary glands; also, virtually all sympathetic target organs except heart | Constricts blood vessels and visceral organ sphincters; dilates pupils of the eyes |
|                  | $\alpha_1$    | Membrane of adrenergic axon terminals; pancreas; blood platelets | Inhibits NE release from adrenergic terminals; inhibits insulin secretion by pancreas; promotes blood clotting |
|                  | $\alpha_2$    | |

* Note that all of these receptor subtypes are also found in the CNS.
Autonomic nervous system – adrenoreceptors

Effects mediated by $\beta_2$-adrenergic receptor activation:

**Cardiovascular system**
- increase of cardiac output (minor degree compared to $\beta_1$)
- increases heart rate in SA node (chronotropic effect)
- increases atrial cardiac muscle contractility (inotropic effect)
- increases contractility and automaticity of ventricular cardiac muscle
- dilate hepatic artery and arterioles in skeletal muscle

**Digestive system**
- glycogenolysis and gluconeogenesis in liver
- glycogenolysis and lactate release in skeletal muscle
- contract sphincters of GIT
- insulin and glucagon secretion from pancreas
Autonomic nervous system – α₁-adrenoreceptors

α₁-receptors are found in vascular smooth muscle of the skin, and splanchnic region, in the sphincters of gastrointestinal tract and bladder and in the radial muscle of the iris.

4. Activated phospholipase C catalyzes the liberation of diacylglycerol and IP₃ from phosphatidylinositol 4,5-diphosphate (step 4). The IP₃ that is generated causes the release of Ca²⁺ from intracellular stores in the endoplasmatic or sarcoplasmatic reticulum, resulting in an increase in intracellular Ca²⁺ concentration (step 5). Together, Ca²⁺ and diacylglycerol activate protein kinase C (step 6), which phosphorylates proteins. These phosphorylated proteins execute the final physiological actions (step 7), such as contraction of smooth muscle.
Autonomic nervous system – $\beta_1$-adrenoreceptors

$\beta_1$-receptors are prominent in the heart (increase of activity), in the saliva glands (increase of secretion), in adipose tissue and in the kidney (where they promote renin secretion).

$\beta_2$-receptors are found in the vascular smooth muscle of skeletal muscle, in the walls of the gastrointestinal tract and bladder and in bronchioles. The activation of $\beta_2$ receptors in these tissue leads to relaxation or dilatation.

4. Activated adenylyl cyclase catalyzes the conversion of ATP to cAMP, which serves as the second messenger (step 4). cAMP, via steps involving activation of protein kinases, initiates the final physiological actions (step 5).
Autonomic nervous system – nicotinic cholinoreceptors

Nicotinic receptors are found in several important locations: on the motor end plate of skeletal muscle, on all postganglionic neurons of both sympathetic and parasympathetic nervous system and on the chromaffin cells of the adrenal medulla.

2. When Ach is bound to each of the two α subunits, a conformational change occurs in all of the subunits, resulting in opening of the central core of the channel. When the core of the channel opens, Na\(^+\) and K\(^+\) flow down their respective electrochemical gradients.
**Autonomic nervous system – autonomic centers**

Sensory information from the somatosensory and visceral receptors goes to the centers for homeostasis in the hypothalamus, in the pons and in the medulla oblongata.
Figure 61-5 Autonomic control areas in the brain stem and hypothalamus.
Nuclei of the hypothalamus

- **Paraventricular nucleus**
  - *Water balance/stress*

- **Lateral hypothalamic area**

- **Dorsal hypothalamic area**

- **Medial preoptic area**
  - *Blood pressure*

- **Anterior hypothalamic area**
  - *Body temperature*

- **Supraoptic nucleus**
  - *Water balance*

- **Suprachiasmatic nuclei**
  - *Biological Clock*

- **Posterior hypothalamic area**
  - *Shivering*

- **Dorsomedial nucleus**
  - *GI tract*

- **Ventromedial nucleus**
  - *Satiety*

- **Mammilary body**
  - *Feeding*

- **Optic nerve**
- **Optic chiasm**
- **Anterior pituitary gland**
- **Posterior pituitary gland**

- **Optic chiasm**
- **Anterior commissure**
- **Frontal cortex**
## Drugs that Influence the ANS

### TABLE 14.3  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</td>
<td>Nicotinic ACh receptors on all ganglionic neurons</td>
<td>Typically stimulation of sympathetic effects; blood pressure increases</td>
<td>Nicotine</td>
<td>Used in smoking cessation products</td>
</tr>
<tr>
<td>therapeutic value, but</td>
<td>and in CNS</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>important because of presence</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>of nicotine in tobacco)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Parasympathomimetic agents</td>
<td>Muscarinic ACh receptors</td>
<td>Mimic effects of ACh, enhance parasympathetic effects</td>
<td>Pilocarpine</td>
<td>Glaucoma (opens aqueous humor drainage pores)</td>
</tr>
<tr>
<td>(muscarinic agents)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acetylcholinesterase</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>Difficulty urinating (increases bladder contraction)</td>
</tr>
<tr>
<td>inhibitors</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sympathomimetic agents</td>
<td>Adrenergic receptors</td>
<td>Enhance sympathetic activity by increasing NE release or binding to</td>
<td>Albuterol (Ventolin)</td>
<td>Asthma (dilates bronchioles by binding to β₂ receptors)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>adrenergic receptors</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sympatholytic agents</td>
<td>Adrenergic receptors</td>
<td>Decrease sympathetic activity by blocking adrenergic receptors or</td>
<td>Propranolol</td>
<td>Hypertension (member of a class of drugs called beta-blockers that decrease heart rate and</td>
</tr>
<tr>
<td></td>
<td></td>
<td>inhibiting NE release</td>
<td></td>
<td>blood pressure)</td>
</tr>
</tbody>
</table>

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