
# Chapter 7 自主神經系統

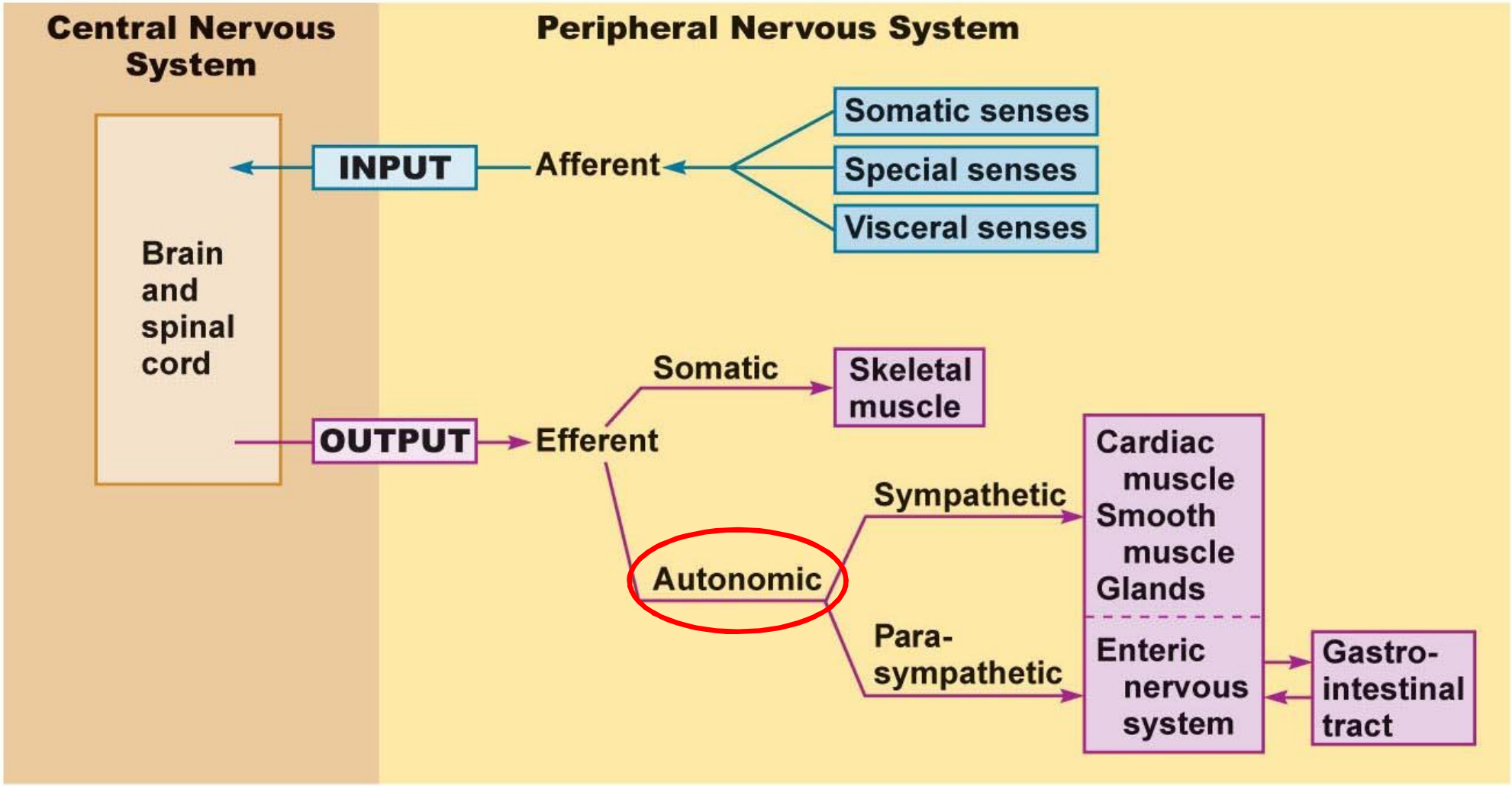
7-1　自主神經系統的結構

7-2　自主神經系統的分系

7-3　自主神經系統的功能

# Autonomic Nervous System

## *Involuntary Control*

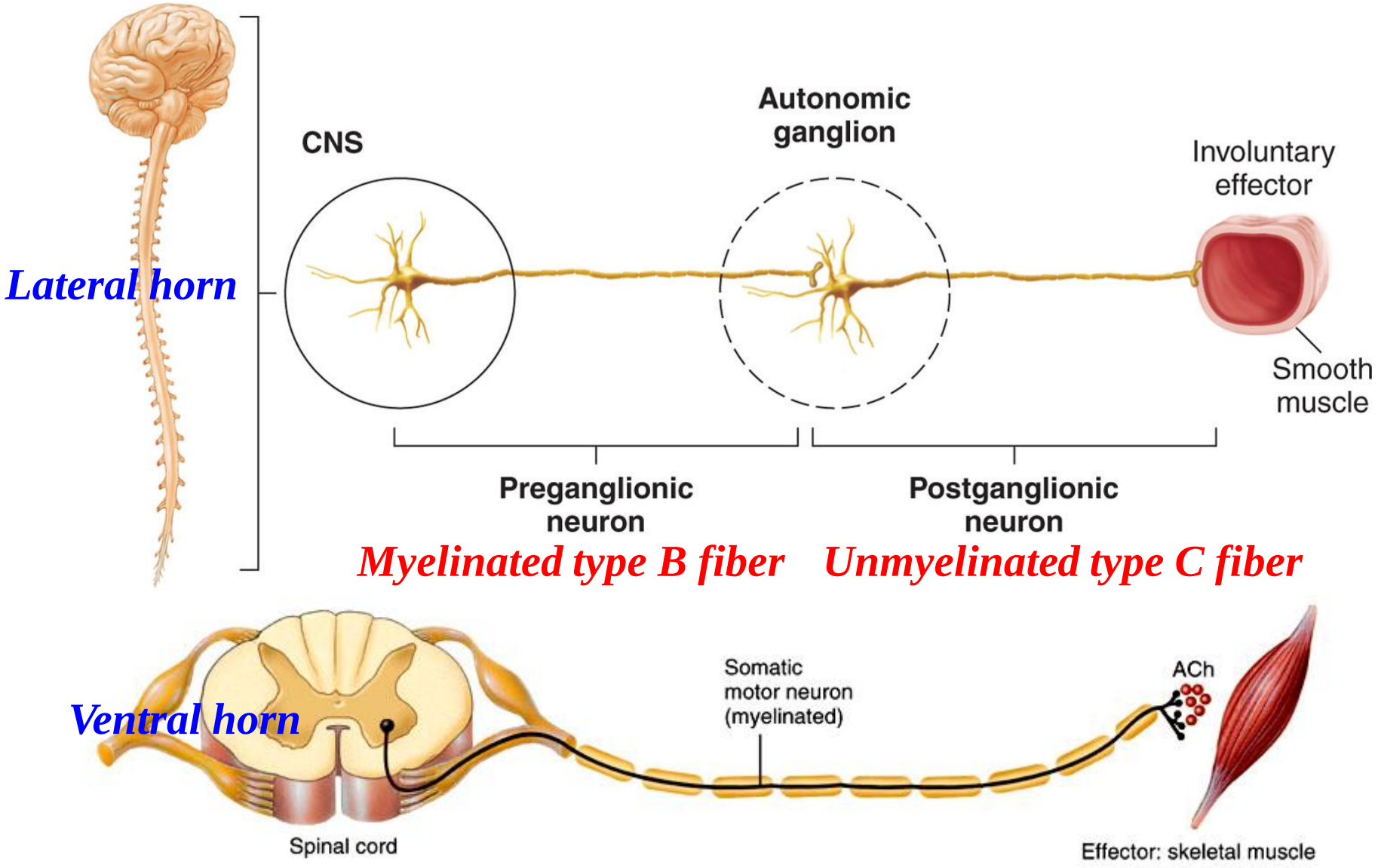


# Autonomic *vs.* Somatic System

| Property | Autonomic: parasympathetic | Autonomic: sympathetic | Somatic |
|---|---|---|---|
| Origin | Brainstem or lateral horns of sacral spinal cord | Lateral horns of thoracic and lumbar spinal cord | Ventral horns of spinal cord |
| Neurons in pathway | Two (preganglionic and postganglionic) *Ganglia* | Two (preganglionic and postganglionic) | One (motor neuron) |
| Effector organs | Cardiac muscle, smooth muscle, glands | Cardiac muscle, smooth muscle, glands, adipose tissue | Skeletal muscle *NMJ* |
| Neurotransmitters at neuroeffector junction | Acetylcholine | Norepinephrine | Acetylcholine |
| Receptor type at effector organ | Muscarinic cholinergic | Adrenergic (all classes) | Nicotinic cholinergic |
| Effects on effector organ | Either excitation or inhibition | Either excitation or inhibition | Excitation |
| Control | Primarily involuntary | Primarily involuntary | Primarily voluntary |

| | | |
|---|---|---|
| **Type of nerve fibers** | Slow-conducting; pregan. fiber (3 μm), and postgan. fiber (1 μm) | Fast-conducting; thick (9-13 μm), and myelinated |
| **Effect of denervation** | Muscle tone and function persist; target cells show denervation hypersensitivity | Flaccid paralysis and atrophy |

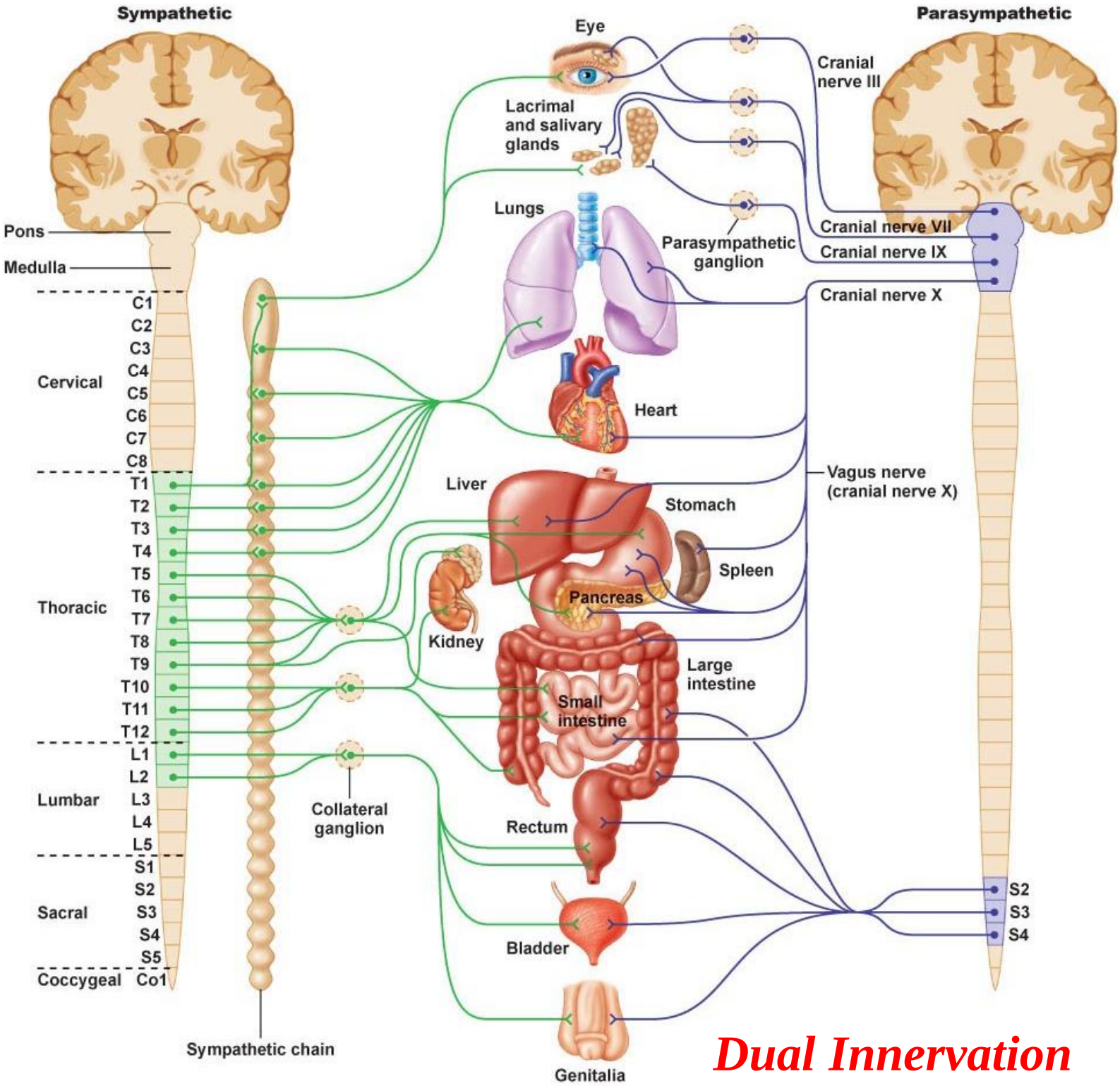
# Autonomic *vs.* Somatic System



# **Dual Innervation** of the Autonomic Nervous System

***Both divisions of the autonomic nervous system innervate most effector organs***

- **Primary function**—regulate organs to maintain homeostasis
- Parasympathetic and sympathetic activities tend to be **antagonistic, complementary or cooperative**
  - --Parasympathetic nervous system—**rest**
  - --Sympathetic nervous system—**fight or flight response**

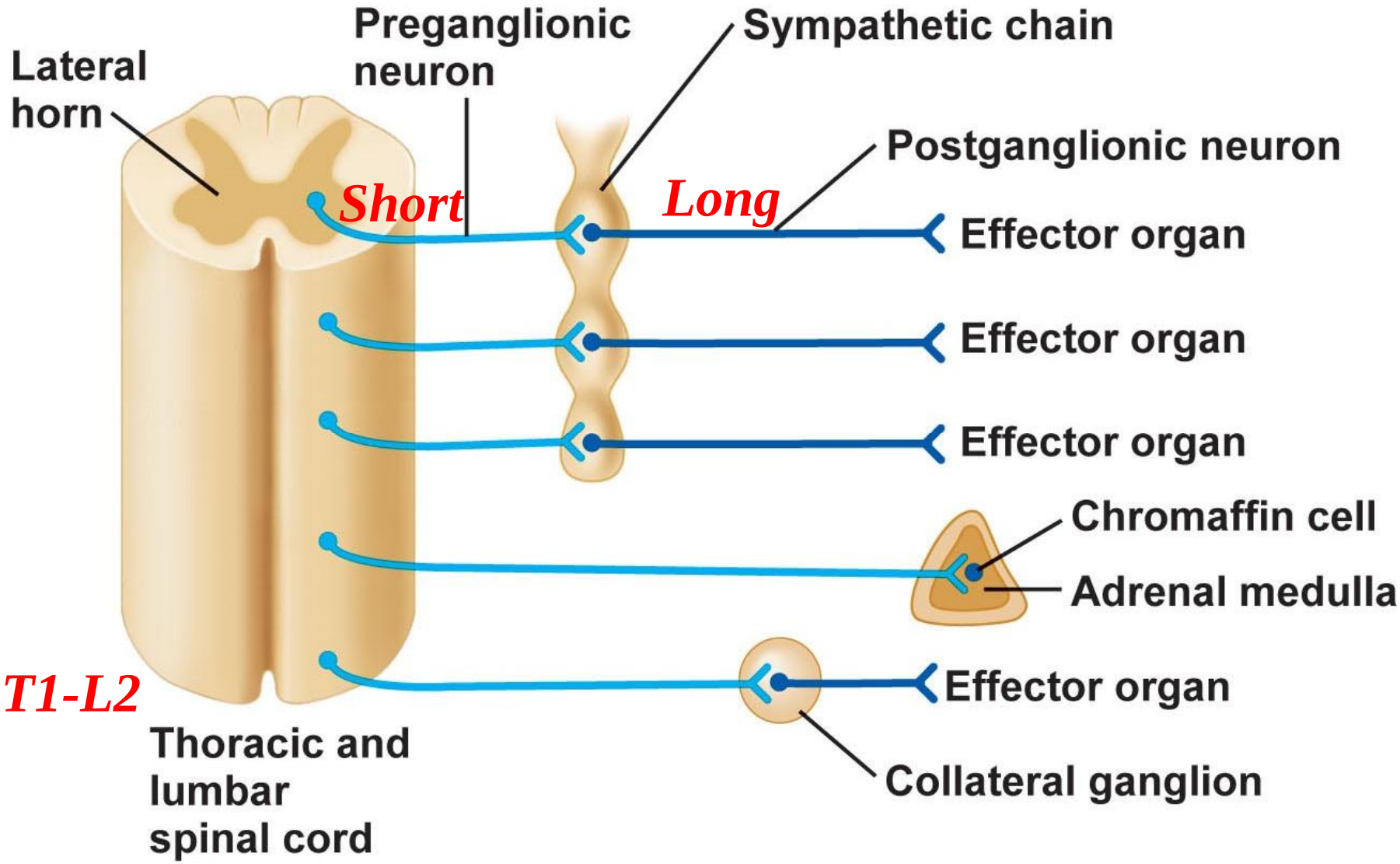



***Dual Innervation***

# Sympathetic Division

- Preganglionic neurons originate in thoracolumbar spinal cord (***Thoracolumbar division: T1-L2***)
- General anatomy
  - --**Short** preganglionic neurons to sympathetic chain
  - --**Long** postganglionic neurons from chain to effector organs
  - --Ganglia linked together in sympathetic chain
- Sympathetic ganglia:
  - --**Sympathetic trunk ganglia** = **paravertebral ganglia** = **sympathetic chain**
  - --**Prevertebral (collateral) ganglia**: celiac, superior mesenteric, and inferior mesenteric

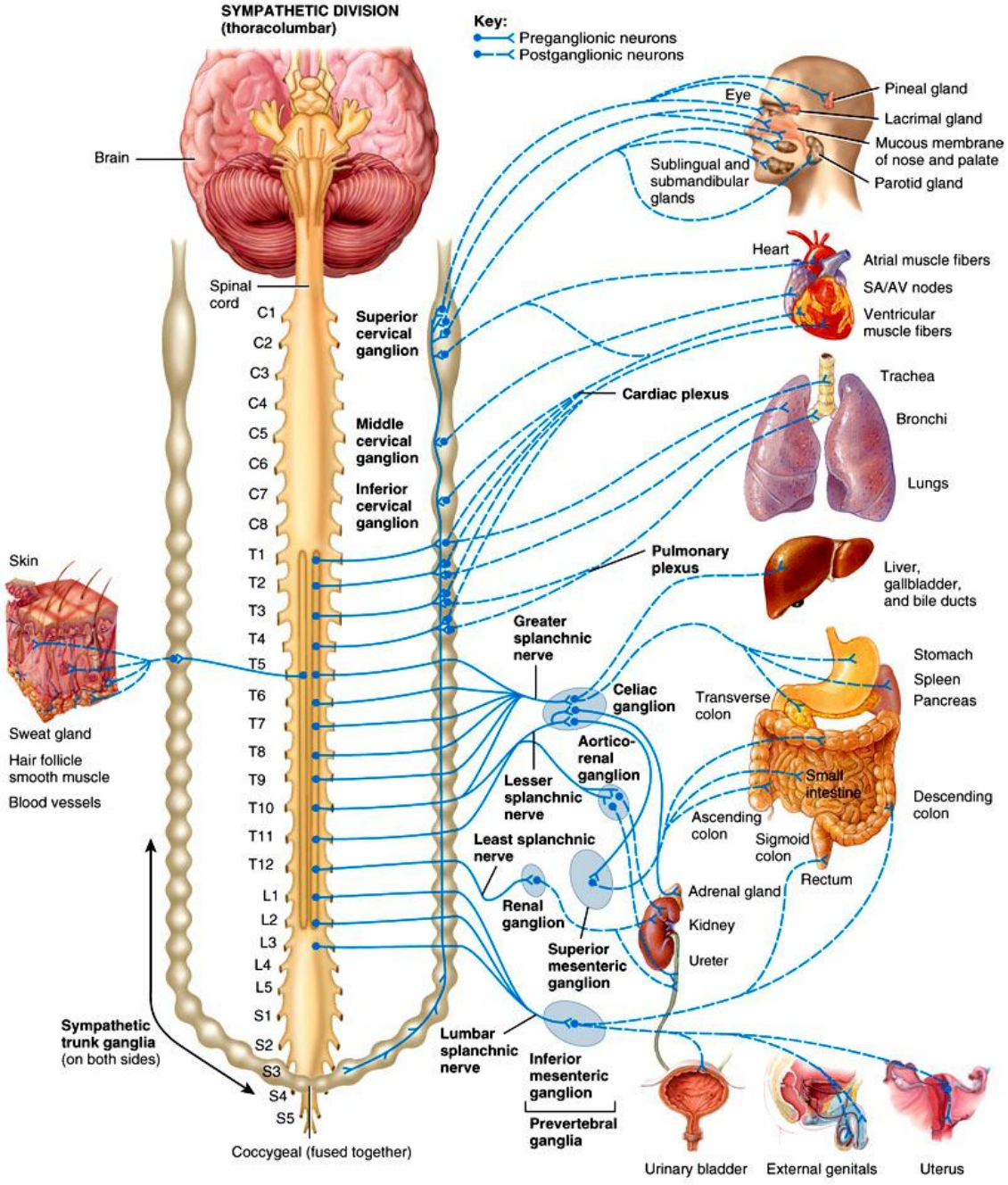
# Sympathetic Division



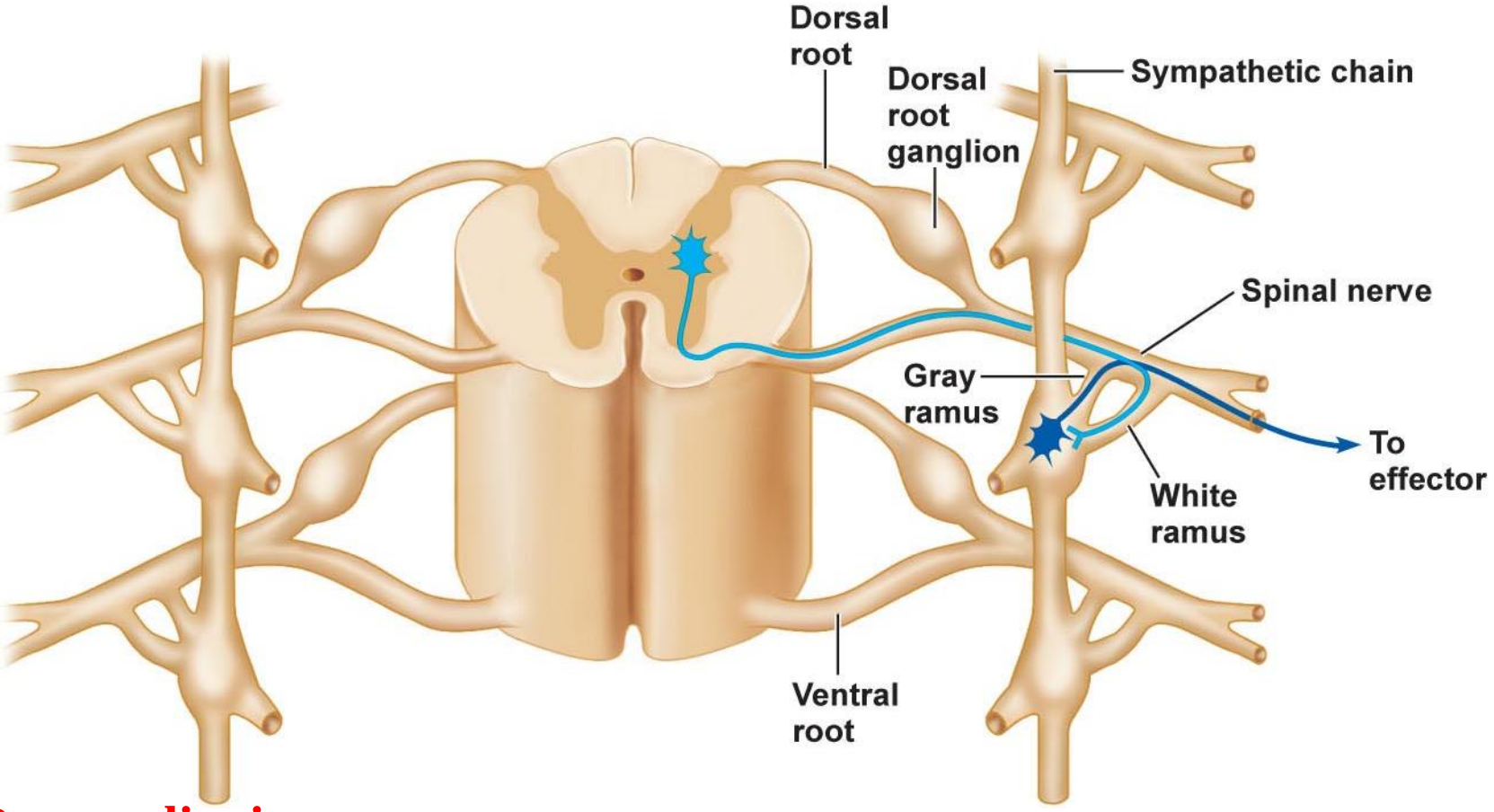

- ***Exception to general anatomy***
  - ***--Collateral ganglia—outside chain***
  - ***--Adrenal medulla***

# Sympathetic Division

- A single sympathetic preganglionic fiber has many axon collaterals and may synapse with 20 or more postganglionic neurons (**divergence發散性**)
- Allows the sympathetic division to act as a single unit through **mass activation**
- Effects of sympathetic stimulation are **more widespread** than the effects of parasympathetic stimulation



# Common Sympathetic Fibers

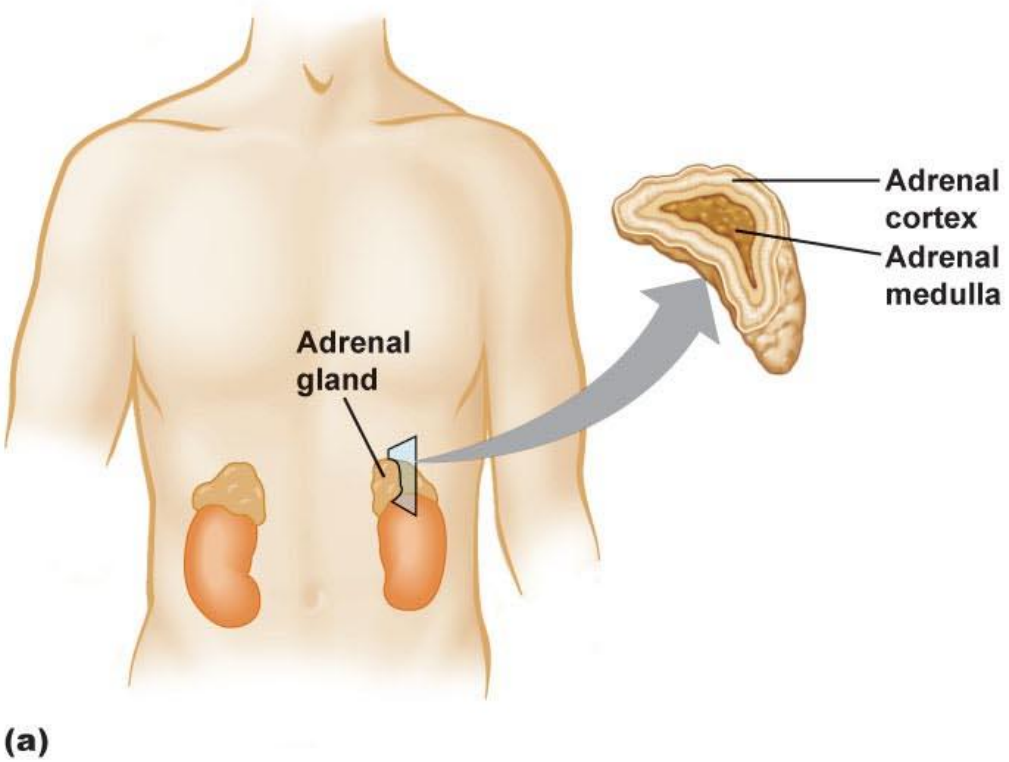


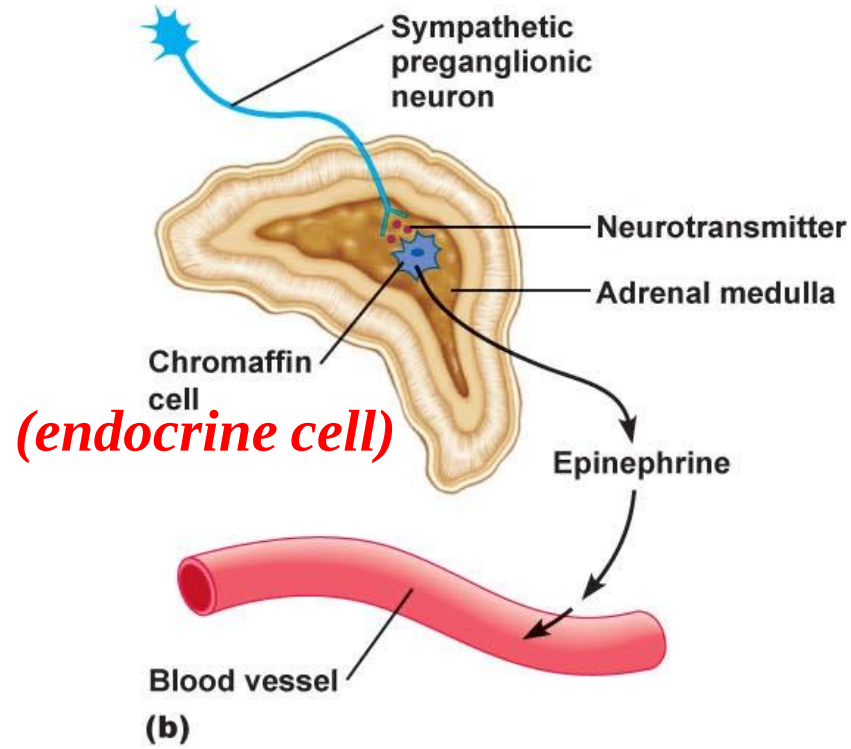

- **Preganglionic**
  - --Exits via ventral root of spinal cord and enters spinal nerve
  - --Axons leave spinal nerve as white ramus and enter sympathetic ganglia
  - --Communicate in ganglia with postganglionic neurons
- **Postganglionic**
  - --Leave ganglia as gray ramus and re-enter spinal nerve
  - --Travel to effector organ in spinal nerve

# Innervation of Adrenal Gland

## *Sympathoadrenal System*

### *Fight-Flight Responses*



# Summary of the Sympathetic Division

| Parts of Body Innervated | Spinal Origin of Preganglionic Fibers | Origin of Postganglionic Fibers |
|---|---|---|
| Eye | C8 and T1 | Cervical ganglia |
| Head and neck | T1 to T4 | Cervical ganglia |
| Heart and lungs | T1 to T5 | Upper thoracic (paravertebral) ganglia |
| Upper extremities | T2 to T9 | Lower cervical and upper thoracic (paravertebral) ganglia |
| Upper abdominal viscera | T4 to T9 | Celiac and superior mesenteric (collateral) ganglia |
| Adrenal | T10 and T11 | Not applicable |
| Urinary and reproductive systems | T12 to L2 | Celiac and interior mesenteric (collateral) ganglia |
| Lower extremities | T9 to L2 | Lumbar and upper sacral (paravertebral) ganglia |

- ***Collateral ganglia: Postganglionic neurons innervate organs of the digestive, urinary, and reproductive systems***

# Parasympathetic Division

- Preganglionic neurons originate in brainstem or sacral spinal cord (***Craniosacral division:***

  ***CN III, VII, IX, X, and S2-S4***)

- General anatomy

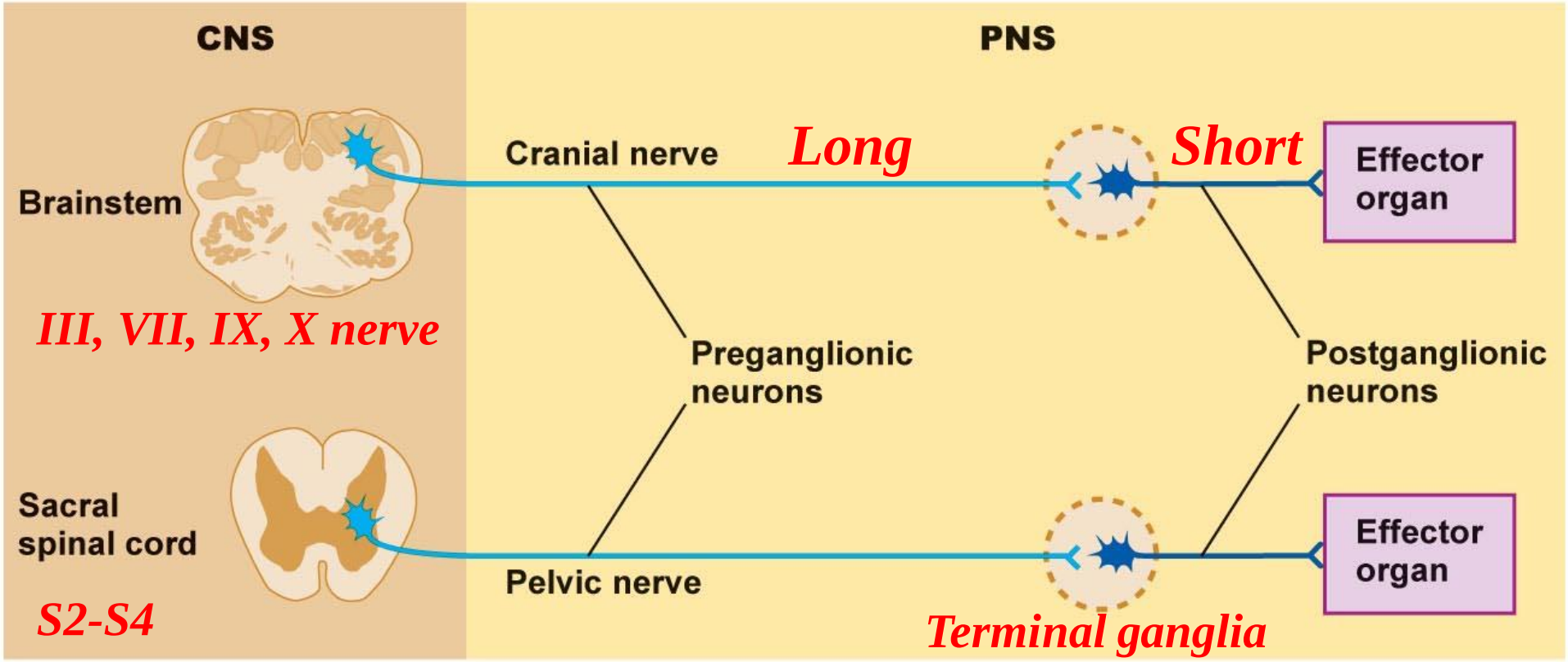
  **--Long** preganglionic neurons to ganglia near effector organ

  --Preganglionic neuron communicates with postganglionic neuron in ganglia

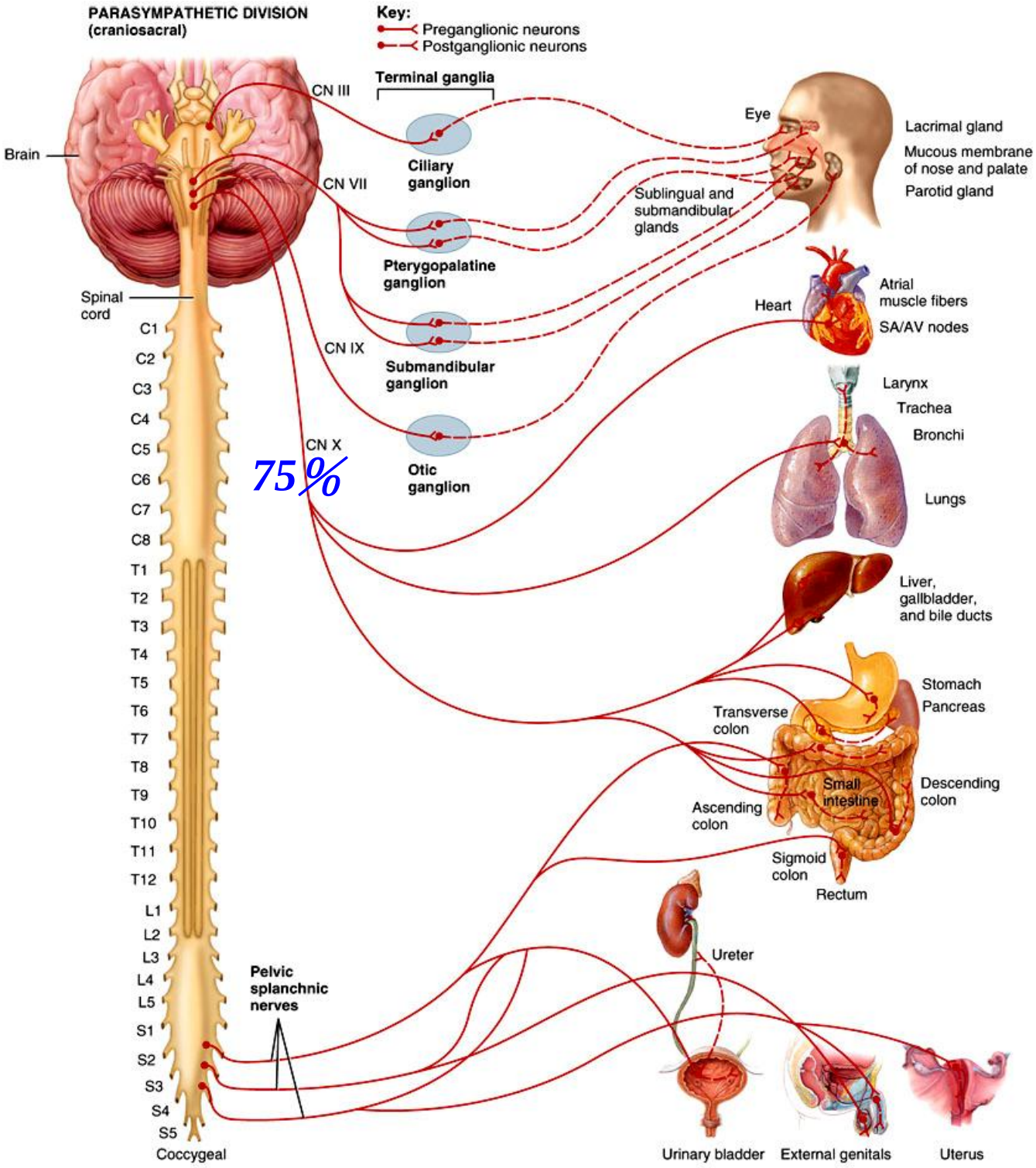
  **--Short** postganglionic neurons from ganglia to effector organs

- They synapse on ganglia located near or in effector organs = **terminal ganglia**

# Parasympathetic Division




- ***Effectors in the adrenal medulla, skin (sweat glands, arrector pili muscle) and skeletal muscles (blood vessels) receive sympathetic but not parasympathetic innervation***


PARASYMPATHETIC DIVISION
(craniosacral)
Key:
Preganglionic neurons
Postganglionic neurons
Terminal ganglia
Brain
Spinal cord
CN III
CN VII
CN IX
CN X
Ciliary ganglion
Pterygopalatine ganglion
Submandibular ganglion
Otic ganglion
75%
C1
C2
C3
C4
C5
C6
C7
C8
T1
T2
T3
T4
T5
T6
T7
T8
T9
T10
T11
T12
L1
L2
L3
L4
L5
S1
S2
S3
S4
S5
Coccygeal
Pelvic splanchnic nerves
Eye
Lacrimal gland
Mucous membrane of nose and palate
Parotid gland
Sublingual and submandibular glands
Heart
Atrial muscle fibers
SA/AV nodes
Larynx
Trachea
Bronchi
Lungs
Liver, gallbladder, and bile ducts
Stomach
Pancreas
Transverse colon
Small intestine
Descending colon
Ascending colon
Sigmoid colon
Rectum
Ureter
Urinary bladder
External genitals
Uterus

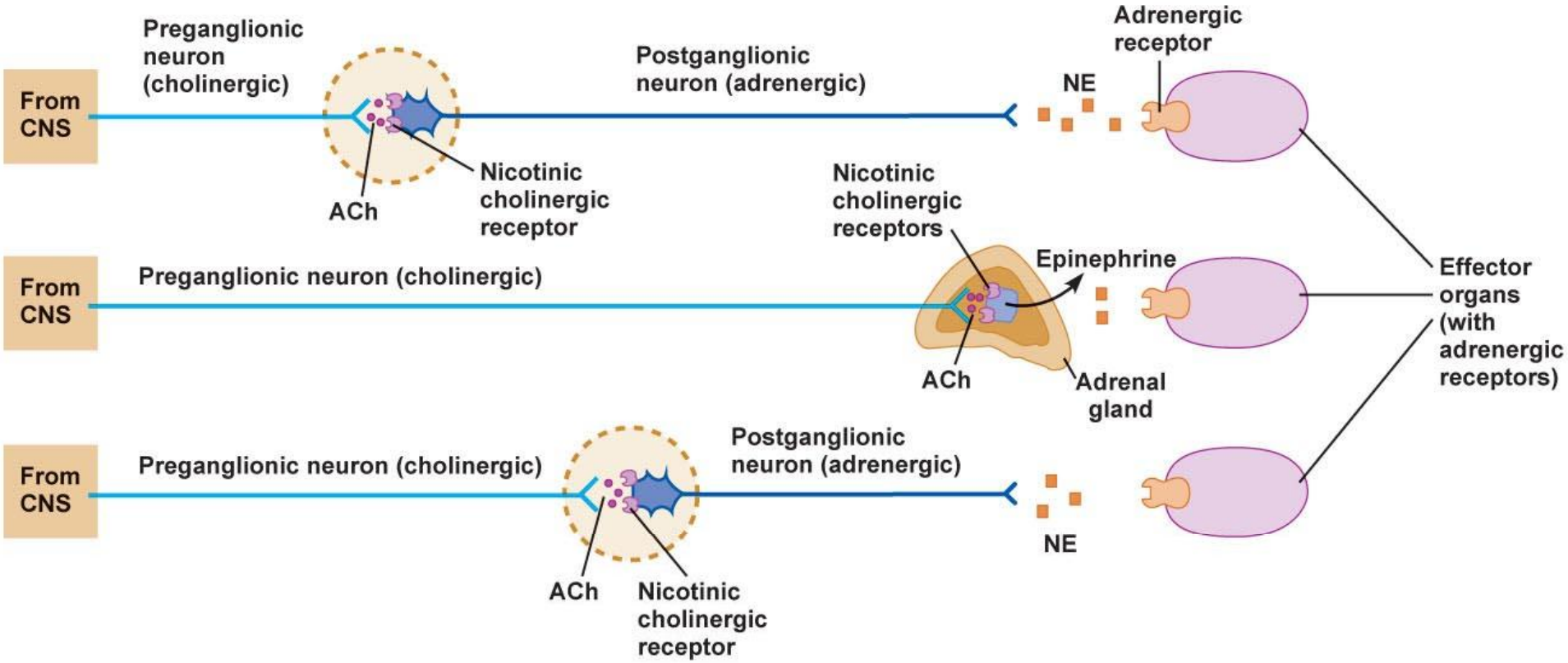
# Summary of the Parasympathetic Division

| Nerve | Origin of Preganglionic Fibers | Location of Terminal Ganglia | Effector Organs |
|---|---|---|---|
| Oculomotor (third cranial) nerve | Midbrain (cranial) | Ciliary ganglion | Eye (smooth muscle in iris and ciliary body) |
| Facial (seventh cranial) | Pons (cranial) | Pterygopalatine and submandibular ganglia | Lacrimal, mucous, and salivary glands |
| Glossopharyngeal (ninth cranial) nerve | Medulla oblongata (cranial) | Otic ganglion | Parotid gland |
| Vagus (tenth cranial) nerve | Medulla oblongata (cranial) | Terminal ganglia in or near organ | Heart, lungs, gastrointestinal tract, liver, pancreas |
| Pelvic spinal nerves | S2 to S4 (sacral) | Terminal ganglia near organs | Lower half of large intestine, rectum, urinary bladder, and reproductive organs |

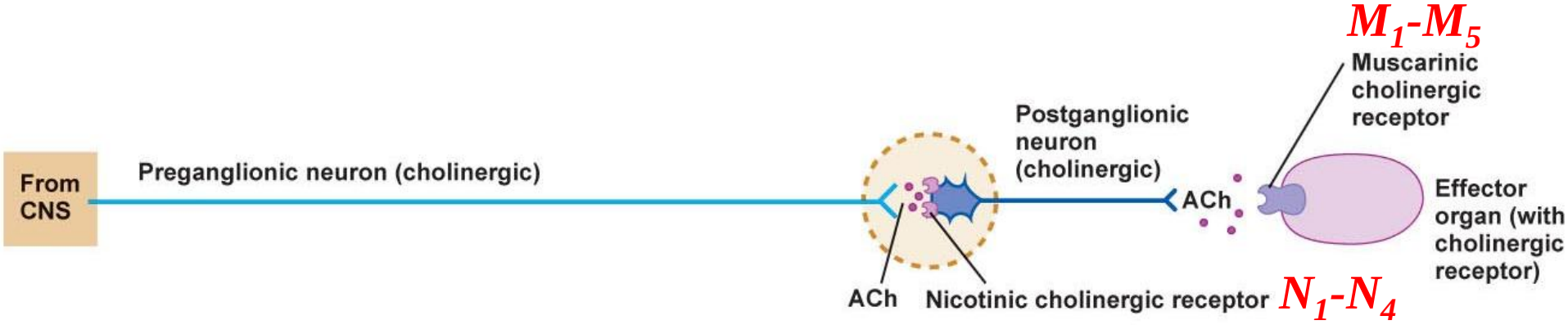
# Comparison of the Sympathetic and Parasympathetic Divisions

| Sympathetic Divisions | Parasympathetic Divisions |
|---|---|
| Originate from T1 to L2 segment of spinal cord (thoracolumbar division) | Originate from brain (Ill, VII, IX, X cranial nerves) and S2—S4 segment of spinal cord (craniosacral division) |
| Pre-ganglionic fibers are short, relay either in lateral ganglia or collateral ganglia | Pre-ganglionic fibers are very long reaching up to terminal ganglia mostly on viscera |
| Post-ganglionic fibers are long. Nerve endings are adrenergic in nature except in sweat gland (ACh) | Post-ganglionic fibers are short. Nerve endings are cholinergic in nature |
| Functionally, it is vasomotor and pilomotor to skin. It is seen when subject is in fear, fight and flight responses. It dilates skeletal muscle blood vessels (ACh) | Functionally, it is seen when subject is fully relaxed. Parasympathetic system has no effect on skin |
| Effect is widely diffused and directed towards mobilization of resources and expenditure of energy during emergency and emotional stress | Effect is discrete, isolated, directed towards conservation and restoration of the resources (rest and digest) |
| It supplies visceral blood vessels, skin | It only supplies viscera |

# Autonomic Neurotransmitters and Receptors




**(a)** Sympathetic nervous system




**(b)** Parasympathetic nervous system

# Response to Cholinergic Stimulation

- ACh released from **pre**ganglionic neurons of both the sympathetic and parasympathetic division is **stimulatory**

- ACh from **post**ganglionic neurons of the parasympathetic division can be **stimulatory or inhibitory**, depending on receptors

# Types of Cholinergic Receptors

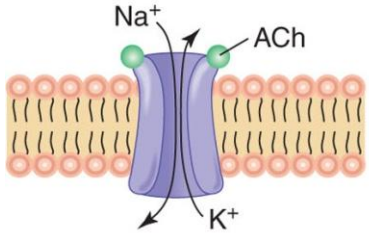
- **Nicotinic cholinergic receptors ($N_1$-$N_4$)**
  - --Found in **autonomic postganglionic** and **NMJ**
  - --Cause cation channels to open (**channel-gated**)
  - --Channel opening results in depolarization
- **Muscarinic cholinergic receptors ($M_1$-$M_5$)**
  - --Found in **visceral organs**
  - --Five subtypes identified; effect can be **stimulatory or inhibitory** (opening $K^+$ or $Ca^{2+}$ channels) on target cell
  - --**G protein–coupled** and second messenger system

## Table 9.6 | Cholinergic Receptors and Responses to Acetylcholine

| Receptor | Tissue | Response | Mechanisms |
|---|---|---|---|
| Nicotinic $N_2$ | Skeletal muscle | Depolarization, producing action potentials and muscle contraction | ACh opens cation channel in receptor |
| Nicotinic $N_1$ | Autonomic ganglia | Depolarization, causing activation of postganglionic neurons | ACh opens cation channel in receptor |
| Muscarinic ($M_3$, $M_5$) | Smooth muscle, glands | Depolarization and contraction of smooth muscle, secretion of glands | ACh activates G-protein coupled receptor, opening $Ca^{2+}$ channels and increasing cytosolic $Ca^{2+}$ |
| Muscarinic ($M_2$) | Heart | Hyperpolarization, slowing rate of spontaneous depolarization | ACh activates G-protein coupled receptor, opening channels for $K^+$ |

**Nicotinic ACh receptors**

Postsynaptic membrane of
- All autonomic ganglia
- All neuromuscular junctions
- Some CNS pathways



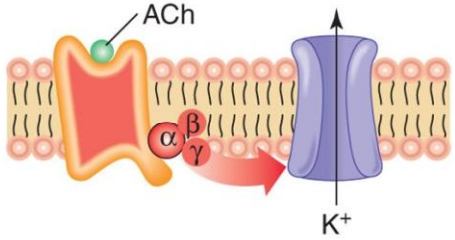

Ligand-gated channels (ion channels are part of receptor)

Depolarization

Excitation

**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)

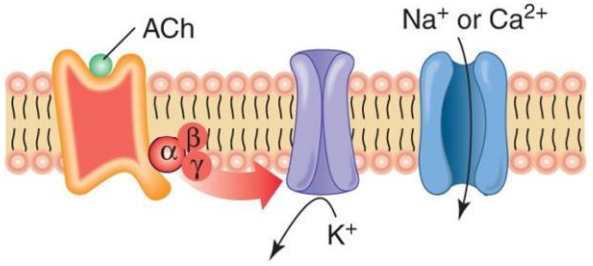



Hyperpolarization

($K^+$ channels opened)

Inhibition

Produces slower heart rate




Depolarization

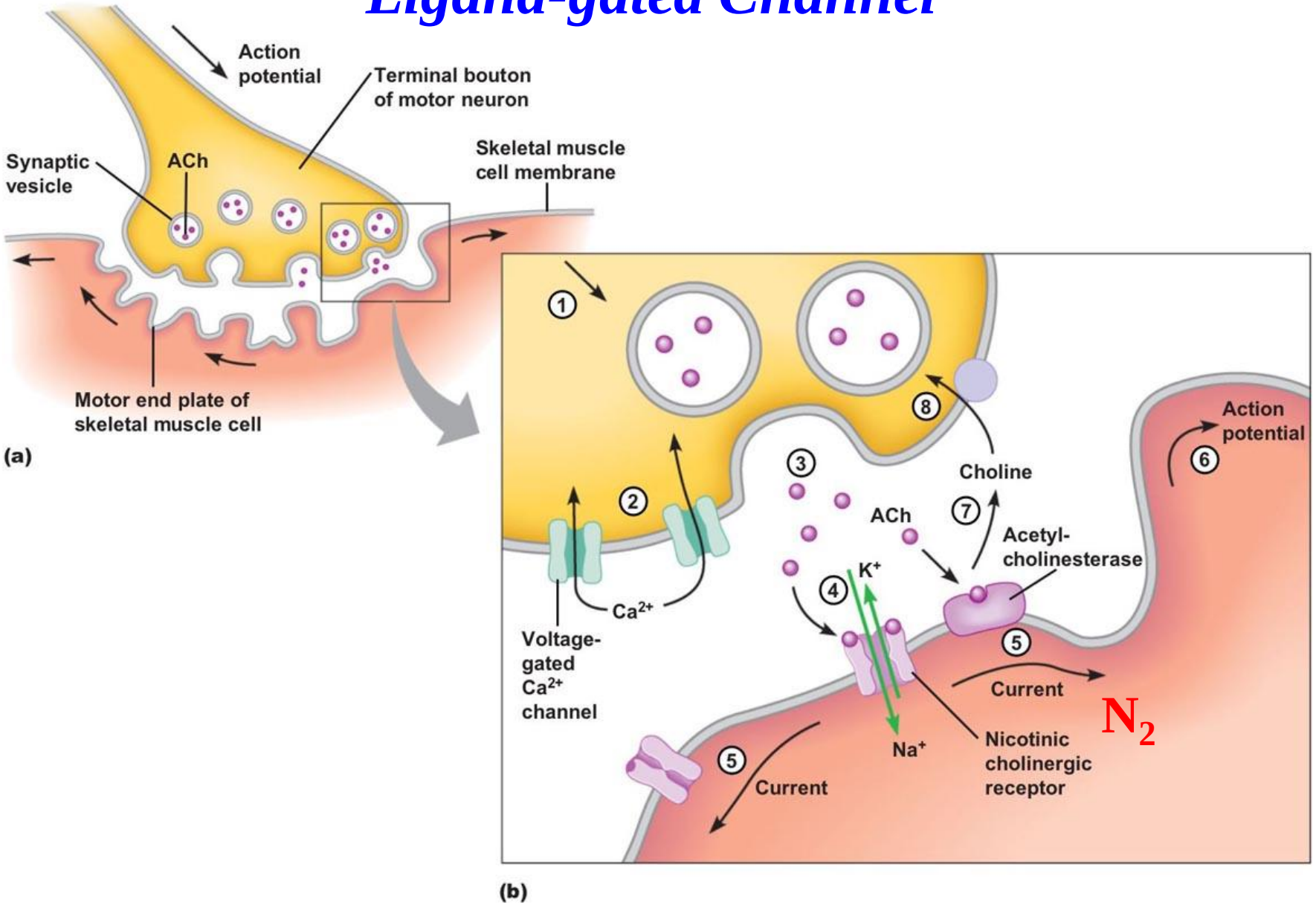
($K^+$ channels closed)

Excitation

Causes smooth muscles of the digestive tract to contract

# Nicotinic Cholinergic Receptors: NMJ

## *Channel-gated Receptor*
## *Ligand-gated Channel*



# Response to Adrenergic Stimulation

- Can **stimulate or inhibit**, depending on receptors

  --**Stimulation:** heart, dilatory muscles of the iris, smooth muscles of some blood vessels (causes vessel constriction)

  --**Inhibition:** Bronchioles in lungs, other blood vessels; inhibits contraction and causes dilation of these structures

# Types of Adrenergic Receptors

- Two main classes: **alpha** and **beta**
- Each has subclasses
- All are **G protein-coupled** and second messenger systems

**Alpha Receptors**

- ***Alpha 1 ($\alpha$1)***
- ***Alpha 2 ($\alpha$2)***

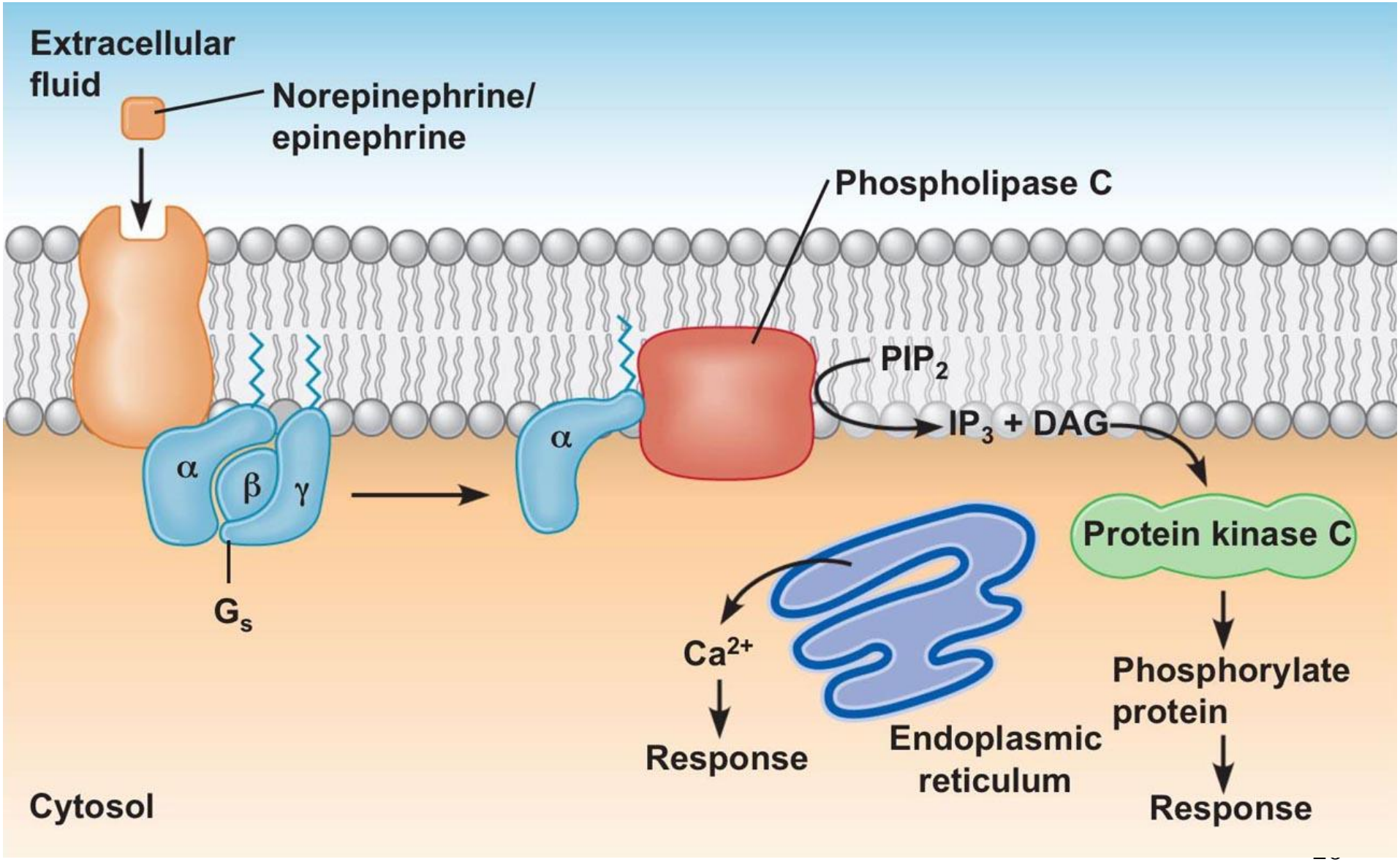
**Beta Receptors**

- ***Beta 1 ($\beta$1)***
- ***Beta 2 ($\beta$2)***
- ***Beta 3 ($\beta$3)***

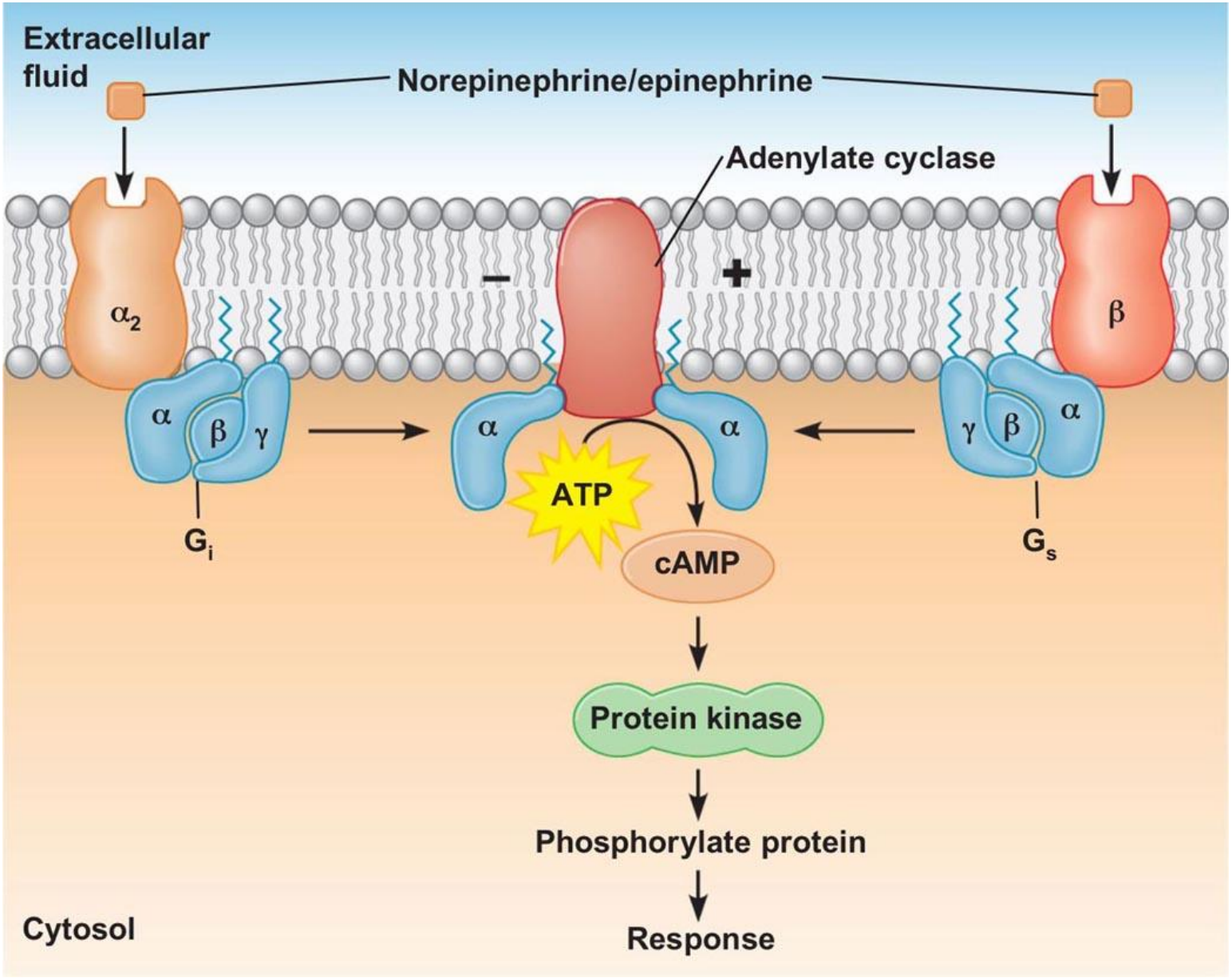
# Properties of Alpha-Adrenergic Receptors

- Located in effector organs of sympathetic nervous system
- Most common
- Usually **excitatory**
- Affinity: norepinephrine > epinephrine
- ***α1*** receptors use a **$Ca^{2+}$** 2nd messenger **(Gs: $Ca^{2+}$ ↑ )**
- ***α2*** receptors used as **autoreceptors (Gi: cAMP ↓ )**
  - --Located on presynaptic axons
  - --When stimulated, result in inhibition of norepinephrine release in the synapse (***clonidine: α2 agonist***)

# Sympathetic Signal Transduction:
# Alpha 1 Receptors



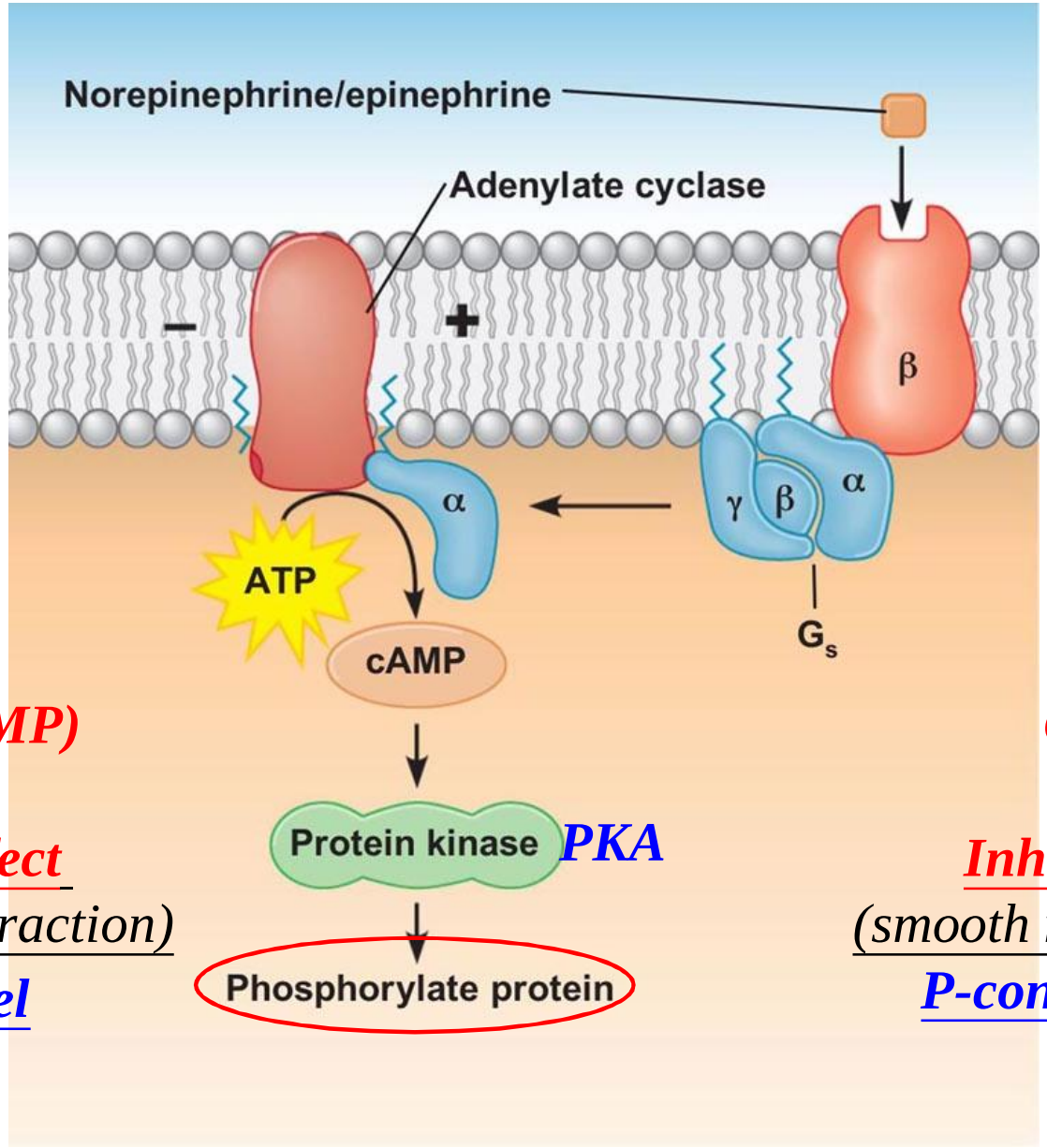
# Sympathetic Signal Transduction:
# Alpha 2 and Beta Receptors



# Properties of Beta-Adrenergic Receptors

- All *activate* ***cAMP*** 2nd messenger
- Affinities for norepinephrine and epinephrine vary
- ***β1*** receptors located in cardiac muscle and the kidneys
  - --Usually excitatory (**Gs**)
  - --Affinity: norepinephrine **=** epinephrine
- ***β2*** receptors located in some blood vessels and smooth muscle
  - --Usually inhibitory (**Gs**)
  - --Affinity: norepinephrine **<<** epinephrine
- ***β3*** receptors located in adipose tissue
  - --Usually excitatory (**Gs**)
  - --Affinity: norepinephrine **=** epinephrine

# Sympathetic Signal Transduction:
# Beta 1 and Beta 2 Receptors




***β1***

***Gs*** | ***(cAMP)***

***Excitatory effect***

*(heart muscle contraction)*

***P-Ca channel***

***β2***

***Gs*** | ***(cAMP)***

***Inhibitory effect***

*(smooth muscle relaxation)*

***P-contractile protein***

# Effects of Beta-Adrenergic Receptors Stimulation

| Receptor type | Tissue in which present | Effect of stimulation *(agonist)* |
|---|---|---|
| $\beta_1$ | Heart | Increased rate, force, conduction velocity, automaticity |
| | Kidney | Renin secretion |
| | Fat tissue | Lipolysis |
| $\beta_2$ | Smooth muscle | |
| | • bronchial | Bronchodilatation |
| | • vascular | Vasodilatation *(reflex tachycardia)* |
| | • intestinal | Reduced motility and tone |
| | • bladder | |
| | Skeletal muscle | Increased contractility, glycogenolysis, potassium uptake; tremor (overdose) *(hypokalemia)* |
| | Pancreas | Increased insulin secretion |
| | Liver | Glycogenolysis, gluconeogenesis |
| | Central nervous system | Nervous tension, headache, insomnia |

- **瘦肉精=Beta 2-receptors agonist**
  - ✓萊克多巴胺(Ractopamine=培林)
  - ✓沙汀胺醇(Salbutamol)
  - ✓克倫特羅(Clenbuterol)
  - ✓特布它林(Terbutaline)

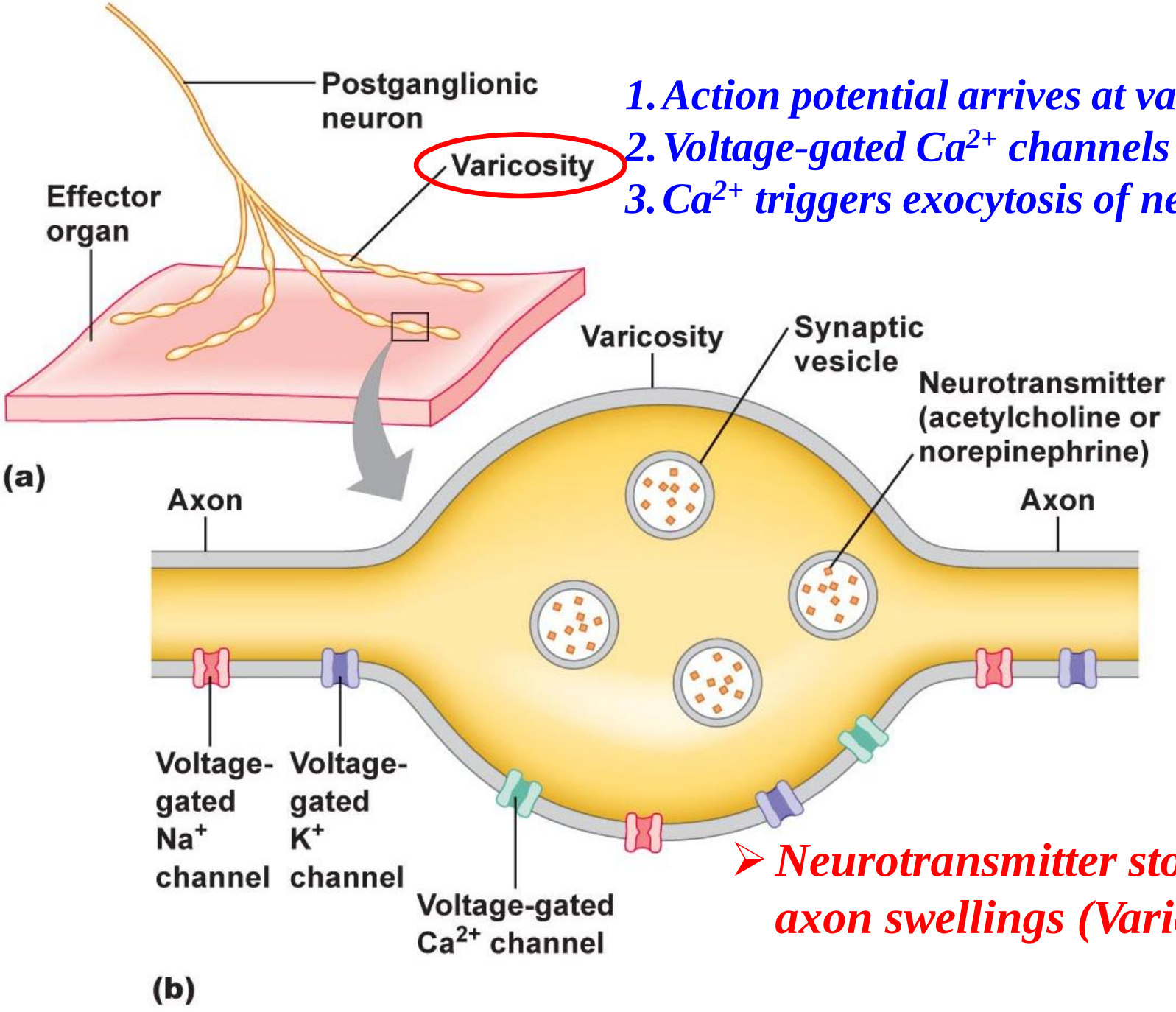
# Adrenergic Receptors

| Receptor type | Effector organ with receptor type | Relative affinities* | Signal transduction mechanism | | Effect on effector organ† |
|---|---|---|---|---|---|
| $\alpha_1$ | Most vascular smooth muscle, pupils | NE > Epi | Activates $IP_3$ | *Gs* | Excitatory |
| $\alpha_2$ | CNS, platelets, adrenergic nerve terminals (autoreceptors), some vascular smooth muscle, adipose tissue | NE > Epi | Inhibits cAMP | *Gi* | Excitatory |
| $\beta_1$ | CNS, cardiac muscle, kidney | NE = Epi | Activates cAMP | *Gs* | Excitatory |
| $\beta_2$ | Some blood vessels, respiratory tract, uterus | Epi ≫ NE | Activates cAMP | *Gs* | Inhibitory |
| $\beta_3$ | Adipose tissue | NE = Epi | Activates cAMP | *Gs* | Excitatory |

*NE = norepinephrine; Epi = epinephrine; > = greater than; ≫ = much greater than
†Effects are generalizations and not absolute.

| Organ | Adrenergic Effects of Sympathoadrenal System | Adrenergic Receptor |
|---|---|---|
| Eye | Contraction of radial fibers of the iris dilates the pupils | $\alpha_1$ |
| Heart | Increase in heart rate and contraction strength | $\beta_1$ primarily |
| Skin and visceral vessels | Arterioles constrict due to smooth muscle contraction | $\alpha_1$ |
| Skeletal muscle vessels | Arterioles constrict due to sympathetic nerve activity | $\alpha_1$ |
| | Arterioles dilate due to hormone epinephrine | $\beta_2$ |
| Lungs | Bronchioles (airways) dilate due to smooth muscle relaxation | $\beta_2$ |
| Stomach and intestine | Contraction of sphincters slows passage of food | $\alpha_1$ |
| Liver | Glycogenolysis and secretion of glucose | $\alpha_1$, $\beta_2$ |

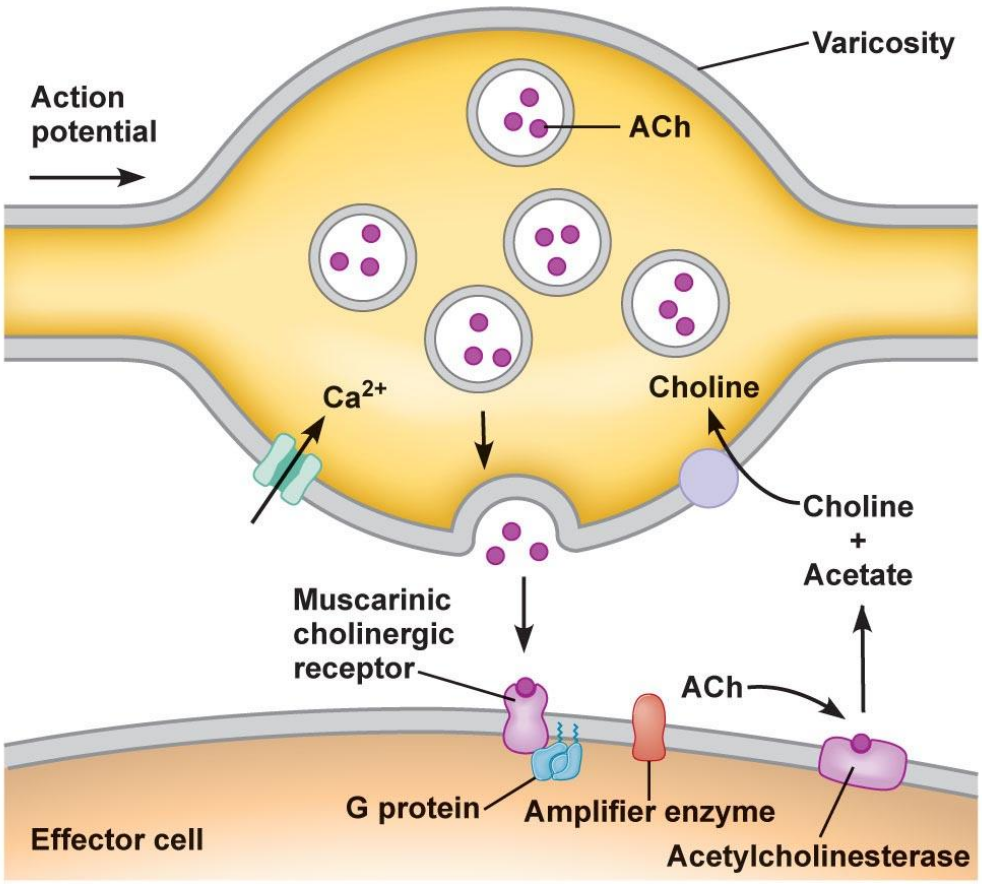
# Autonomic Neuroeffector Junctions



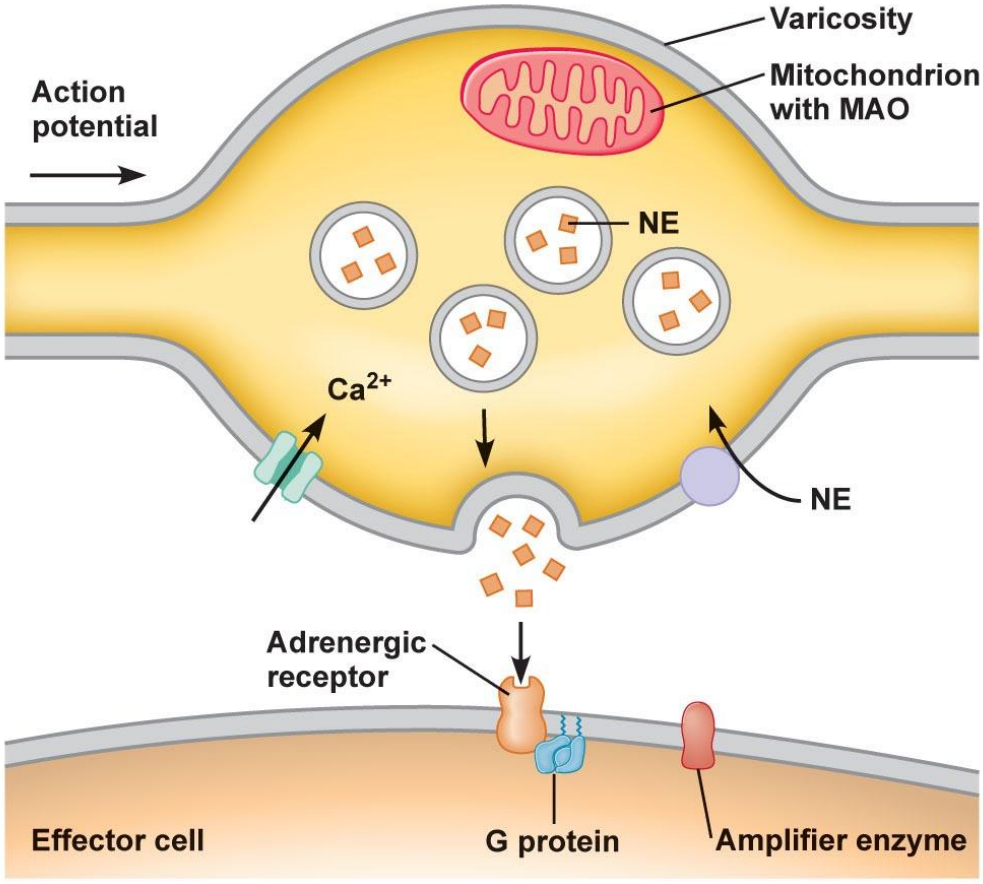

1. *Action potential arrives at varicosity*
2. *Voltage-gated $Ca^{2+}$ channels open*
3. *$Ca^{2+}$ triggers exocytosis of neurotransmitter*

➢ *Neurotransmitter stored in axon swellings (Varicosities)*

# Neurotransmitters from Varicosities




(a) Acetylcholine release from postganglionic neuron




(b) Norepinephrine release from postganglionic neuron

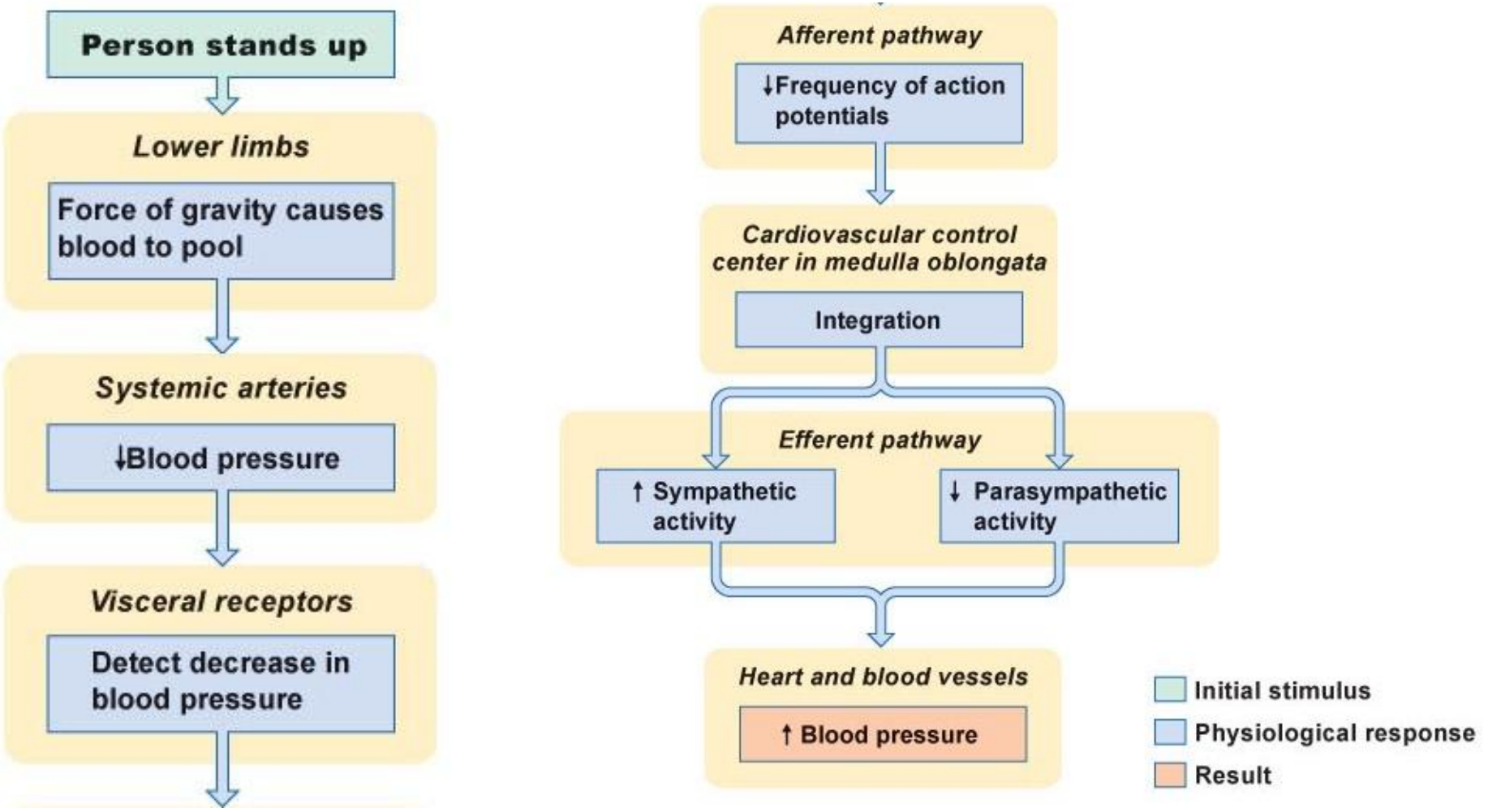
**Parasympathetic**

**Sympathetic**

# Regulation of Autonomic Function

- **Dual innervation** of organs (antagonists)
- **Balance** between parasympathetic and sympathetic activity
  - ***--Parasympathetic—rest***
  - ***--Sympathetic—excitation***
- Increases in parasympathetic activity coupled with decreases in sympathetic activity
- Increases in sympathetic activity coupled with decreases in parasympathetic activity

# Autonomic Control: Blood Pressure



# Autonomic Function

- ***Parasympathetic Activity***

--Quiet, relaxed states

--Active in “rest and digest”

--Energy stores

--Increase gastrointestinal activities

--Decrease heart rate and blood pressure

--Dilates visceral blood vessels

- ***Sympathetic Activity***

--Fight-or-flight response

--Prepare for emergency, stress, and exercise

--Increase heart rate and blood pressure

--Mobilize energy stores

--Pupillary dilation

--Decrease gastrointestinal and urinary functions

# Autonomic Function in Organ System

| | Parasympathetic Nervous System* | Sympathetic Nervous System | |
|---|---|---|---|
| **Organ system** | **Effect** | **Effect** | **Adrenergic receptor class** |
| ***Heart*** | | | |
| SA node | Decreases heart rate | Increases heart rate | $\beta_1$ |
| AV node | Decreases conduction velocity | Increases conduction velocity | $\beta_1$ |
| Force of contraction | Decreases (small effect) | Increases | $\beta_1$ |
| ***Blood vessels*** | | | |
| Arterioles to most of body | None | Vasoconstriction | $\alpha_1$ |
| Arterioles to skeletal muscle | None | Vasoconstriction<br>Vasodilation (epinephrine) | $\alpha_1$<br>$\beta_2$ |
| Arterioles to brain | None | None | |
| Veins | None | Vasoconstriction<br>Vasodilation (epinephrine) | $\alpha_1$<br>$\beta_2$ |

$M_2$

*Receptor types for the parasympathetic nervous system are not given, because

†Sympathetic postganglionic neurons to the sweat glands release acetylcholine as the neurotransmitter.

# Autonomic Function in Organ System

| Organ system | Parasympathetic Nervous System* Effect | Sympathetic Nervous System Effect | Sympathetic Nervous System Adrenergic receptor class |
|---|---|---|---|
| ***Lungs*** | | | |
| Bronchial muscle | Contraction | Relaxation | $\beta_2$ |
| Bronchial glands | Stimulates secretion | Inhibits secretion | $\alpha$ |
| ***Digestive tract*** | | | |
| Motility | Increased | Decreased | $\alpha_1, \alpha_2, \beta_2$ |
| Secretions | Stimulated | Inhibited | $\alpha_2$ |
| Sphincters | Relaxation | Contraction | $\alpha_1$ |
| ***Pancreas*** | | | |
| Exocrine glands | Stimulates secretion | Inhibits secretion | $\alpha$ |
| Endocrine glands | Stimulates secretion | Inhibits secretion | $\alpha_2$ |
| ***Salivary glands*** | Stimulates watery secretion | Stimulates mucus secretion | $\alpha_1$ |
| ***Kidneys*** | | | |
| Renin release | None | Stimulated | $\beta_1$ |

*Receptor types for the parasympathetic nervous system are not given, because *all* effector organs have muscarinic cholinergic receptors.
†Sympathetic postganglionic neurons to the sweat glands release acetylcholine as the neurotransmitter.

$M_3$

$M_3$

***Complementary Effects***

# Autonomic Function in Organ System

| | Parasympathetic Nervous System* | Sympathetic Nervous System | |
|---|---|---|---|
| **Organ system** | **Effect** | **Effect** | **Adrenergic receptor class** |
| ***Urinary bladder*** | $M_3$ | | |
| Bladder wall | Contraction | Relaxation (small effect) | $\beta_2$ |
| Sphincter | Relaxation | Contraction | $\alpha_1$ |
| ***Male reproductive tract*** | ***Cooperative Effects*** | | |
| Blood vessels (erection) | Vasodilation | None | |
| Vas deferens and seminal vesicles (ejaculation) | None | Ejaculation | $\alpha_1$ |
| ***Female reproductive tract*** | | | |
| Uterus, nonpregnant | Unknown | Relaxation | $\beta_2$ |
| Uterus, pregnant | Unknown | Contraction | $\alpha_1$ |

*Receptor types for the parasympathetic nervous system are not given, because *all* effector organs have muscarinic cholinergic receptors.

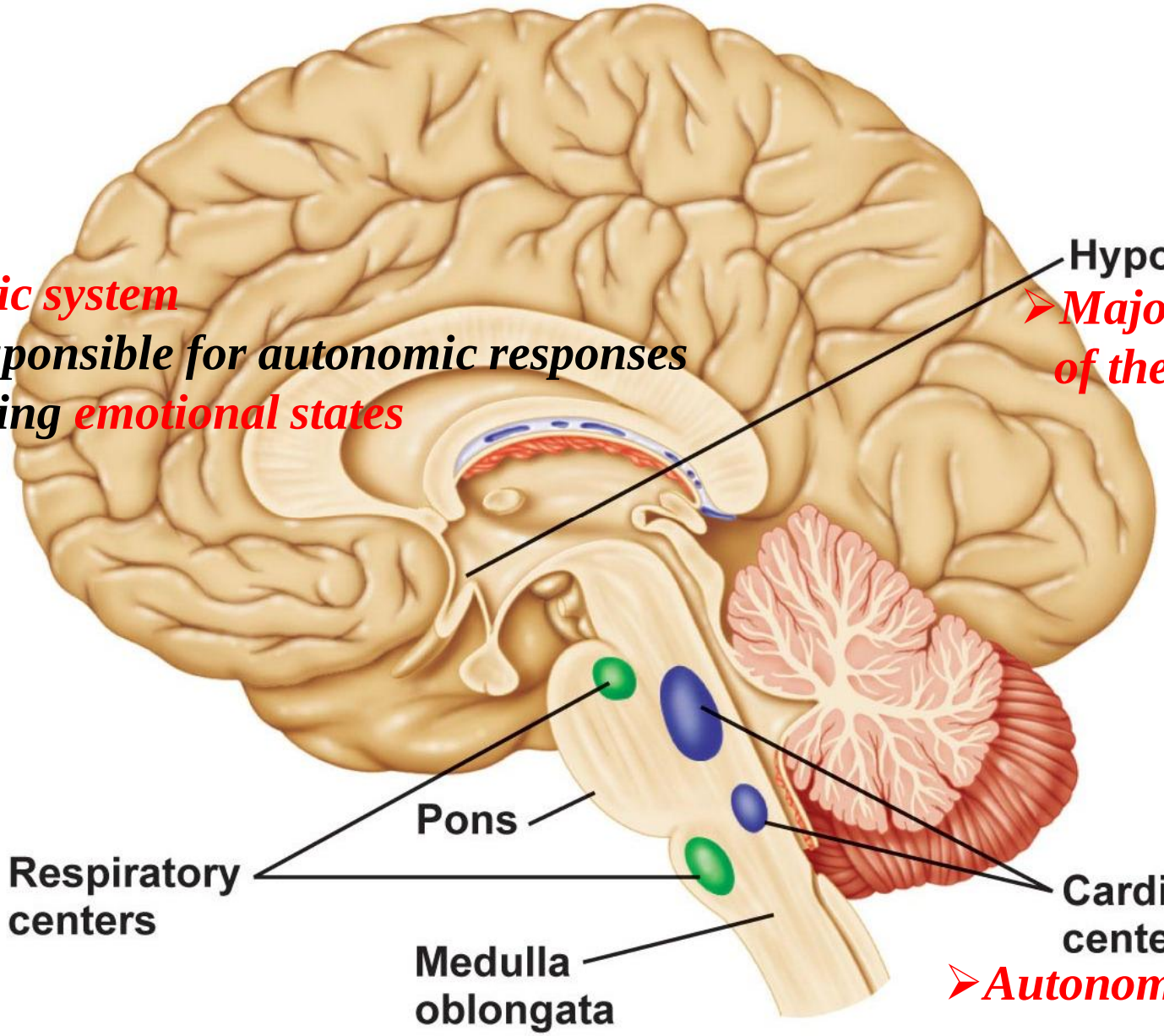
†Sympathetic postganglionic neurons to the sweat glands release acetylcholine as the neurotransmitter.

# Autonomic Function in Organ System

| | Parasympathetic Nervous System* | Sympathetic Nervous System | |
|---|---|---|---|
| **Organ system** | **Effect** | **Effect** | **Adrenergic receptor class** |
| ***Skin*** | | | |
| Sweat glands | Stimulates secretion | Stimulates secretion | $\alpha_1$, muscarinic† |
| Piloerector muscles | None | Contraction (hairs stand up) | $\alpha_1$ |
| ***Eye*** | $M_3$ | | |
| Iris muscles (pupil size) | Contraction of circular muscle (pupillary constriction) | Contraction of radial muscle (pupillary dilation) | $\alpha_1$ |
| Ciliary muscles (accommodation) | Contraction for near vision | Relaxation for far vision (small effect) | $\beta_2$ |
| ***Metabolism*** | | | |
| Liver | None | Stimulates glycogenolysis and gluconeogenesis | $\alpha_1$, $\beta_2$ |
| ***Adipose tissue*** | None | Stimulates lipolysis | $\beta_3$ |

*Receptor types for the parasympathetic nervous system are not given, because *all* effector organs have muscarinic cholinergic receptors.
†Sympathetic postganglionic neurons to the sweat glands release acetylcholine as the neurotransmitter.

# Brain Areas of Autonomic Regulation




***Limbic system***

- ***Responsible for autonomic responses during emotional states***

- ***Major regulatory center of the ANS***

- ***Autonomic reflexes center***

# Autonomic Reflexes

- ***Many visceral functions are regulated by autonomic reflexes***

  --Sensory input is sent to brain centers=medulla (usually by the vagus nerve), which integrate the information and modify the activity of preganglionic neurons

表 7-5　感覺訊息經迷走神經傳入到延腦中樞後的反射效應

| 位 置 | 接受器型式 | 反射效應 |
|---|---|---|
| 胃腸道 | 牽張感受器 | 飽足感、疼痛、胃腸不適 |
| 主動脈 | 壓力感受器 | 受血壓上升的刺激，造成反射性心跳減慢 |
| | 化學感受器 | 血中 $CO_2$ 濃度增加和 $O_2$ 濃度減少的刺激，會造成呼吸加快、心跳速率增加及血管收縮 |
| 肺 部 | J 型感受器 | 受肺充血的刺激，造成喘不過氣的感覺、反射性心跳減慢、血壓下降 |
| | 牽張感受器 | 抑制吸氣動作；血管擴張；心跳速率加快 |
| 心 臟 | 心房牽張感受器 | 抑制抗利尿激素的分泌，造成排尿量增加 |
| | 心室牽張感受器 | 血管擴張、反射性心跳減慢 |