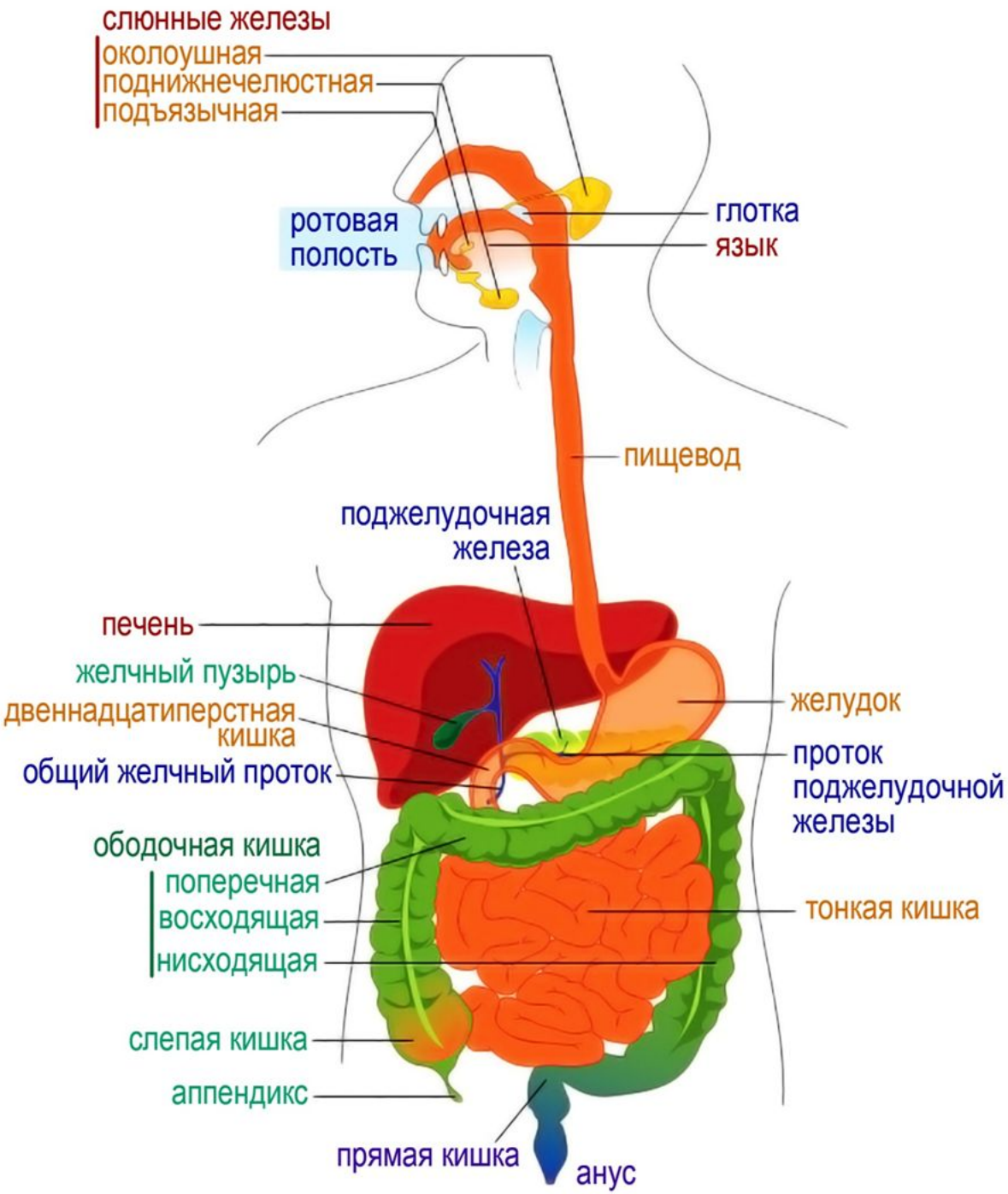
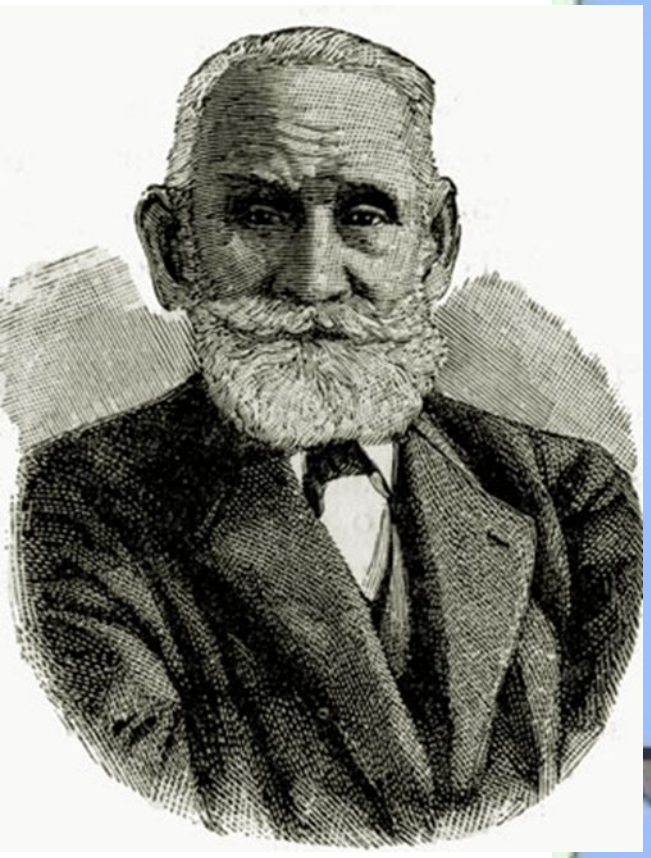
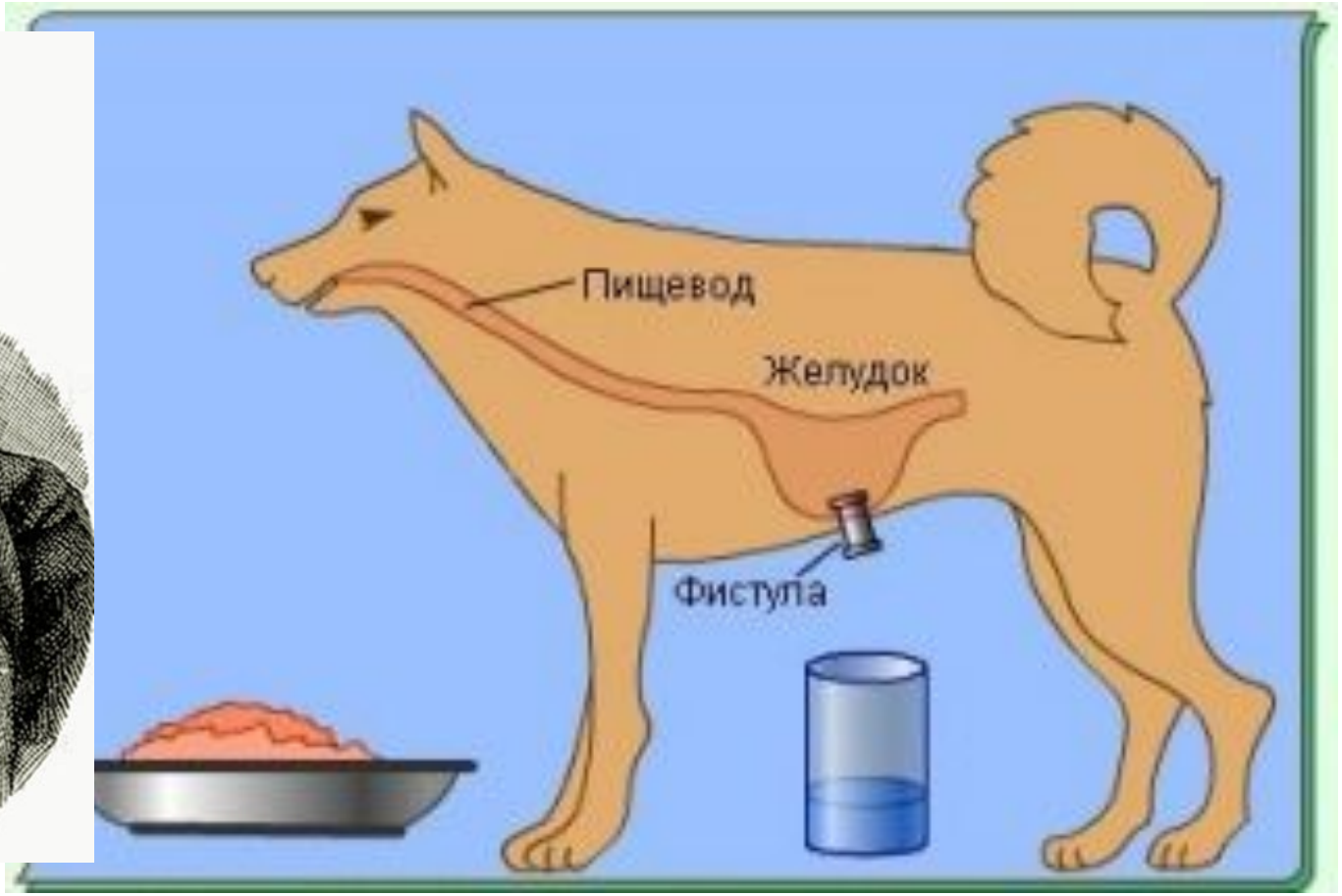
Секреторная функция пищеварительных желёз


слюнные железы
околоушная
поднижнечелюстная
подъязычная
ротовая полость
глотка
язык
пищевод
поджелудочная железа
печень
желчный пузырь
двенадцатиперстная кишка
общий желчный проток
желудок
проток поджелудочной железы
ободочная кишка
поперечная
восходящая
нисходящая
тонкая кишка
слепая кишка
аппендикс
прямая кишка
анус




Пищевод
Желудок
Фистула

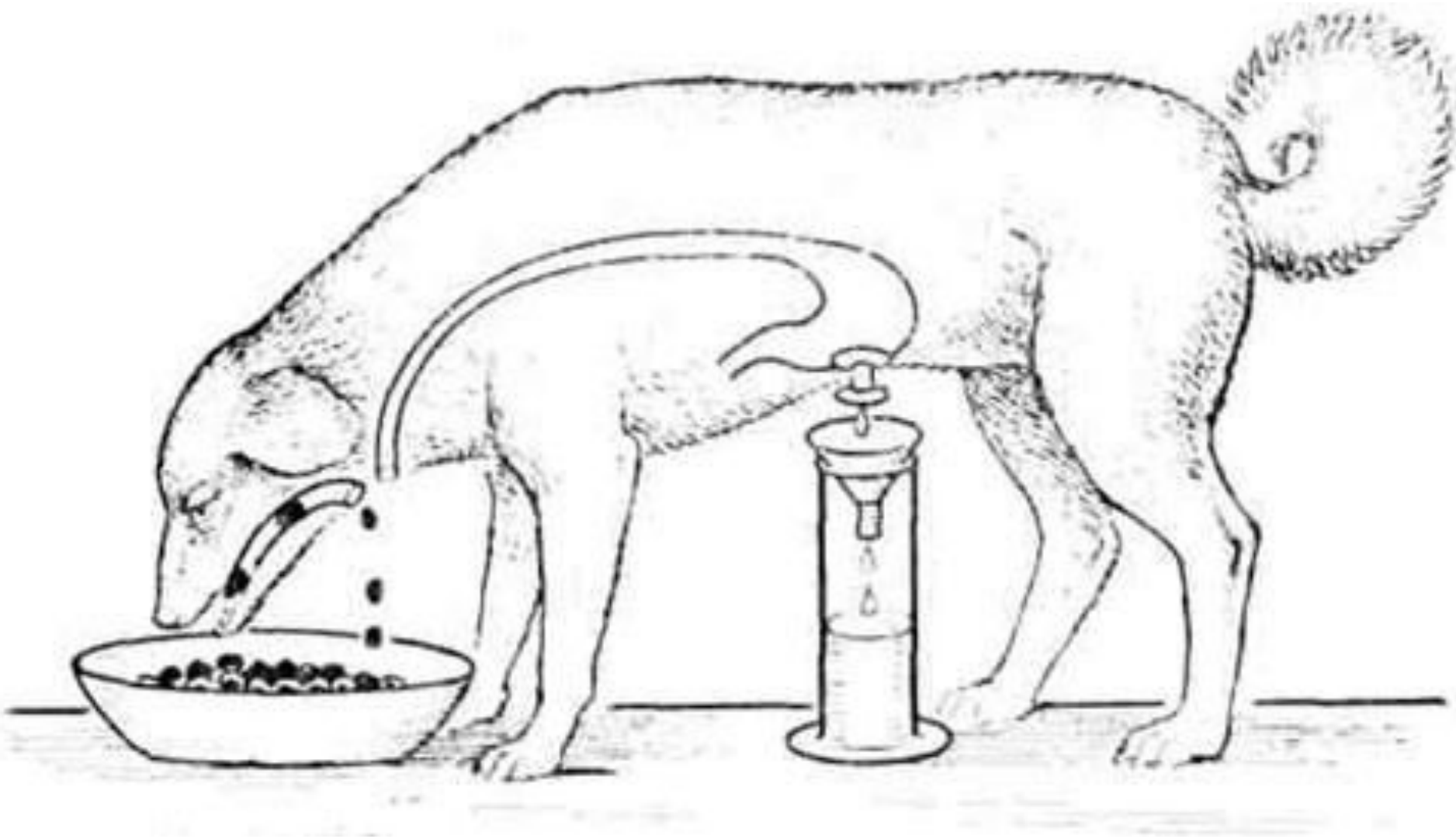


Схема операций маленького желудочка по И.П. Павлову и Гейденгайну

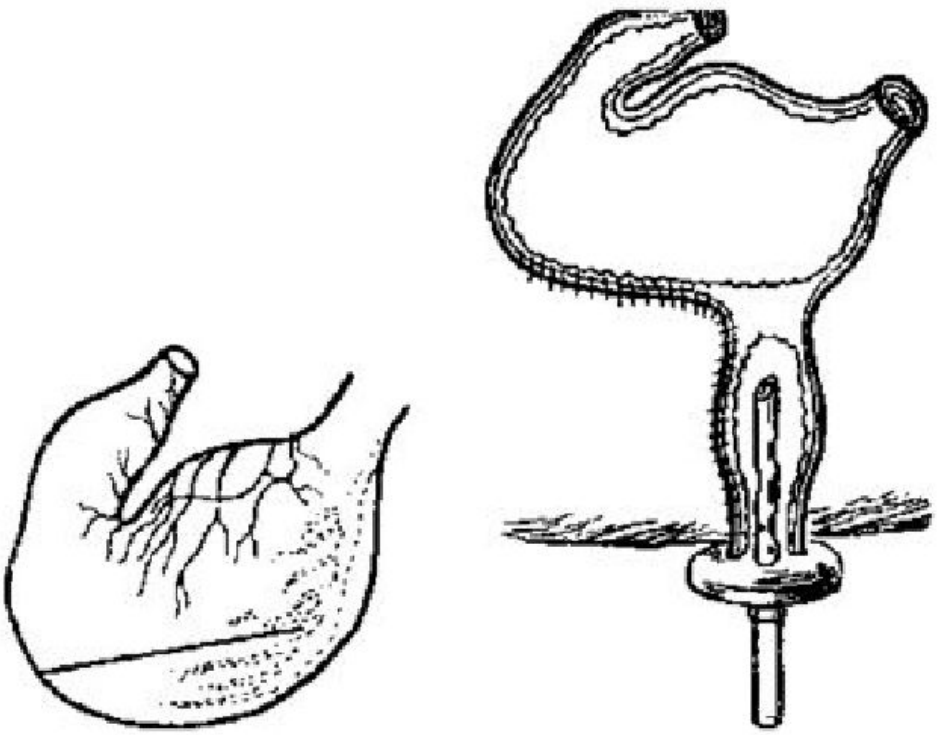


Рис. 73. Схема операции изолированного желудочка по Павлову.

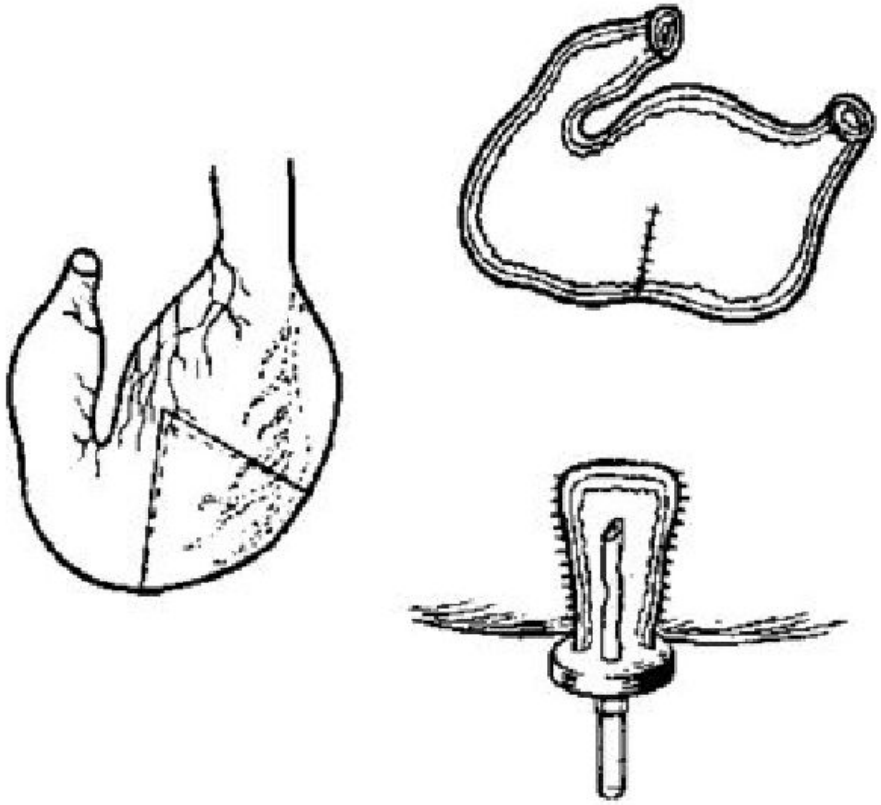
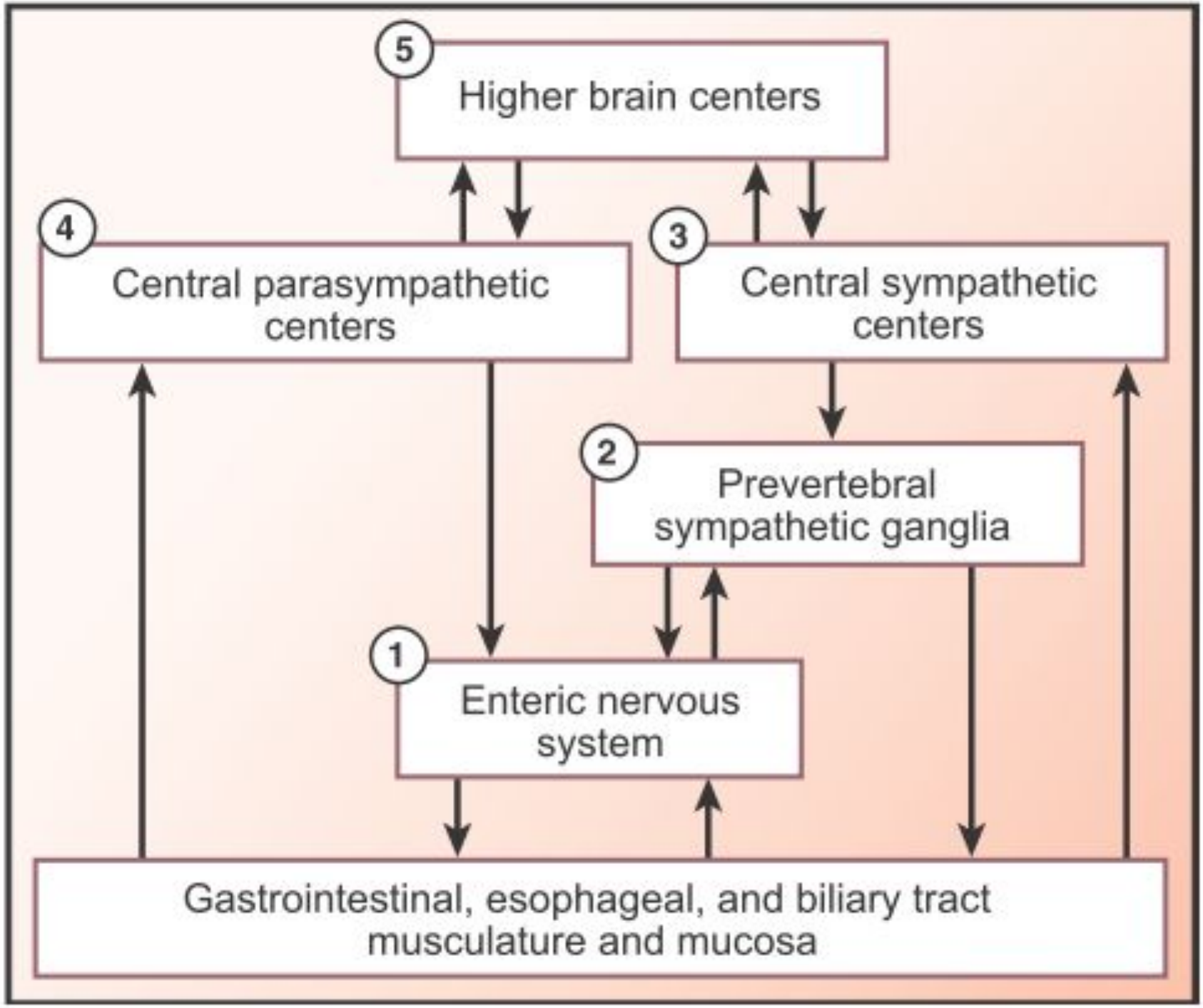
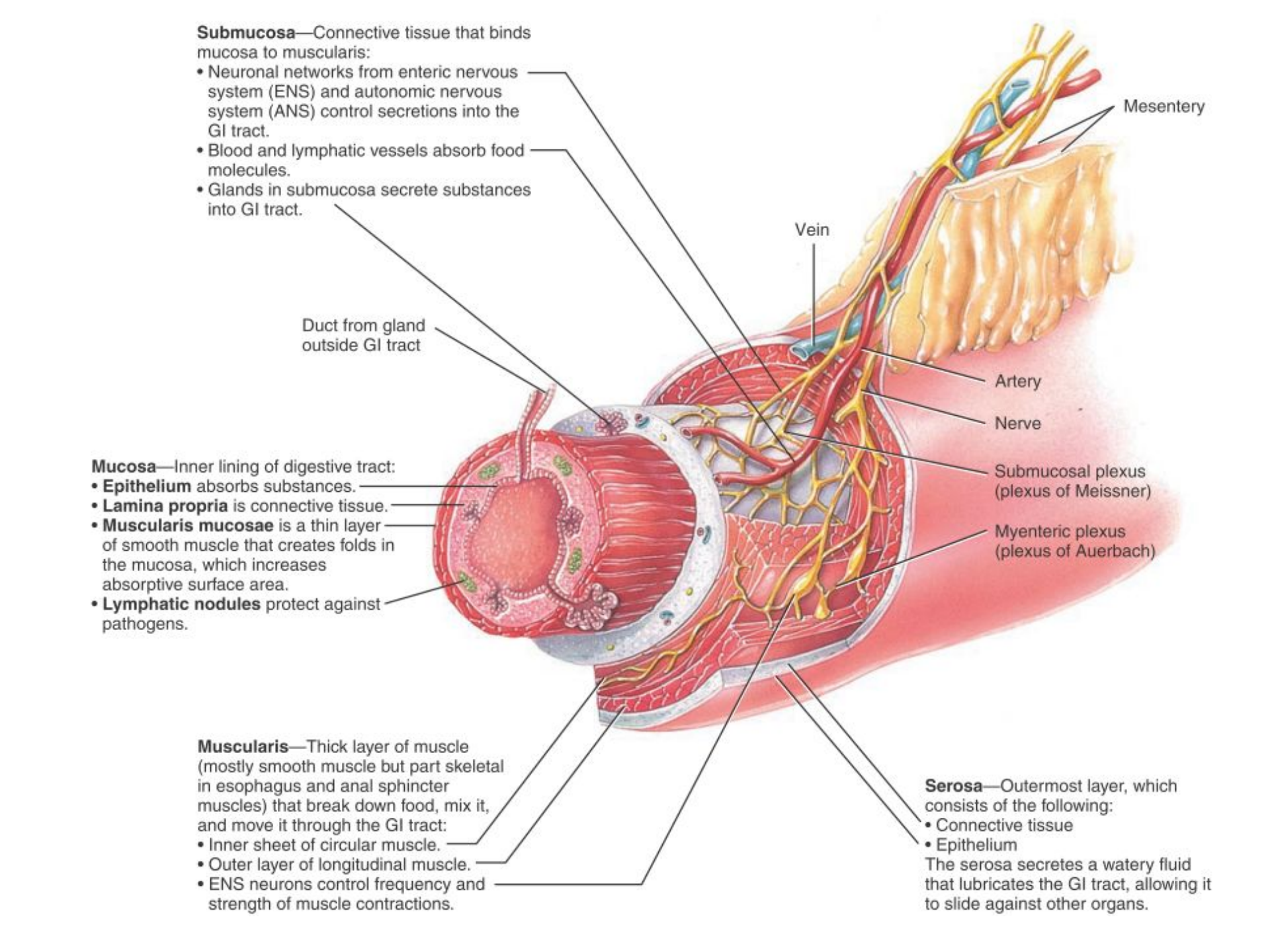
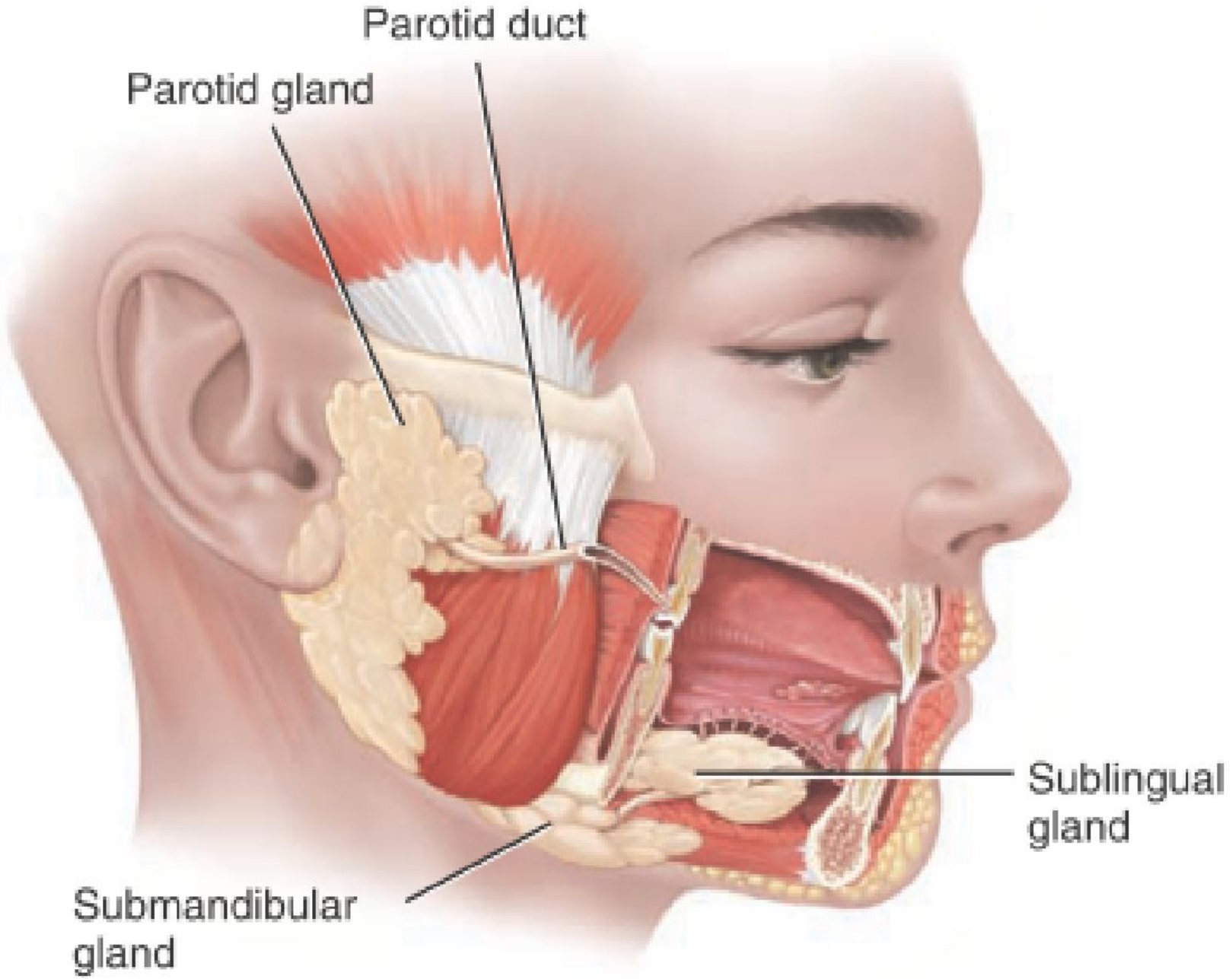
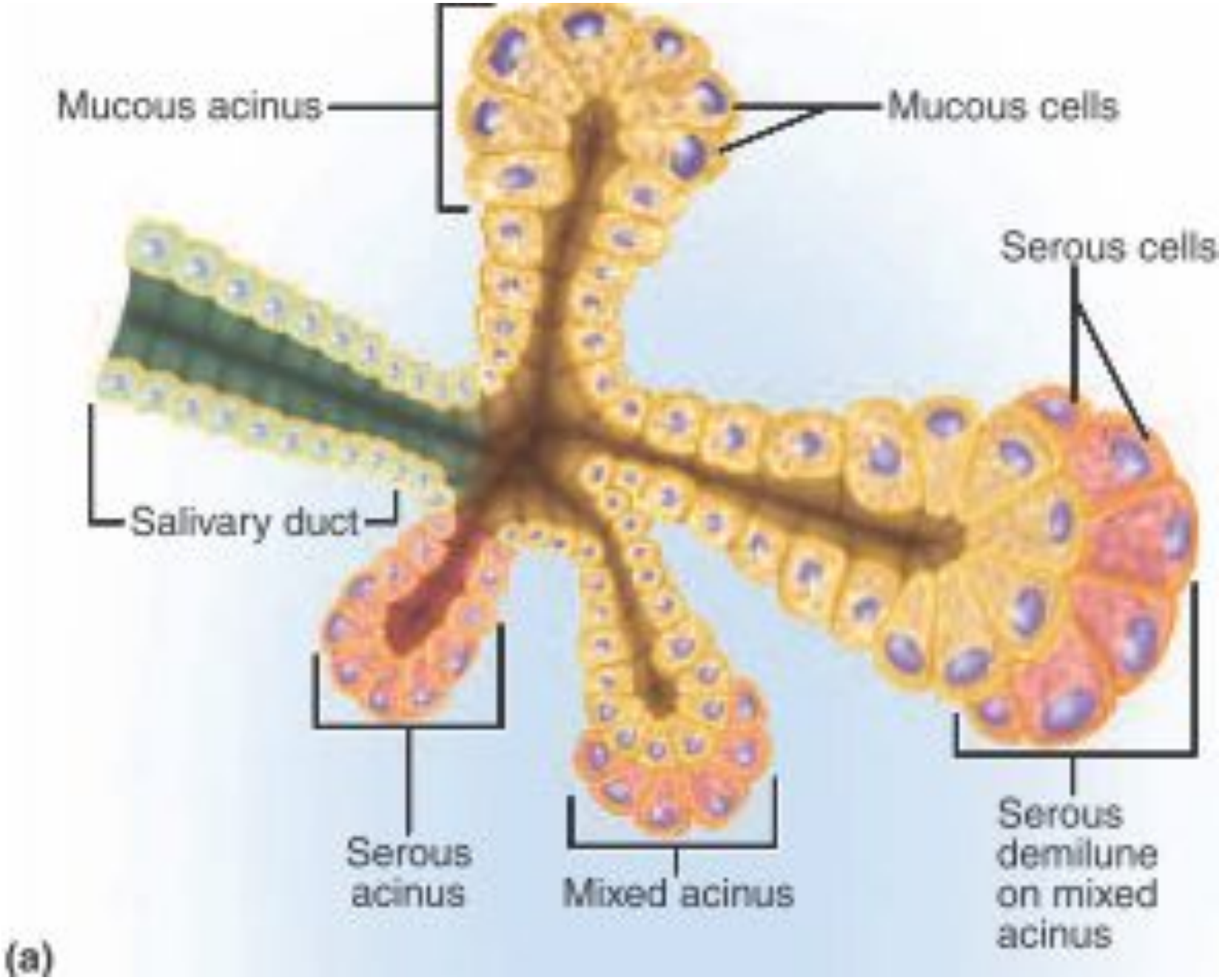


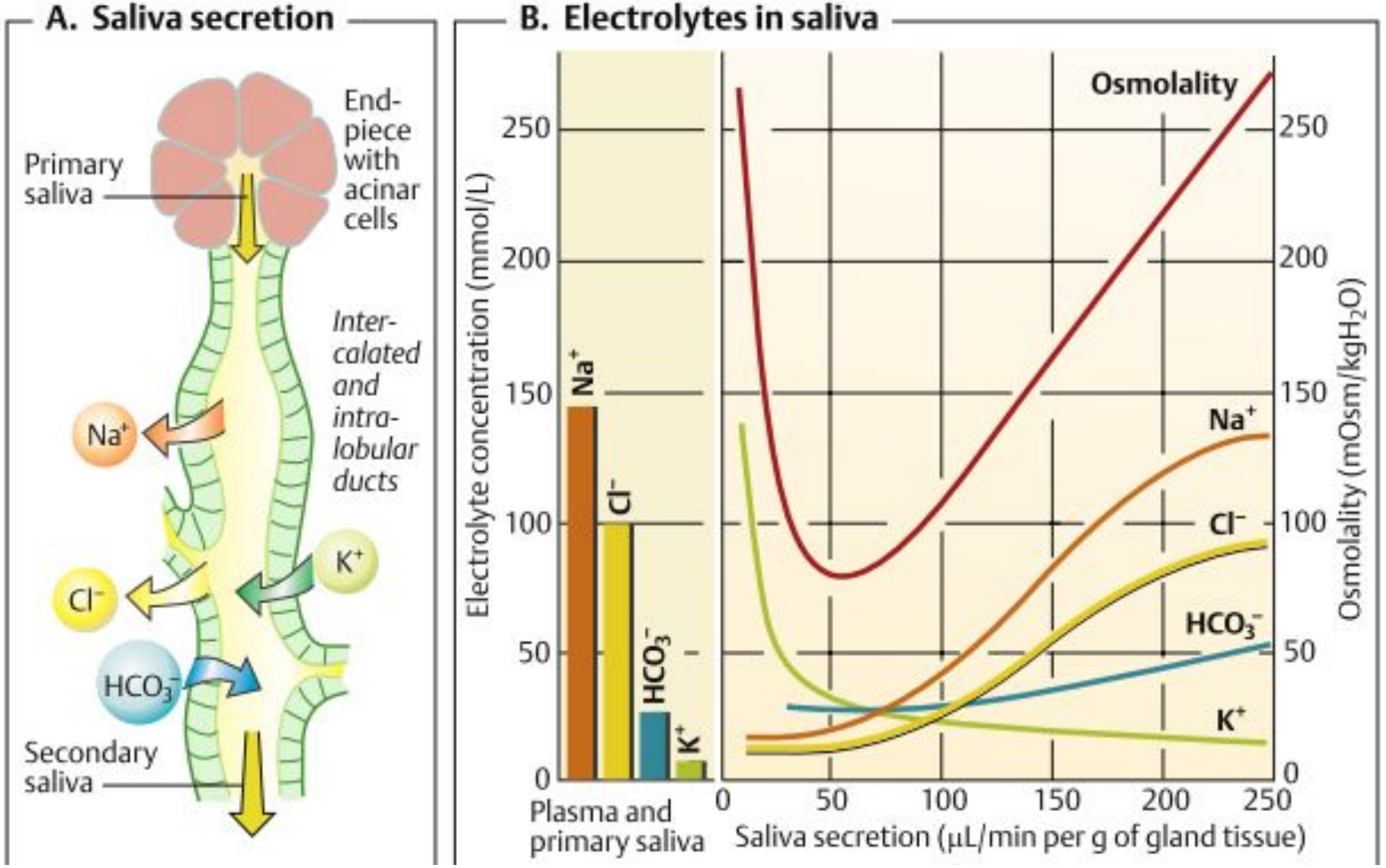
Рис. 74. Схема операции изолированного желудочка по Гейденгайну.

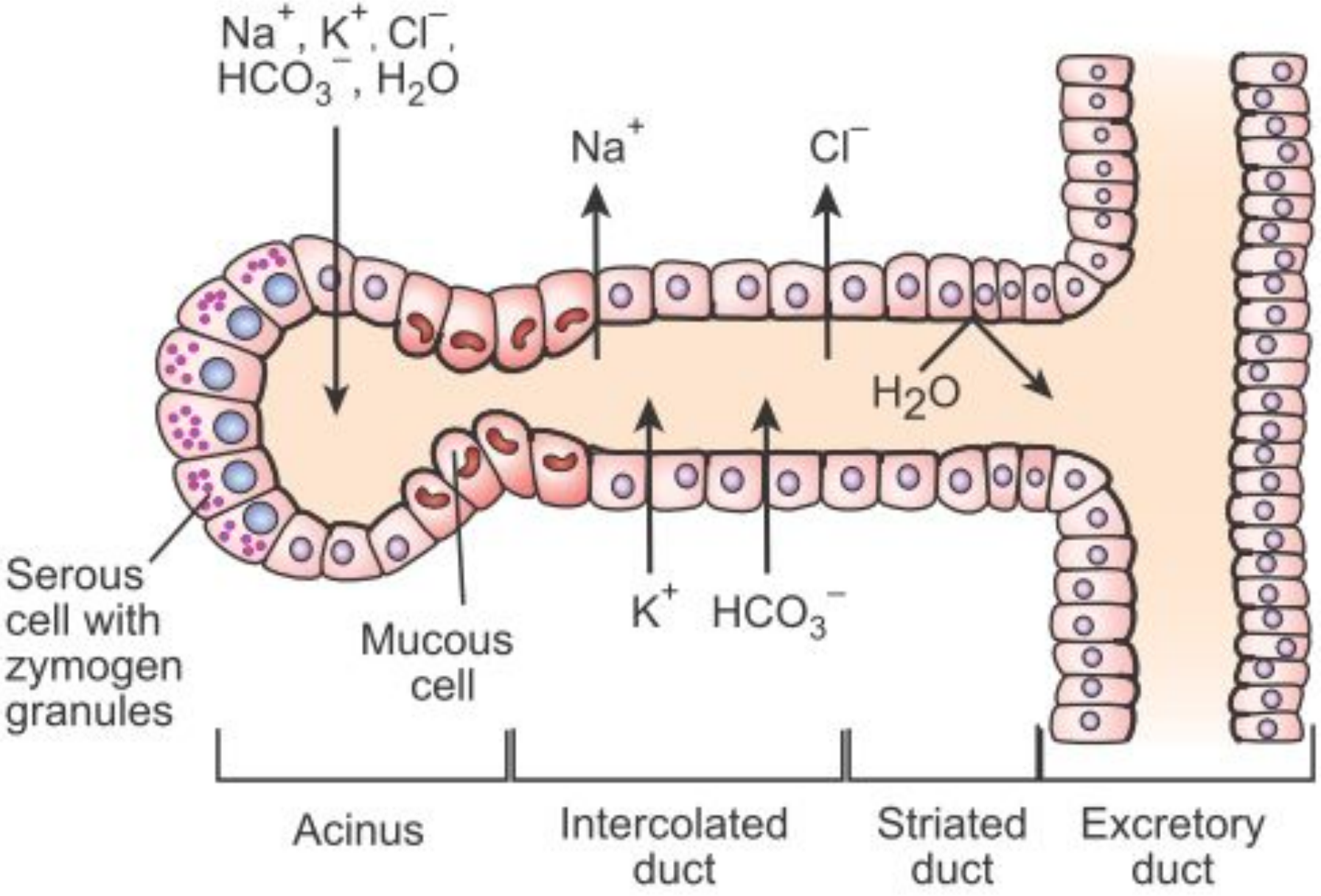

5
Higher brain centers
4
Central parasympathetic centers
3
Central sympathetic centers
2
Prevertebral sympathetic ganglia
1
Enteric nervous system
Gastrointestinal, esophageal, and biliary tract musculature and mucosa


Submucosa—Connective tissue that binds mucosa to muscularis:
• Neuronal networks from enteric nervous system (ENS) and autonomic nervous system (ANS) control secretions into the GI tract.
• Blood and lymphatic vessels absorb food molecules.
• Glands in submucosa secrete substances into GI tract.
Mesentery
Vein
Duct from gland outside GI tract
Artery
Nerve
Submucosal plexus (plexus of Meissner)
Myenteric plexus (plexus of Auerbach)
Mucosa—Inner lining of digestive tract:
• **Epithelium** absorbs substances.
• **Lamina propria** is connective tissue.
• **Muscularis mucosae** is a thin layer of smooth muscle that creates folds in the mucosa, which increases absorptive surface area.
• **Lymphatic nodules** protect against pathogens.
Muscularis—Thick layer of muscle (mostly smooth muscle but part skeletal in esophagus and anal sphincter muscles) that break down food, mix it, and move it through the GI tract:
• Inner sheet of circular muscle.
• Outer layer of longitudinal muscle.
• ENS neurons control frequency and strength of muscle contractions.
Serosa—Outermost layer, which consists of the following:
• Connective tissue
• Epithelium
The serosa secretes a watery fluid that lubricates the GI tract, allowing it to slide against other organs.

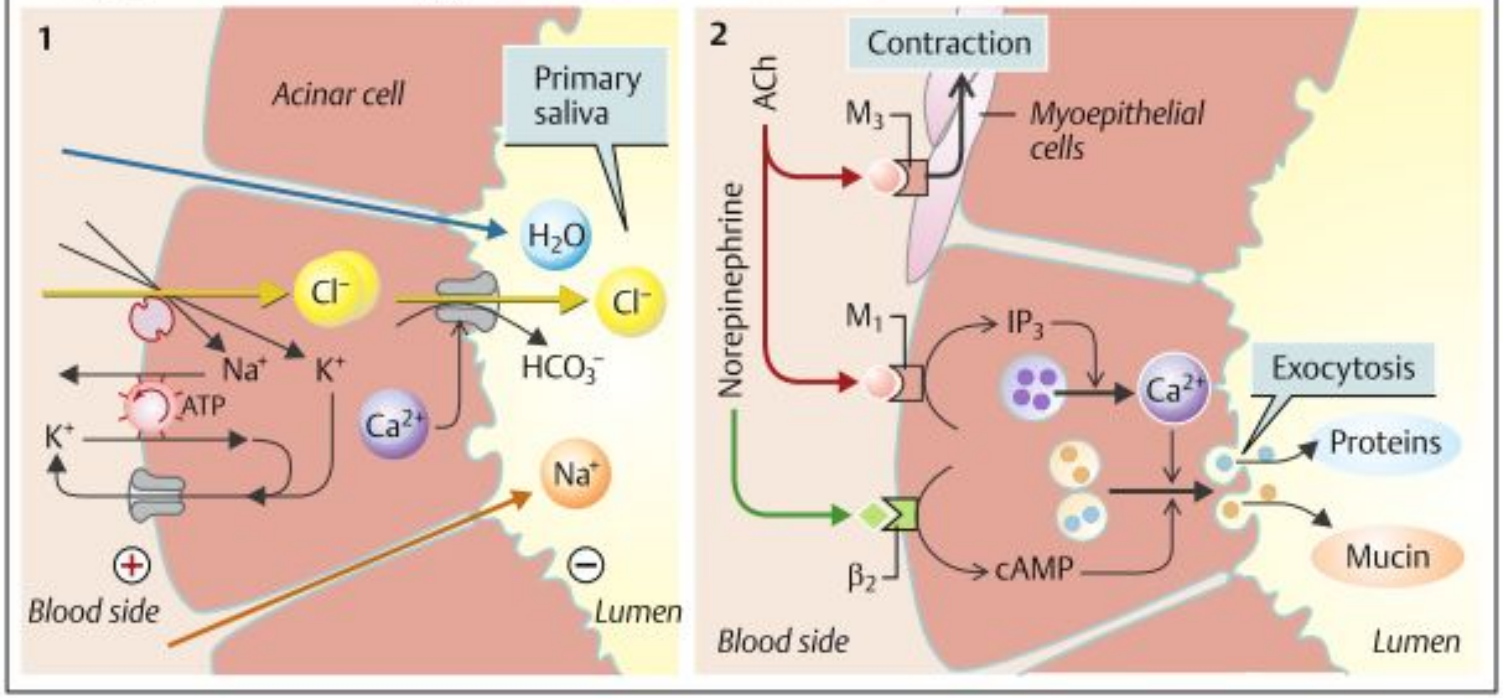

Parotid duct
Parotid gland
Sublingual gland
Submandibular gland


Mucous acinus
Mucous cells
Serous cells
Salivary duct
Serous acinus
Mixed acinus
Serous demilune on mixed acinus
(a)

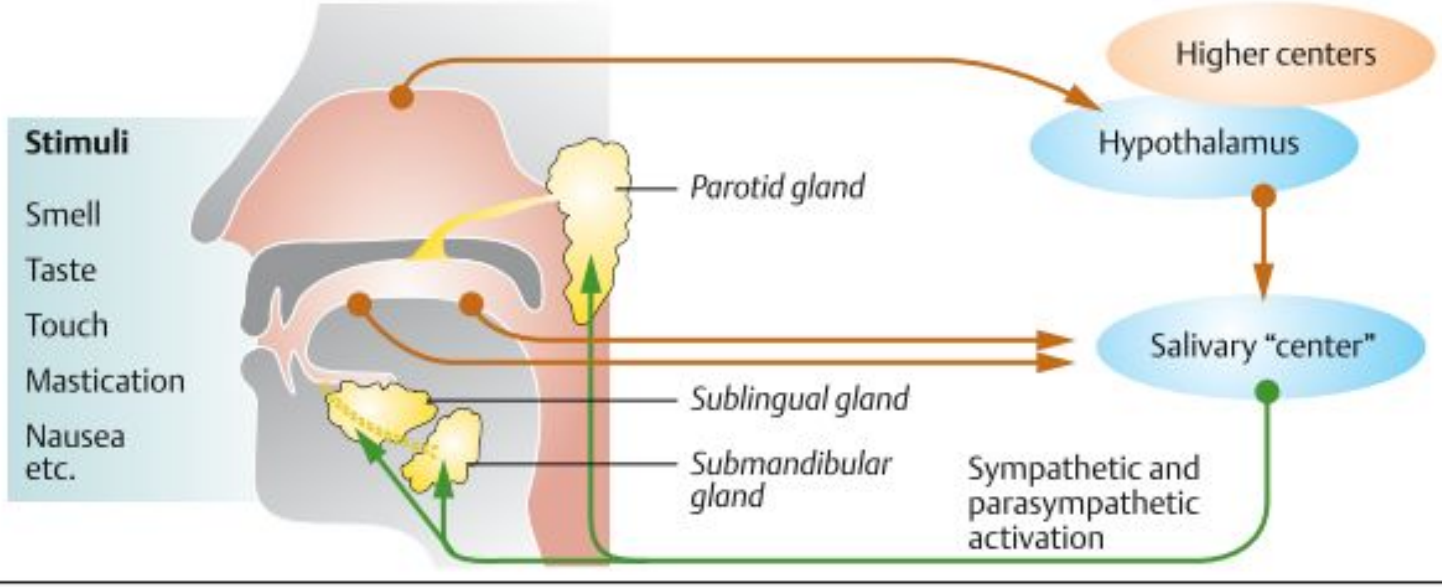

A. Saliva secretion
End-piece with acinar cells
Primary saliva
Inter-calated and intra-lobular ducts
Na+
K+
Cl−
HCO3−
Secondary saliva
B. Electrolytes in saliva
Electrolyte concentration (mmol/L)
Osmolality (mOsm/kgH2O)
Osmolality
Na+
Cl−
HCO3−
K+
Plasma and primary saliva
Saliva secretion (µL/min per g of gland tissue)
0
50
100
150
200
250

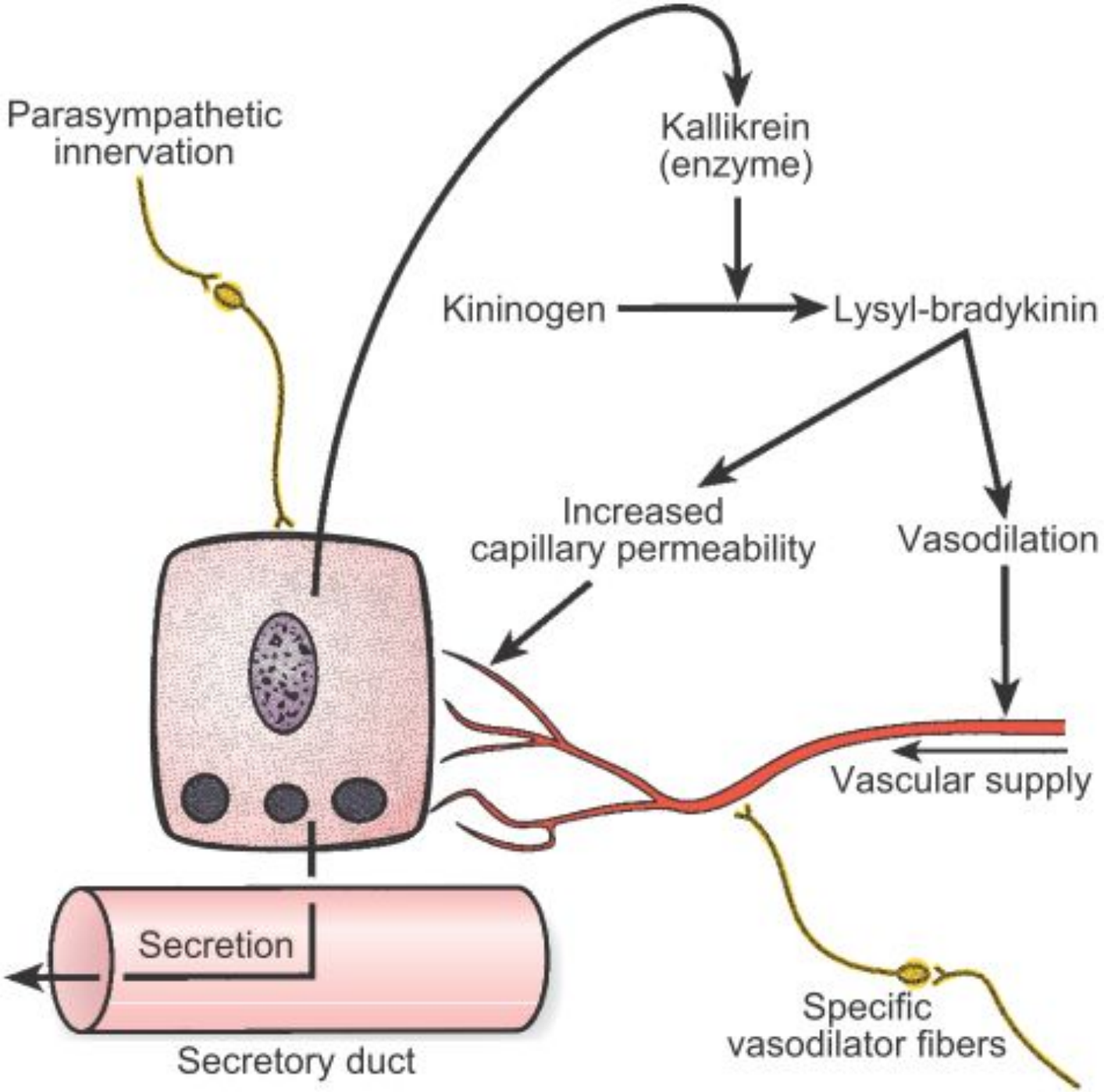

Na^+, K^+, Cl^-, HCO_3^-, H_2O
Na^+
Cl^-
H_2O
K^+
HCO_3^-
Serous cell with zymogen granules
Mucous cell
Acinus
Intercolated duct
Striated duct
Excretory duct

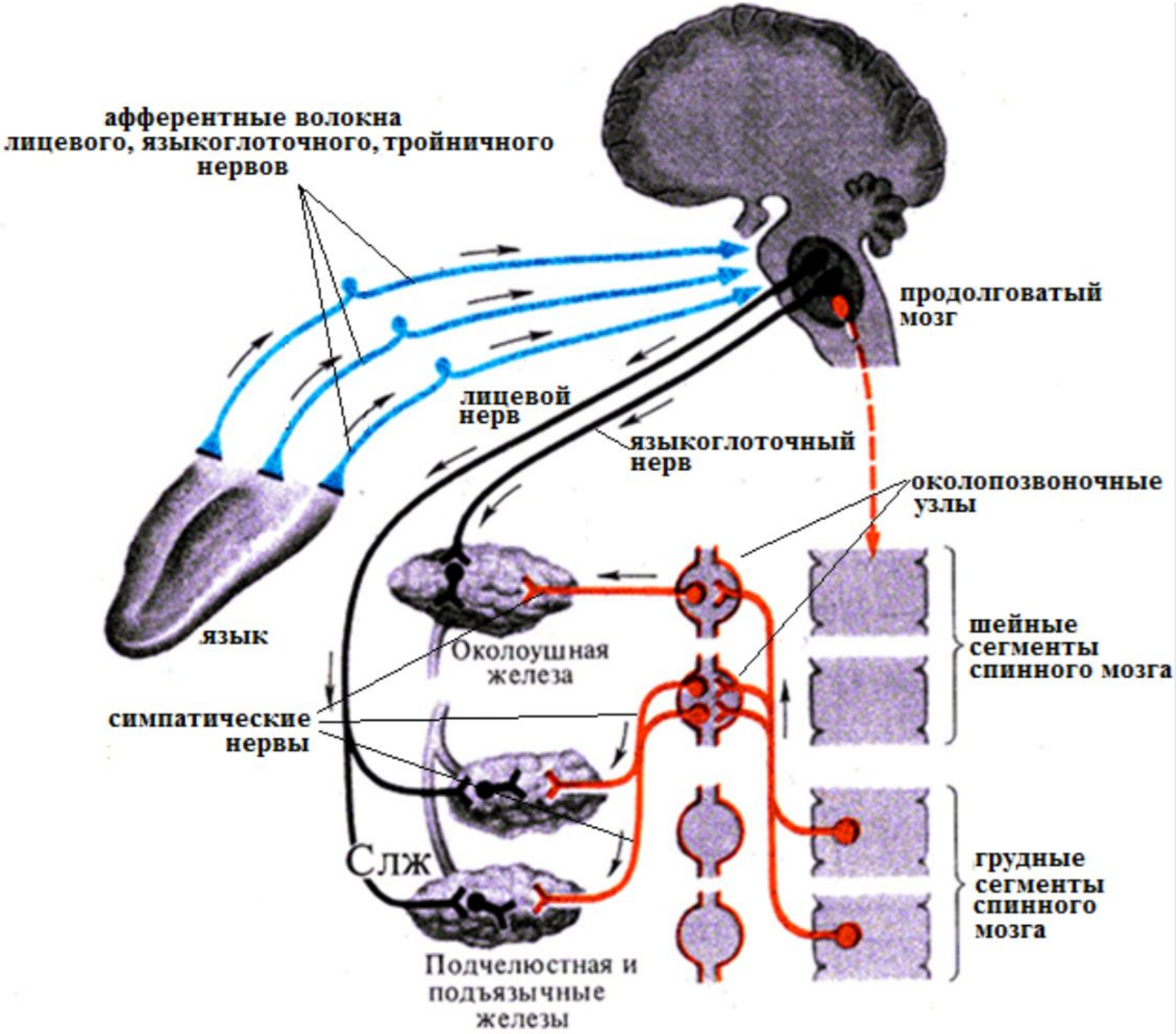
C. (1) Mechanism and (2) control of saliva secretion in acinar cells

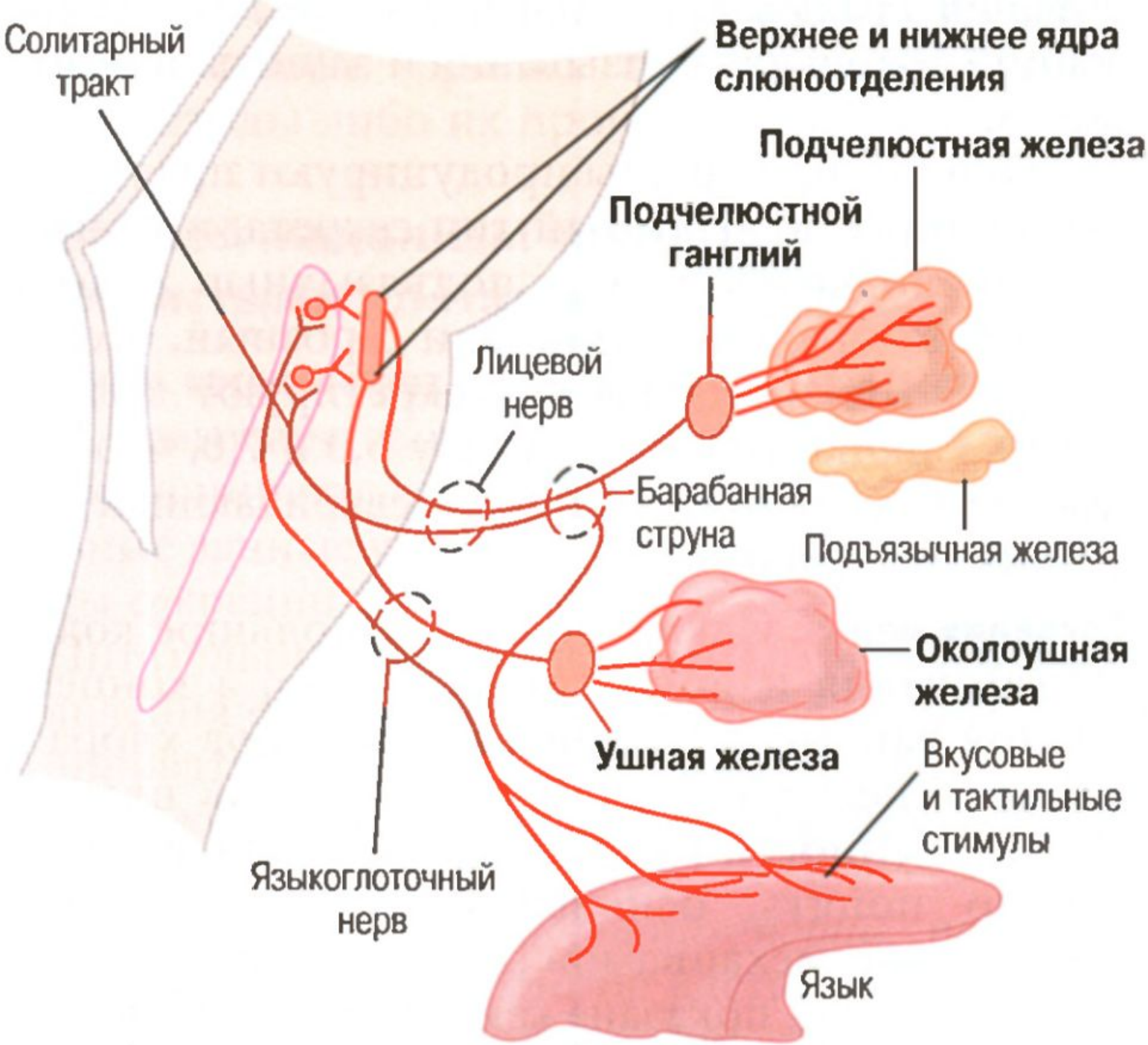


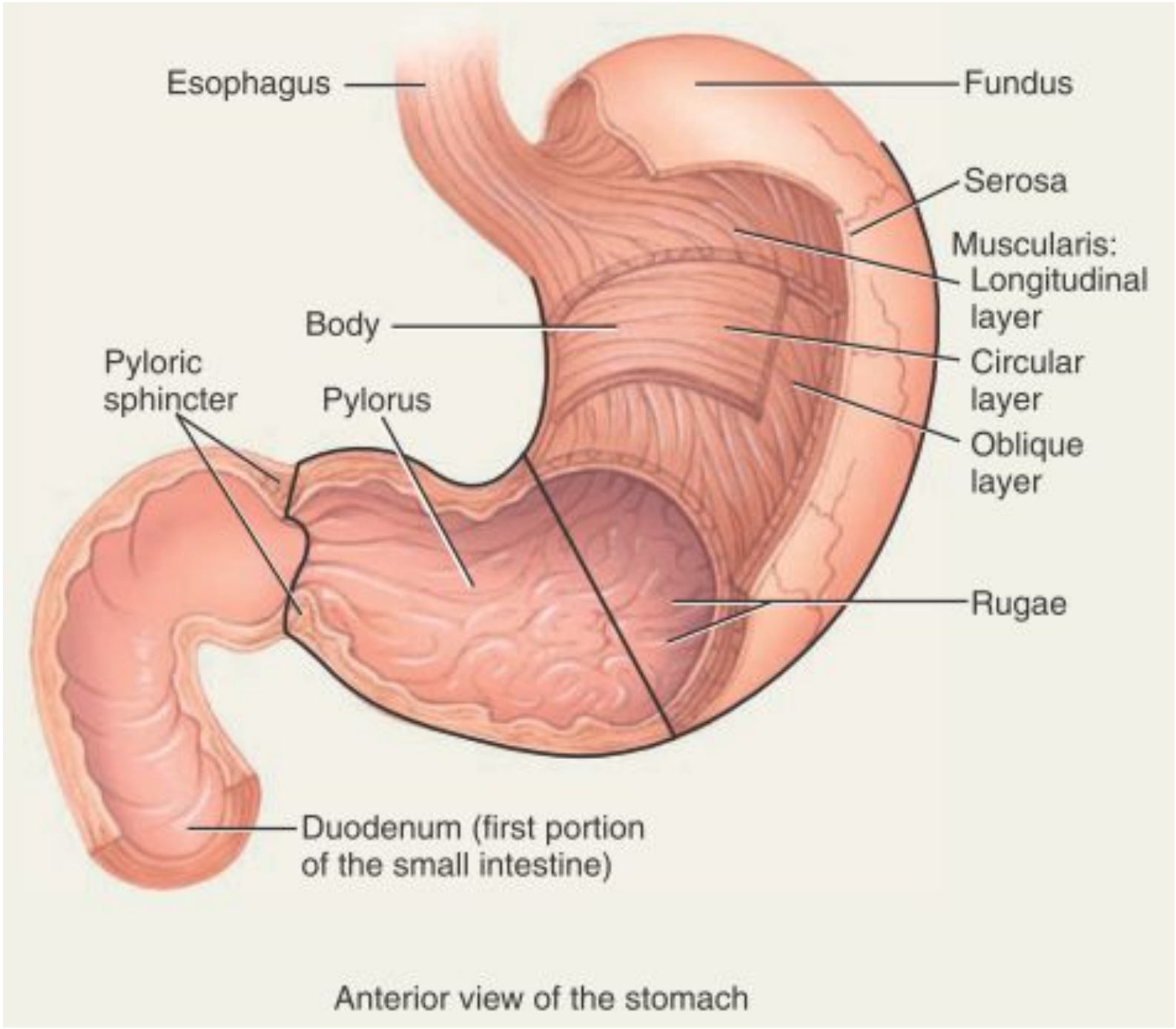
D. Stimulation of saliva secretion



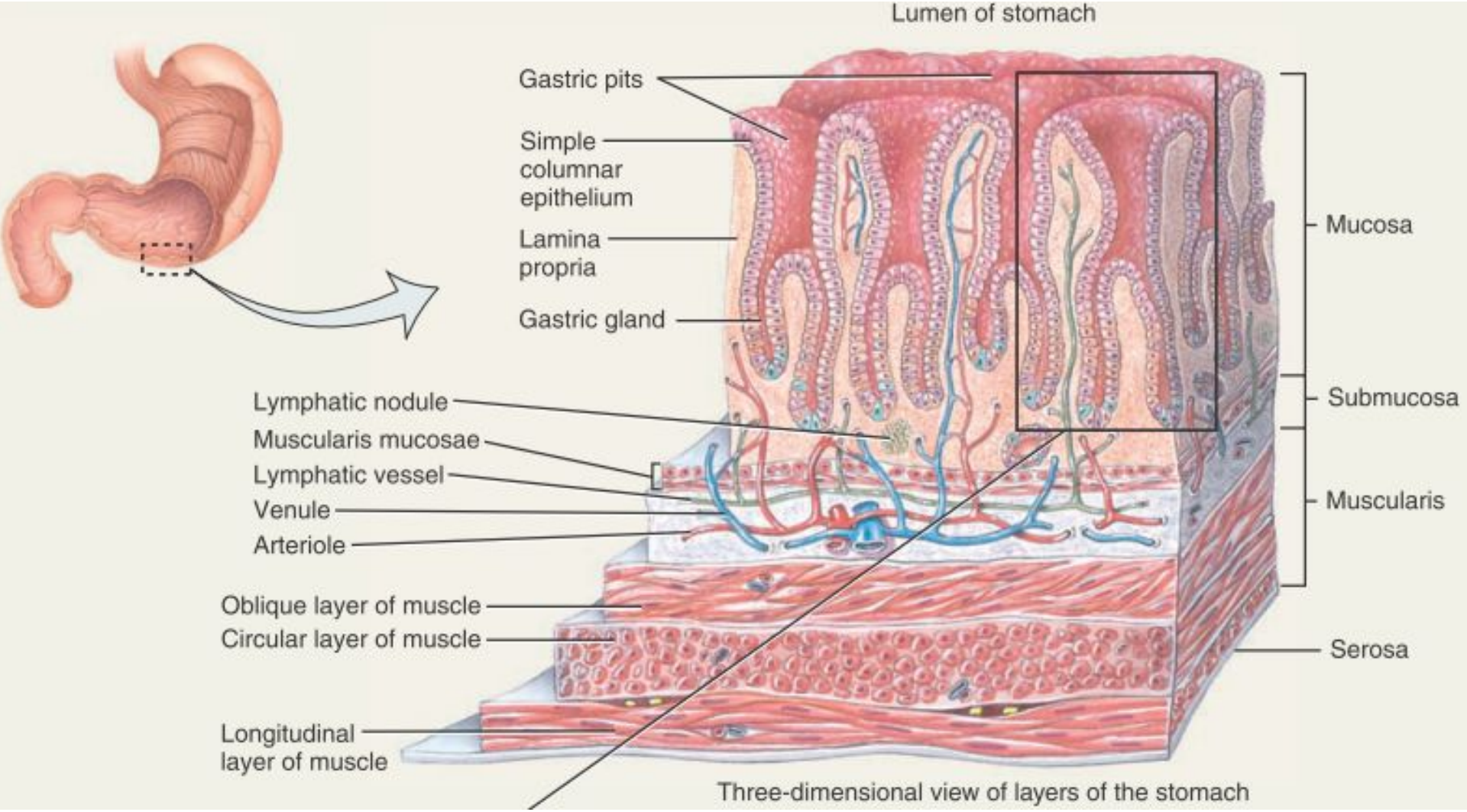

Parasympathetic innervation
Kallikrein (enzyme)
Kininogen
Lysyl-bradykinin
Increased capillary permeability
Vasodilation
Vascular supply
Secretion
Secretory duct
Specific vasodilator fibers


афферентные волокна
лицевого, языкоглоточного, тройничного
нервов
продолговатый
мозг
лицевой
нерв
языкоглоточный
нерв
околопозвоночные
узлы
язык
Околоушная
железа
шейные
сегменты
спинного мозга
симпатические
нервы
Слж
грудные
сегменты
спинного
мозга
Подчелюстная и
подъязычные
железы

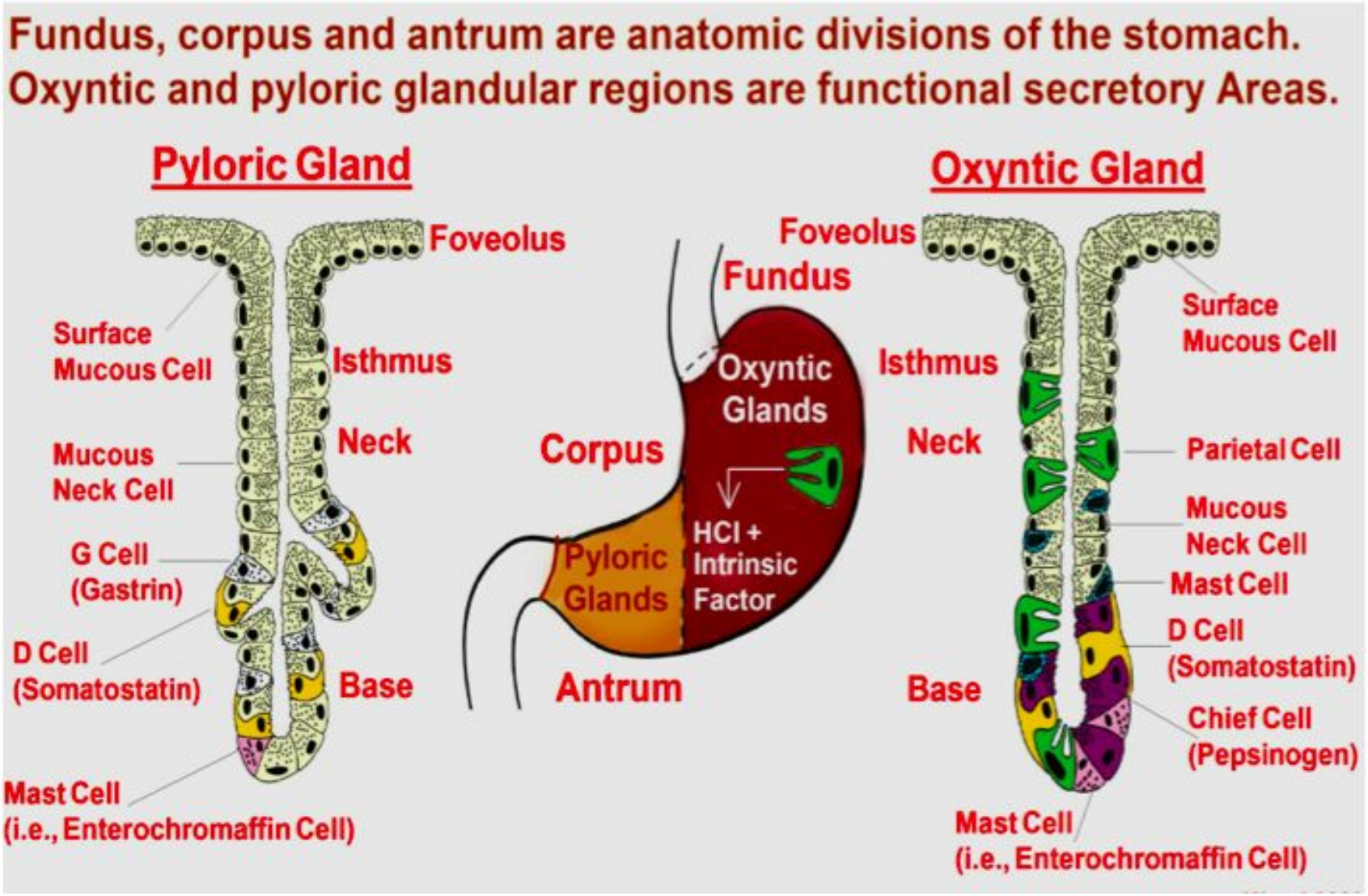

Солитарный тракт
Верхнее и нижнее ядра слюноотделения
Подчелюстная железа
Подчелюстной ганглий
Лицевой нерв
Барабанная струна
Подъязычная железа
Околоушная железа
Ушная железа
Вкусовые и тактильные стимулы
Языкоглоточный нерв
Язык

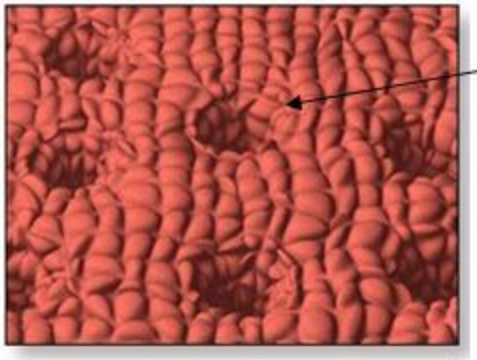


Anterior view of the stomach


Lumen of stomach
Gastric pits
Simple columnar epithelium
Lamina propria
Gastric gland
Lymphatic nodule
Muscularis mucosae
Lymphatic vessel
Venule
Arteriole
Oblique layer of muscle
Circular layer of muscle
Longitudinal layer of muscle
Mucosa
Submucosa
Muscularis
Serosa
Three-dimensional view of layers of the stomach

Gastric Glands





Pyloric Region

Fundus/Body Region

Gastric pit

Gastric gland

Surface epithelium
• Thick, alkaline mucus.

Mucous (neck) cells
• Thin, watery mucus.

Chief cells
• Pepsinogen

G cell
• Gastrin

:tric pit

: gland

Surface epithelium

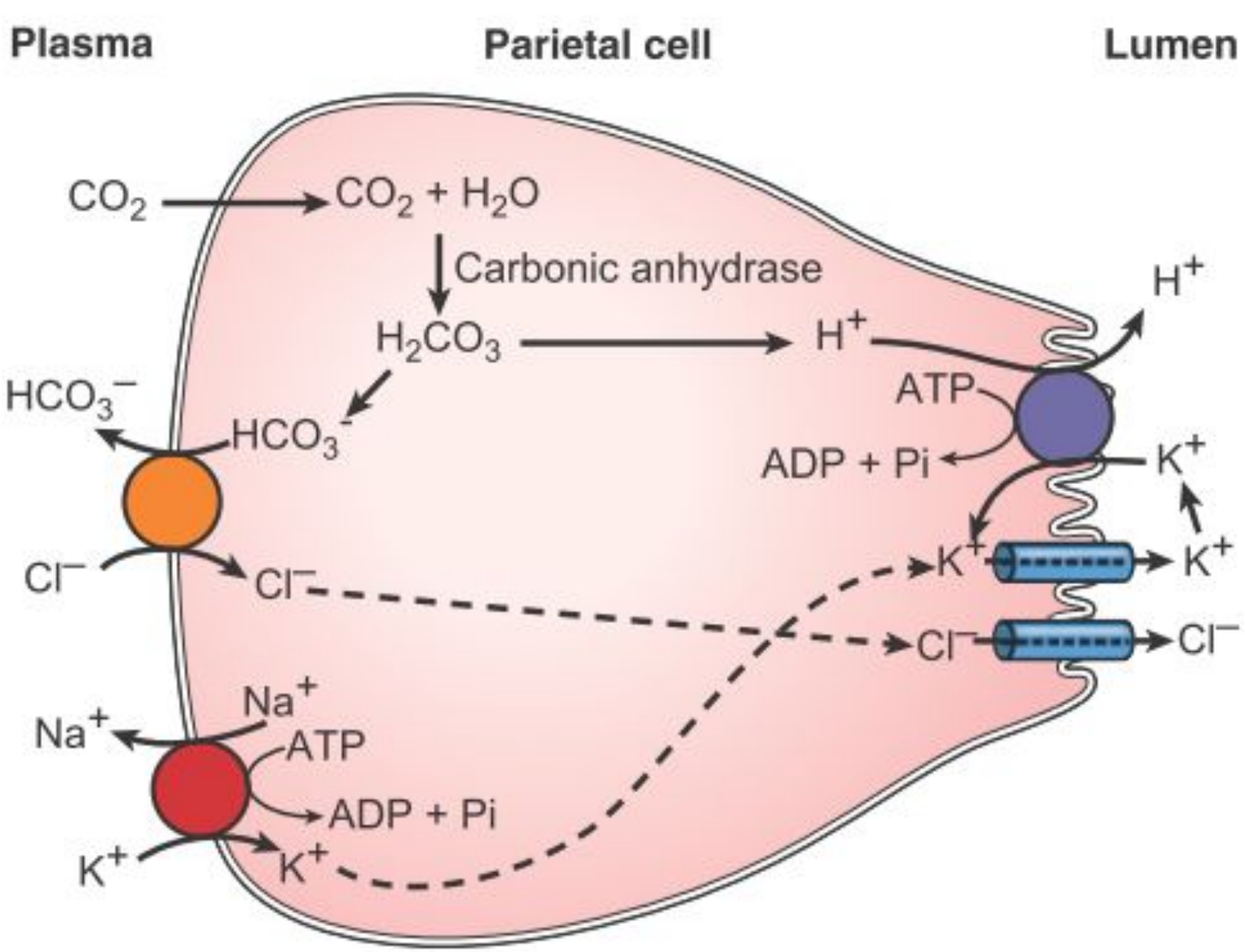
Mucous (neck) cells

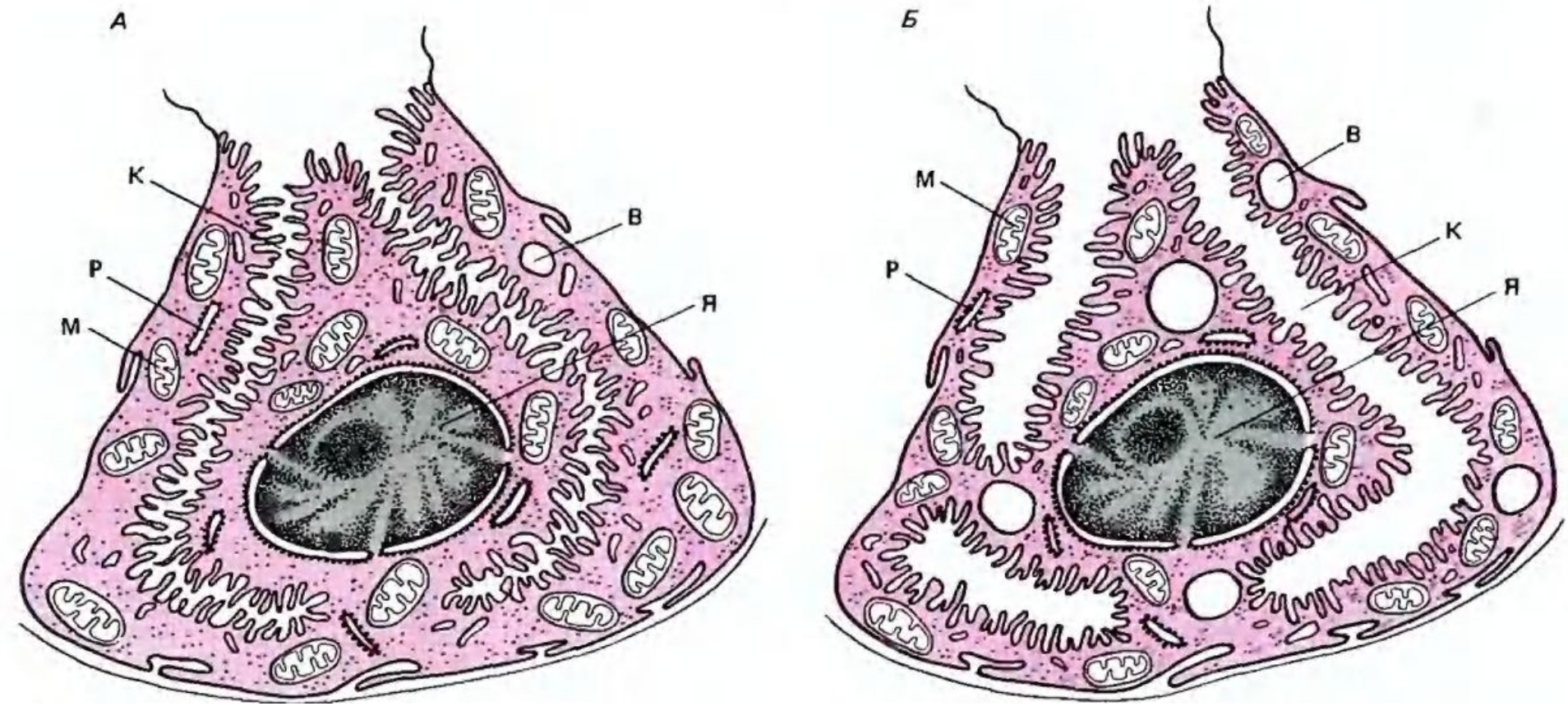
Parietal cells

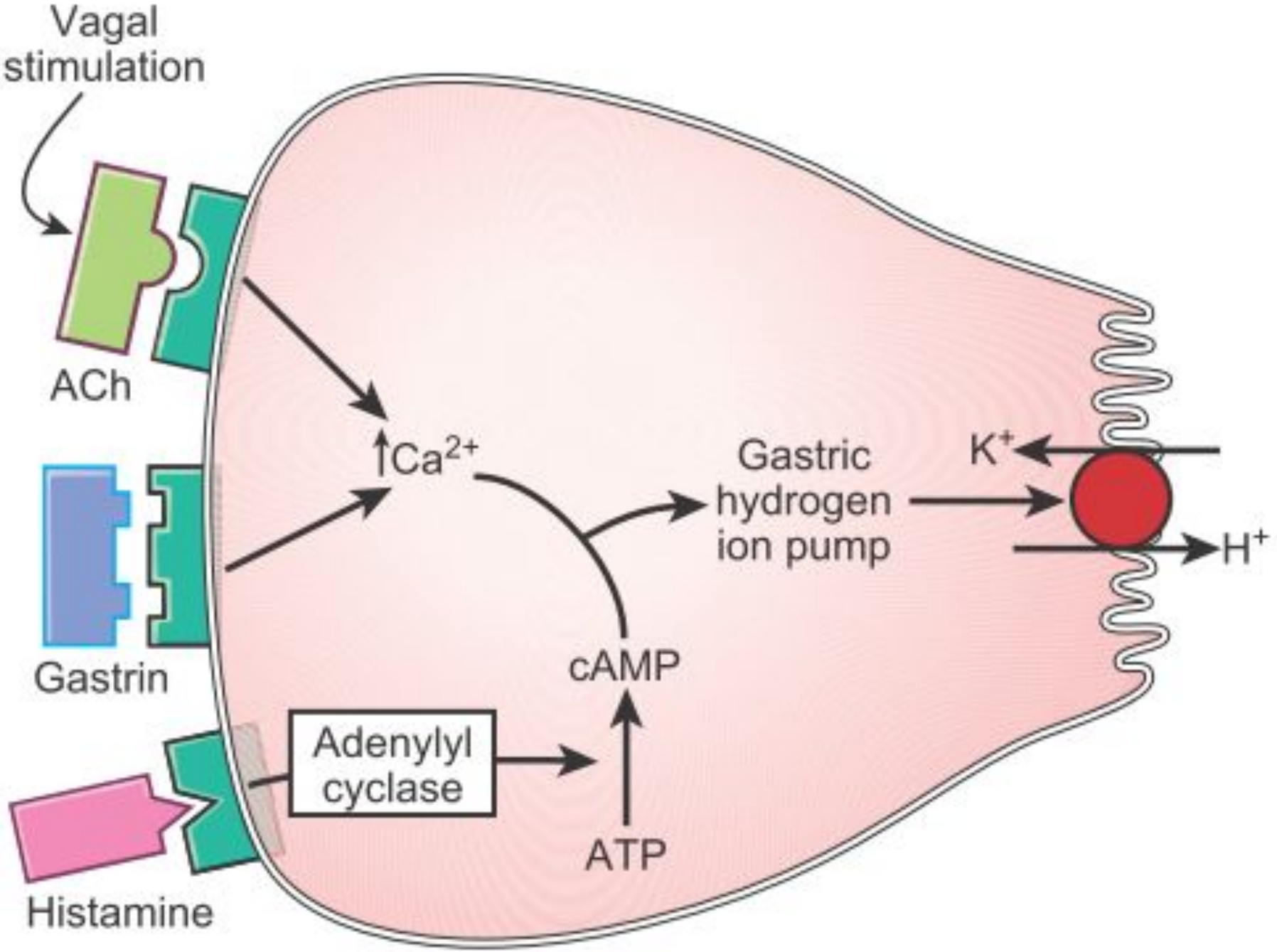
Chief cells

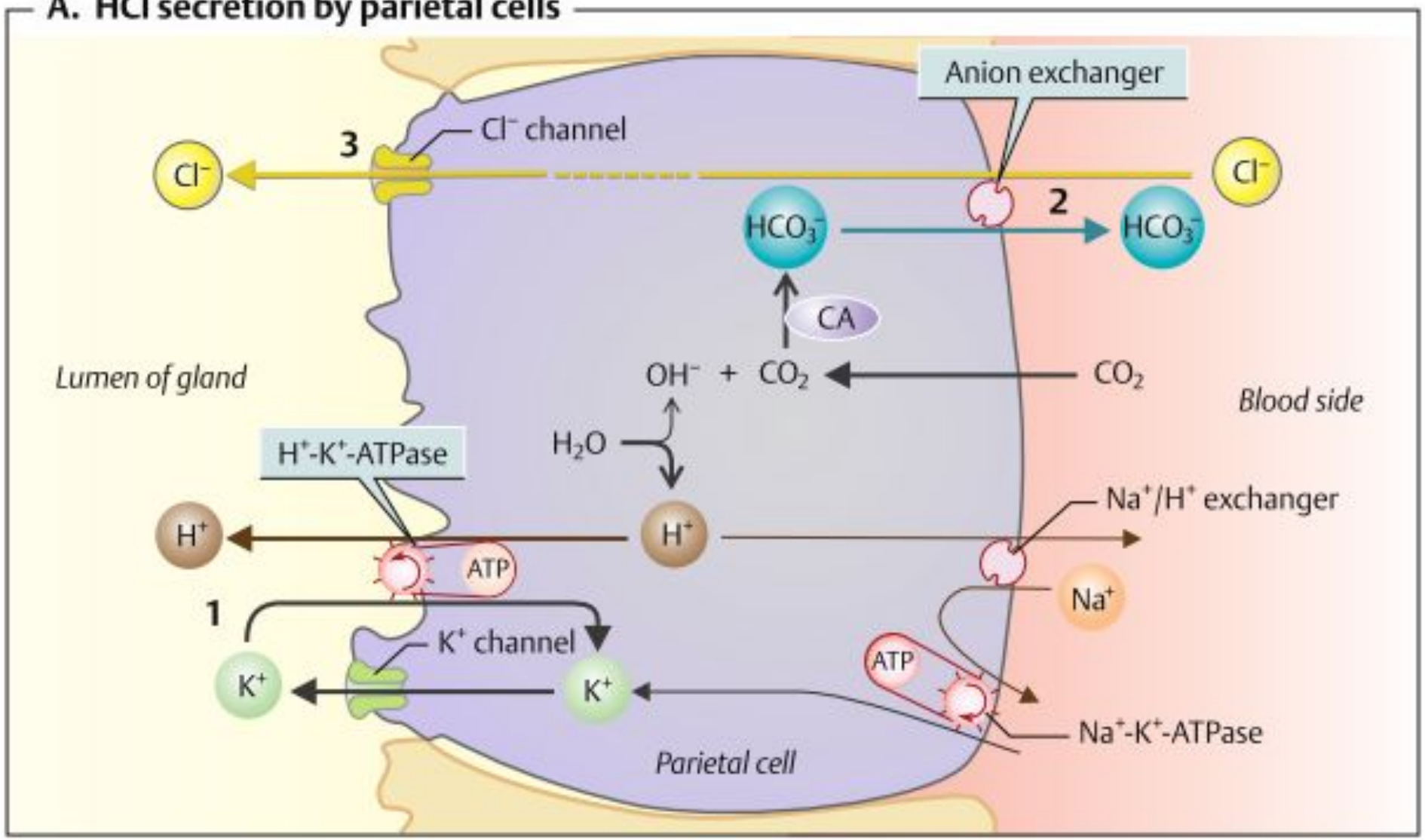
Paracrine cells

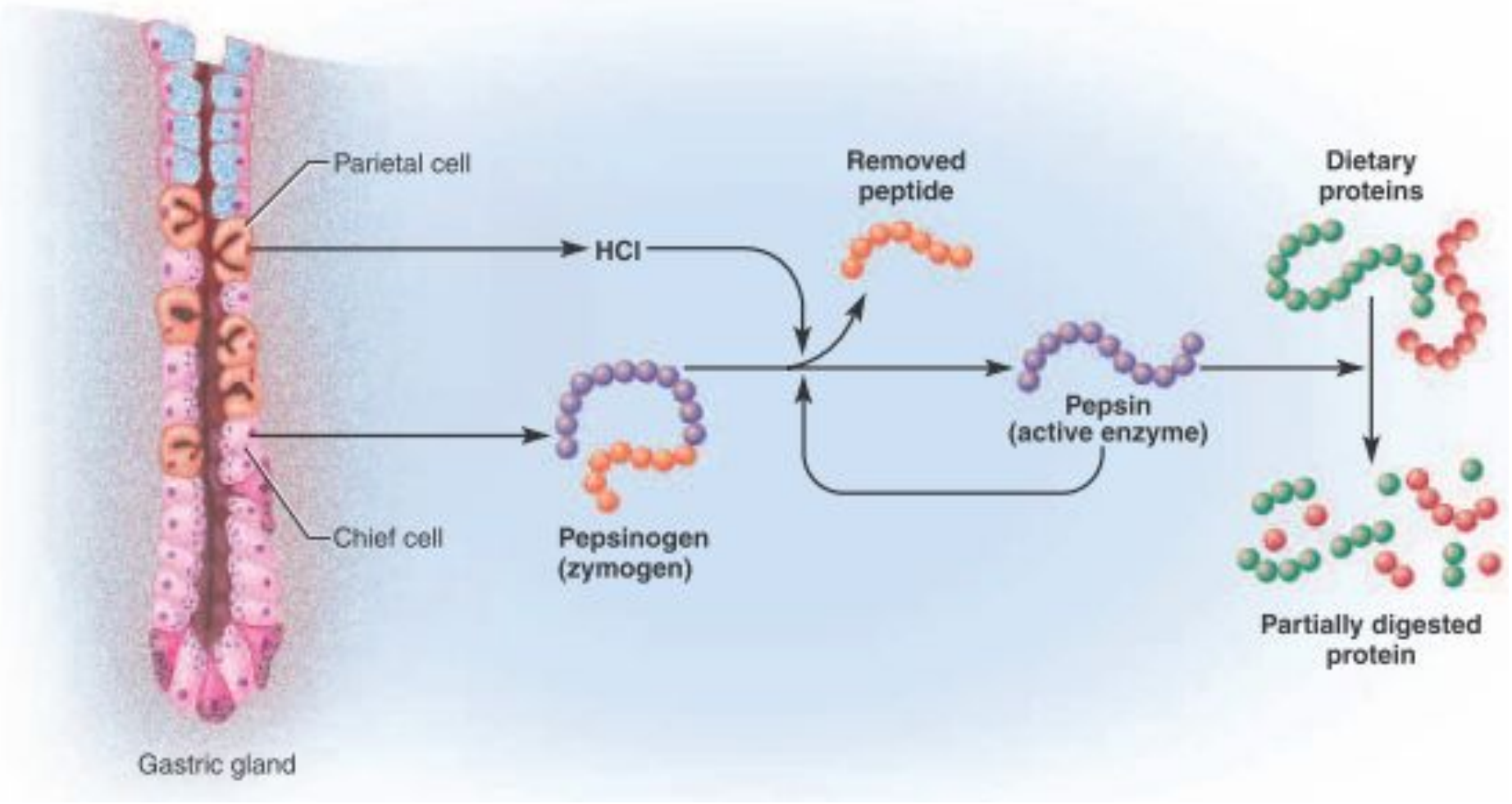
[Enterochromaffin-like (ECL)]
• histamine

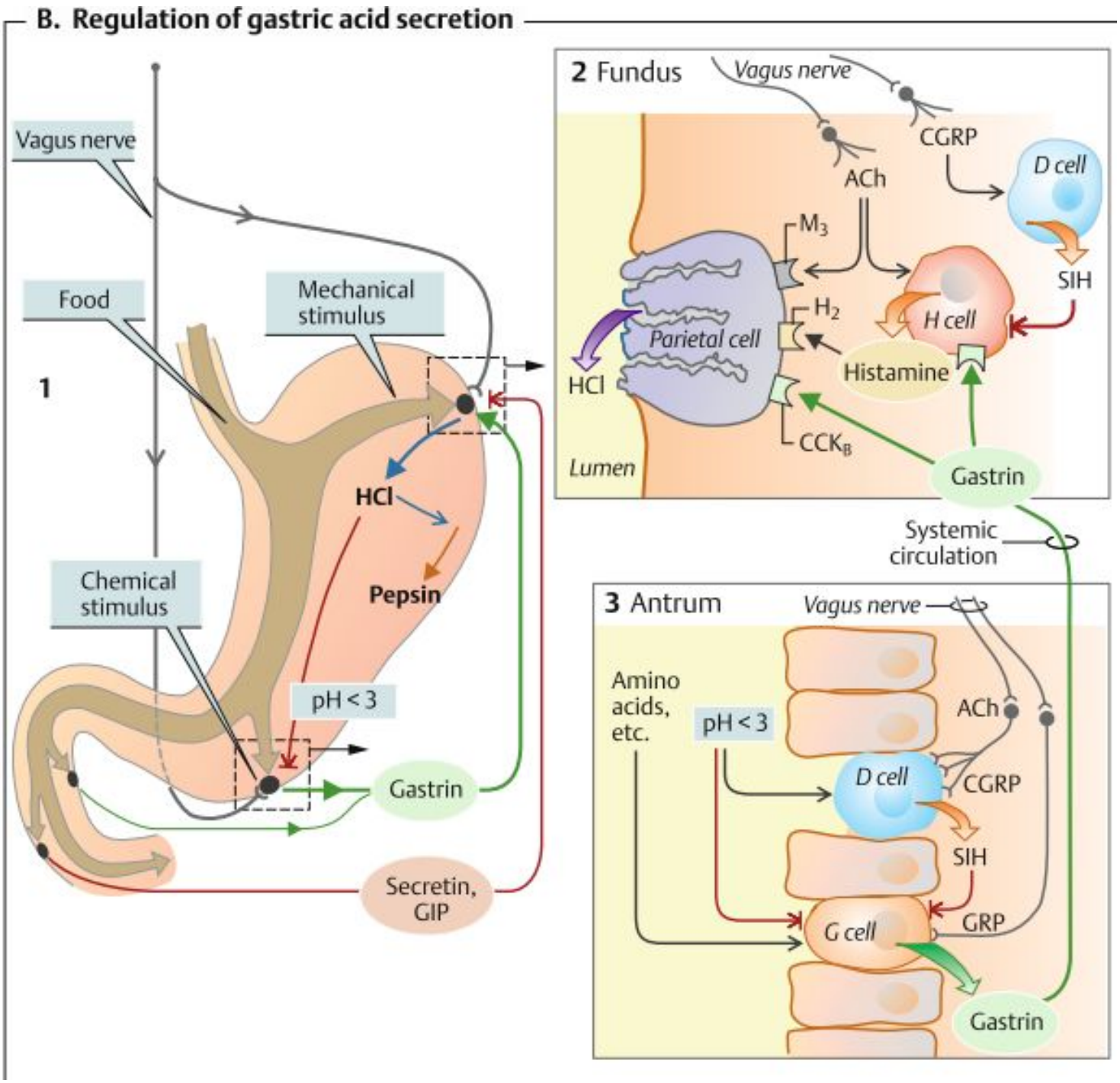

Plasma
Parietal cell
Lumen
CO_2
$CO_2 + H_2O$
Carbonic anhydrase
H_2CO_3
H^+
H^+
ATP
ADP + Pi
K^+
HCO_3^-
HCO_3^-
Cl^-
Cl^-
K^+
K^+
Cl^-
Cl^-
Na^+
Na^+
ATP
ADP + Pi
K^+
K^+

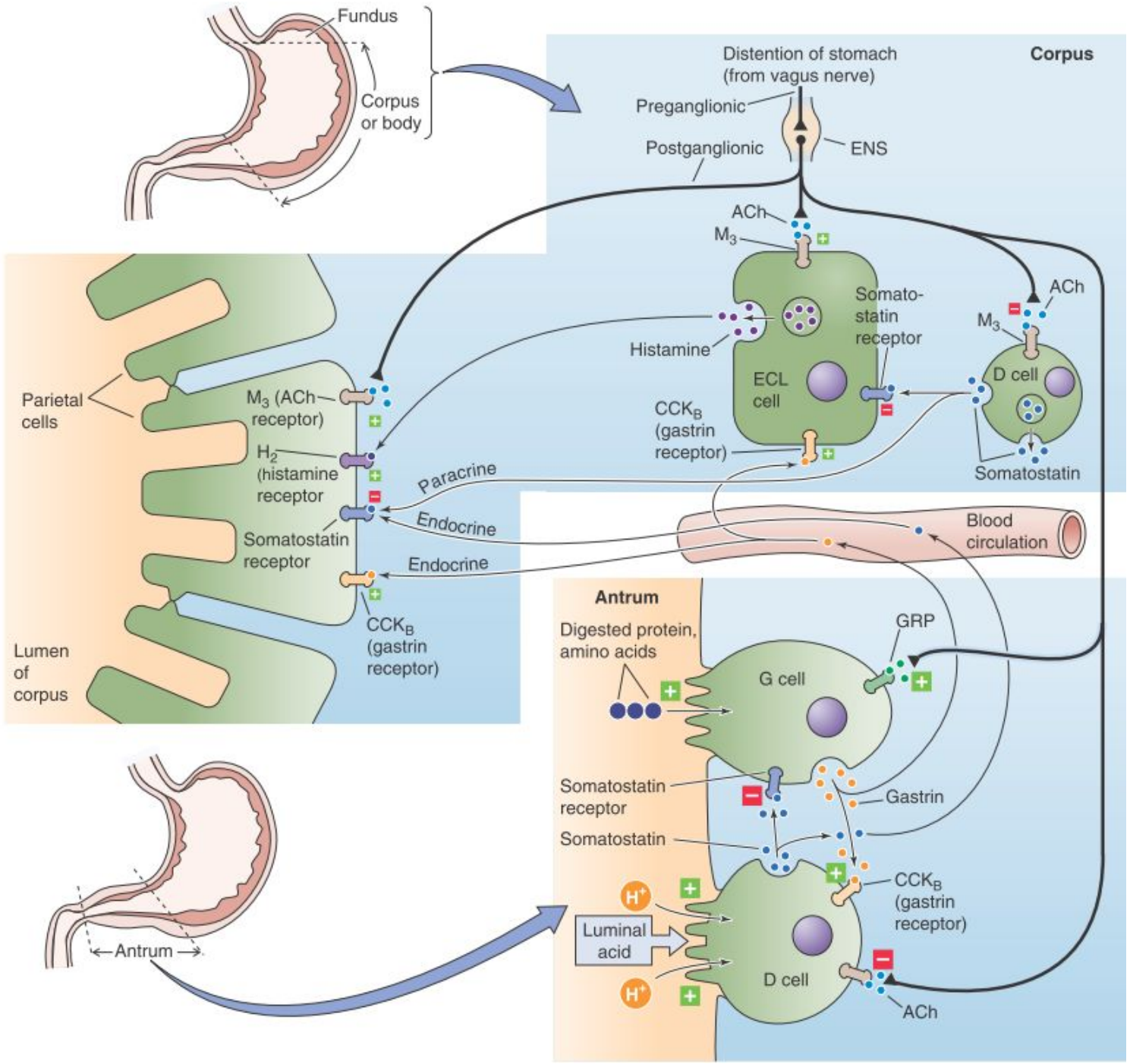

А
К
В
Р
Я
М
Б
М
В
К
Р
Я

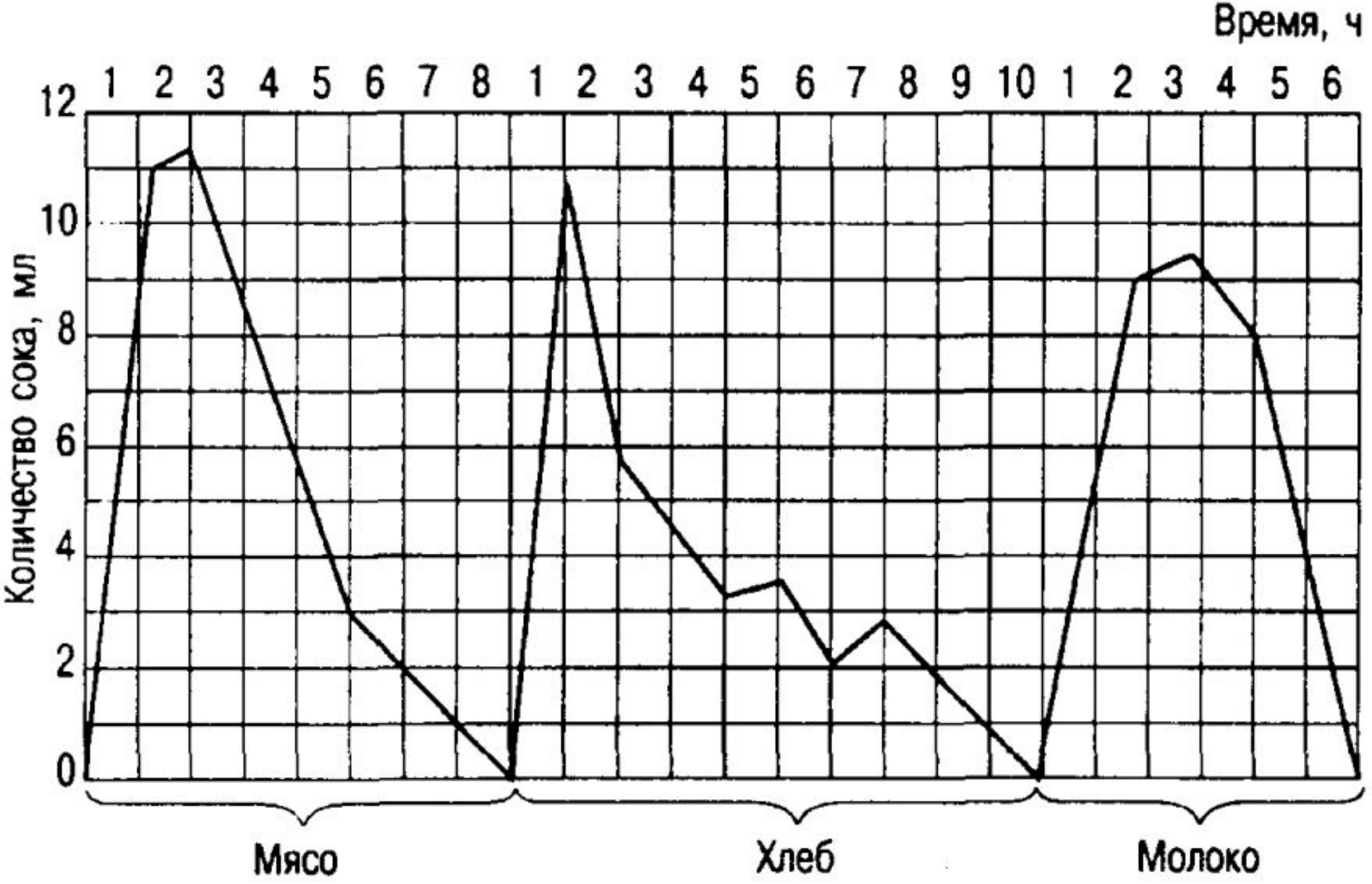

Vagal stimulation
ACh
Gastrin
Histamine
↑Ca2+
cAMP
Adenylyl cyclase
ATP
Gastric hydrogen ion pump
K+
H+

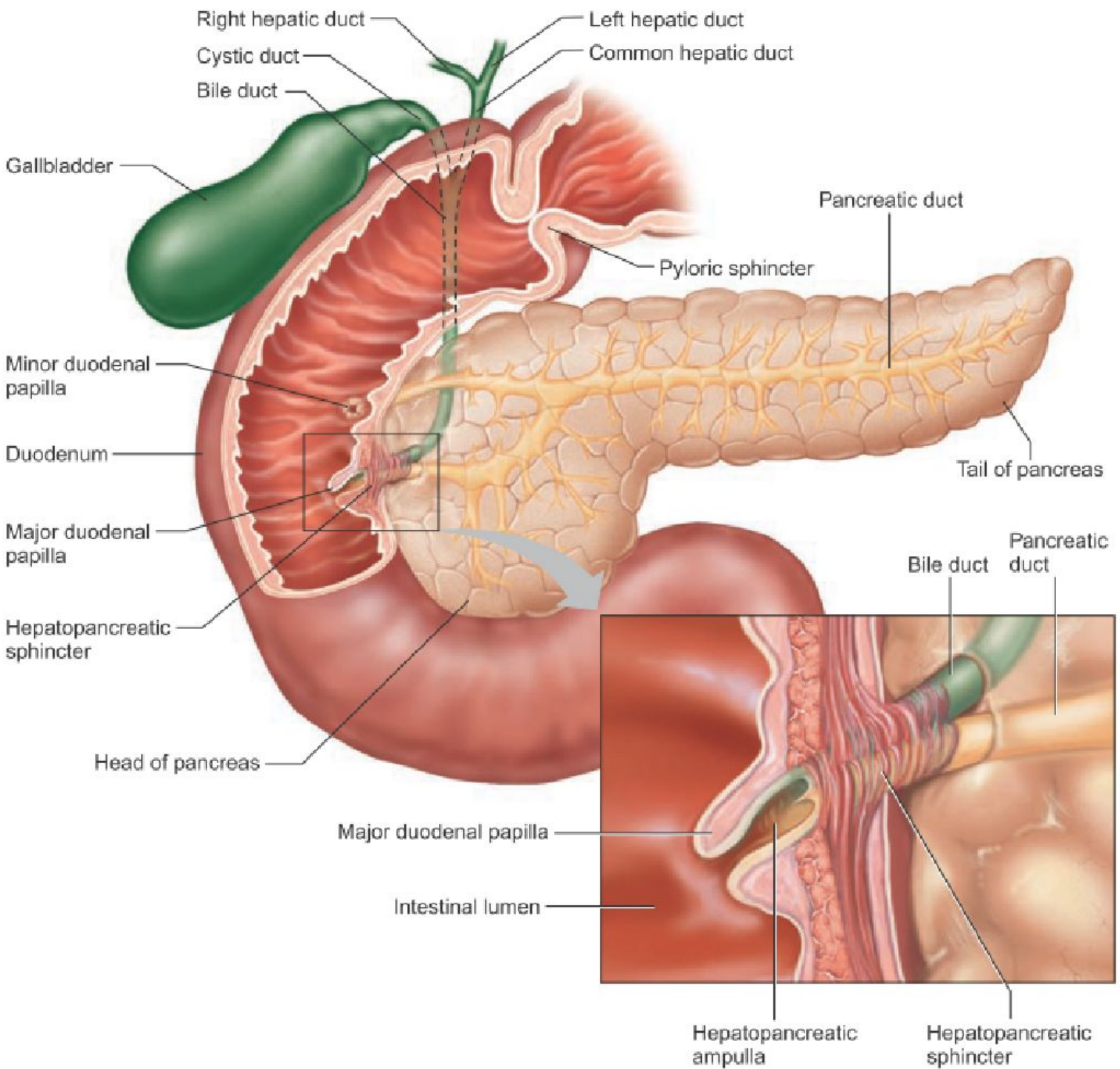

A. HCl secretion by parietal cells
Anion exchanger
Cl⁻ channel
3
Cl⁻
Cl⁻
2
HCO3⁻
HCO3⁻
CA
Lumen of gland
OH⁻ + CO2
CO2
Blood side
H2O
H⁺-K⁺-ATPase
Na⁺/H⁺ exchanger
H⁺
H⁺
ATP
Na⁺
1
K⁺ channel
ATP
K⁺
K⁺
Na⁺-K⁺-ATPase
Parietal cell

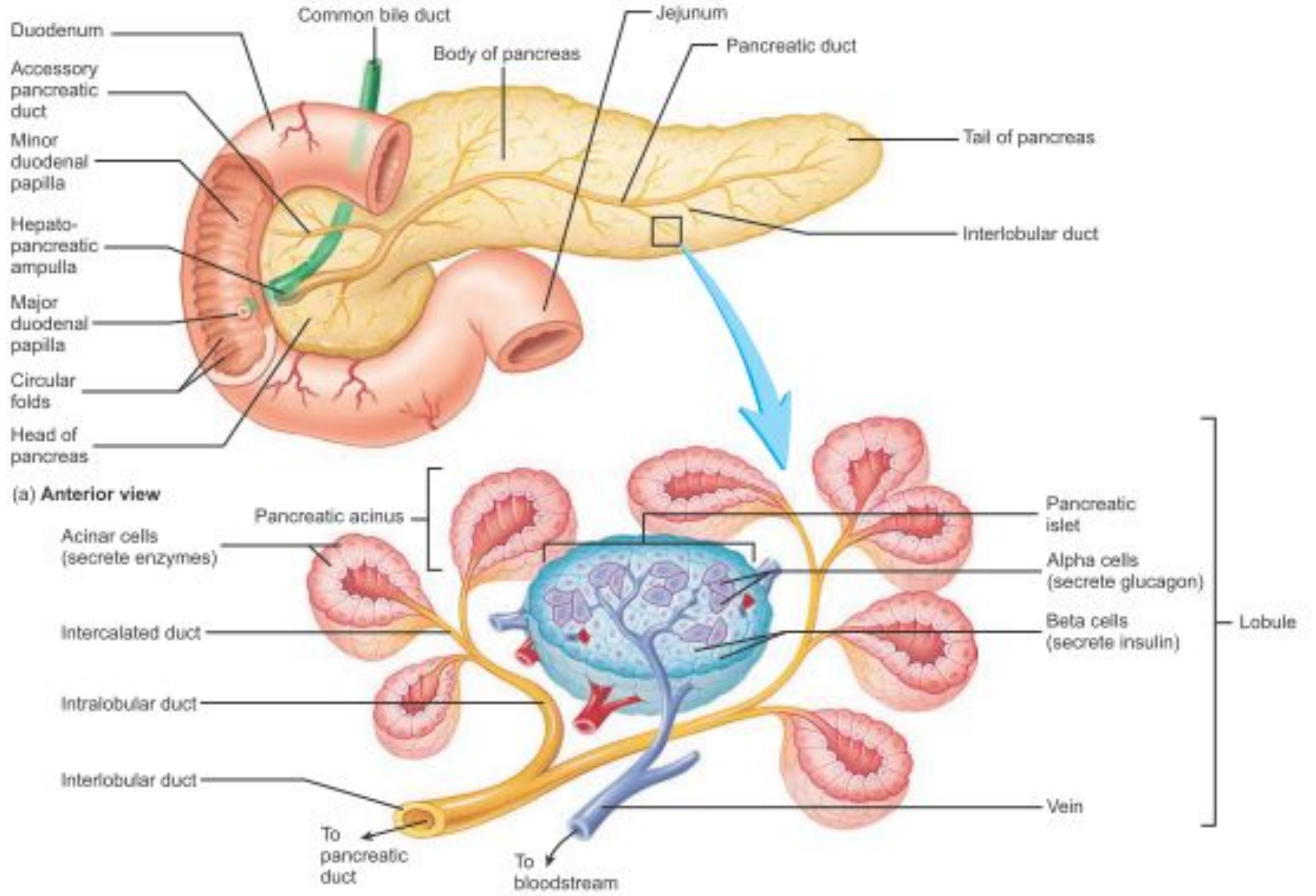

Parietal cell
HCl
Removed peptide
Dietary proteins
Pepsinogen (zymogen)
Pepsin (active enzyme)
Chief cell
Partially digested protein
Gastric gland


B. Regulation of gastric acid secretion
Vagus nerve
Food
Mechanical stimulus
1
HCl
Pepsin
Chemical stimulus
pH < 3
Gastrin
Secretin, GIP
2 Fundus
Vagus nerve
CGRP
ACh
D cell
M3
SIH
H2
H cell
Parietal cell
HCl
Histamine
CCKB
Lumen
Gastrin
Systemic circulation
3 Antrum
Vagus nerve
Amino acids, etc.
pH < 3
ACh
D cell
CGRP
SIH
G cell
GRP
Gastrin

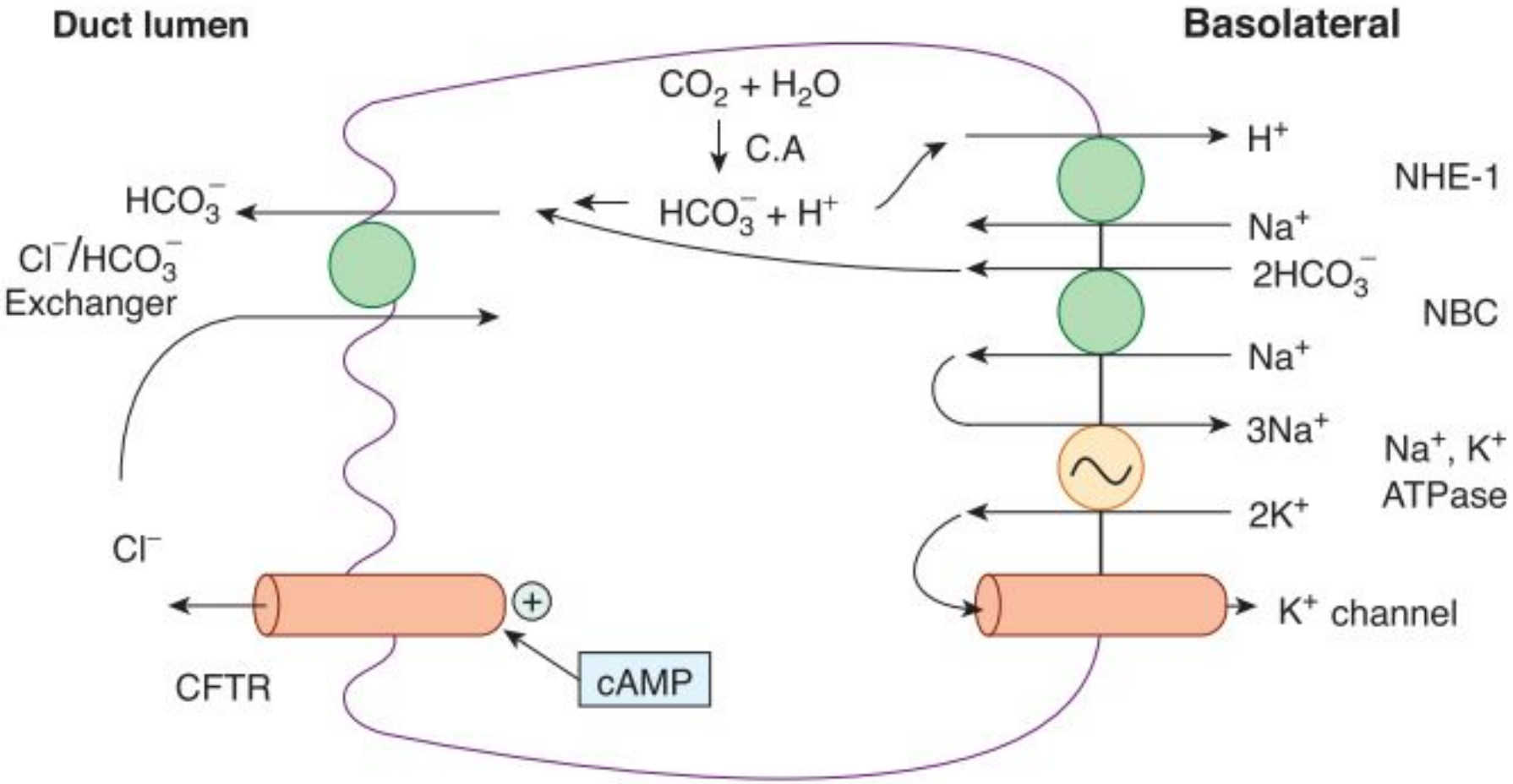

Fundus
Corpus or body
Corpus
Distention of stomach (from vagus nerve)
Preganglionic
Postganglionic
ENS
ACh
M3
Somato-statin receptor
Histamine
ECL cell
CCKB (gastrin receptor)
D cell
Somatostatin
Parietal cells
M3 (ACh receptor)
H2 (histamine receptor
Somatostatin receptor
CCKB (gastrin receptor)
Paracrine
Endocrine
Endocrine
Blood circulation
Lumen of corpus
Antrum
Digested protein, amino acids
G cell
GRP
Somatostatin receptor
Somatostatin
Gastrin
CCKB (gastrin receptor)
H+
Luminal acid
D cell
ACh
Antrum

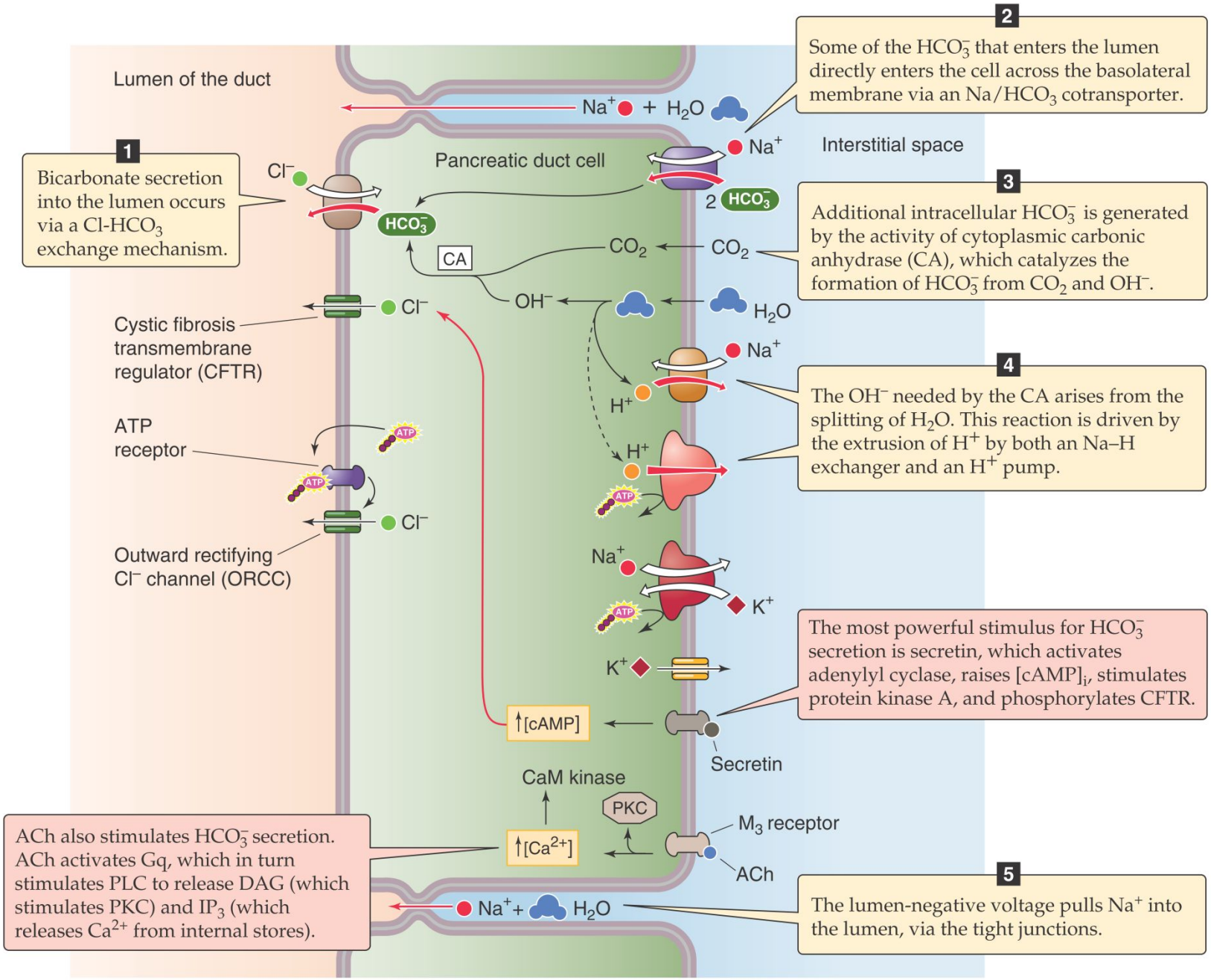

Время, ч
1 2 3 4 5 6 7 8 1 2 3 4 5 6 7 8 9 10 1 2 3 4 5 6
12
10
8
6
4
2
0
Количество сока, мл
Мясо
Хлеб
Молоко

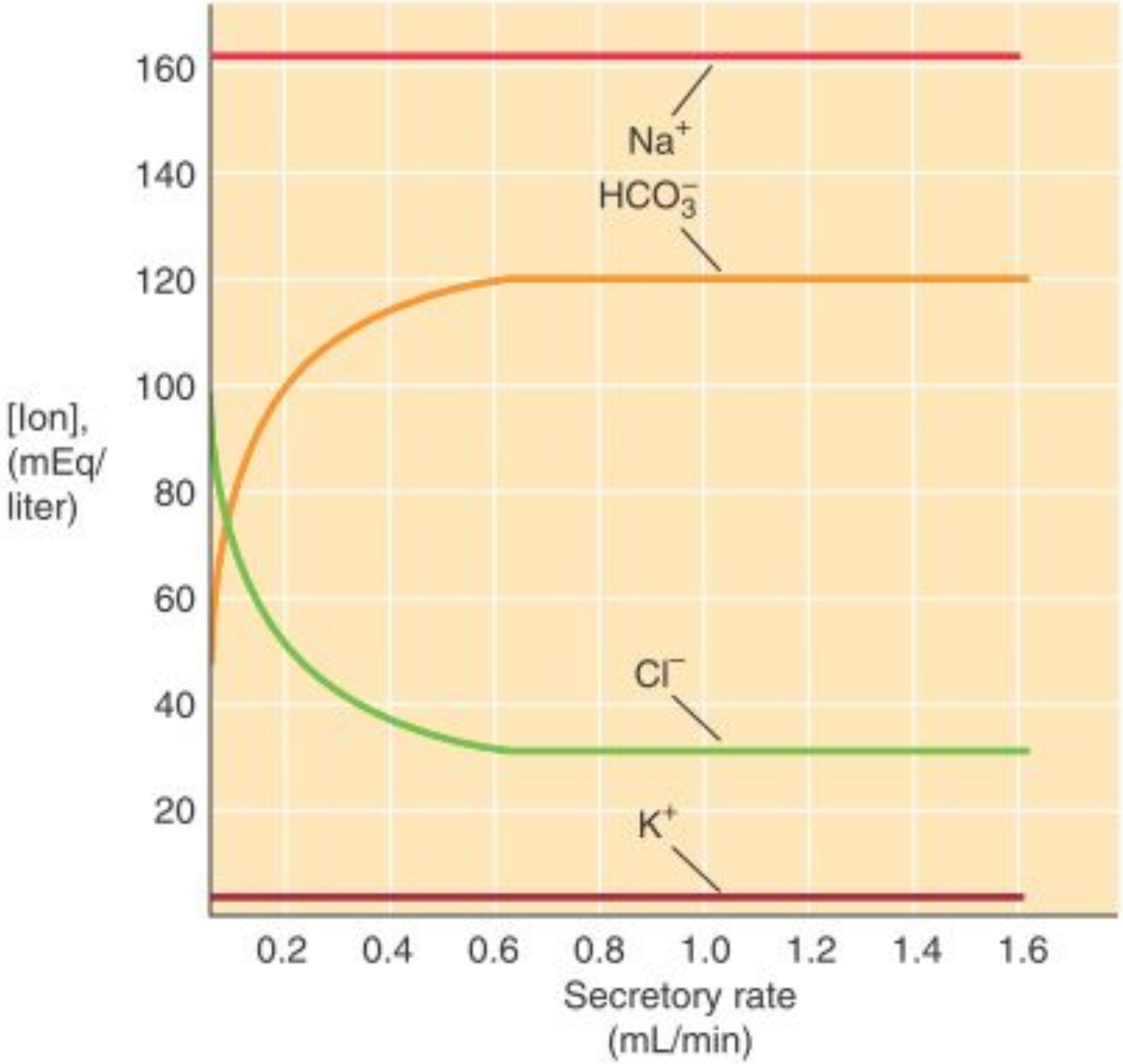

Right hepatic duct
Left hepatic duct
Cystic duct
Common hepatic duct
Bile duct
Gallbladder
Pancreatic duct
Pyloric sphincter
Minor duodenal papilla
Duodenum
Tail of pancreas
Major duodenal papilla
Hepatopancreatic sphincter
Bile duct
Pancreatic duct
Head of pancreas
Major duodenal papilla
Intestinal lumen
Hepatopancreatic ampulla
Hepatopancreatic sphincter


Duodenum
Common bile duct
Jejunum
Body of pancreas
Pancreatic duct
Accessory pancreatic duct
Minor duodenal papilla
Tail of pancreas
Hepato-pancreatic ampulla
Interlobular duct
Major duodenal papilla
Circular folds
Head of pancreas
(a) Anterior view
Pancreatic acinus
Pancreatic islet
Acinar cells (secrete enzymes)
Alpha cells (secrete glucagon)
Intercalated duct
Beta cells (secrete insulin)
Lobule
Intralobular duct
Interlobular duct
Vein
To pancreatic duct
To bloodstream

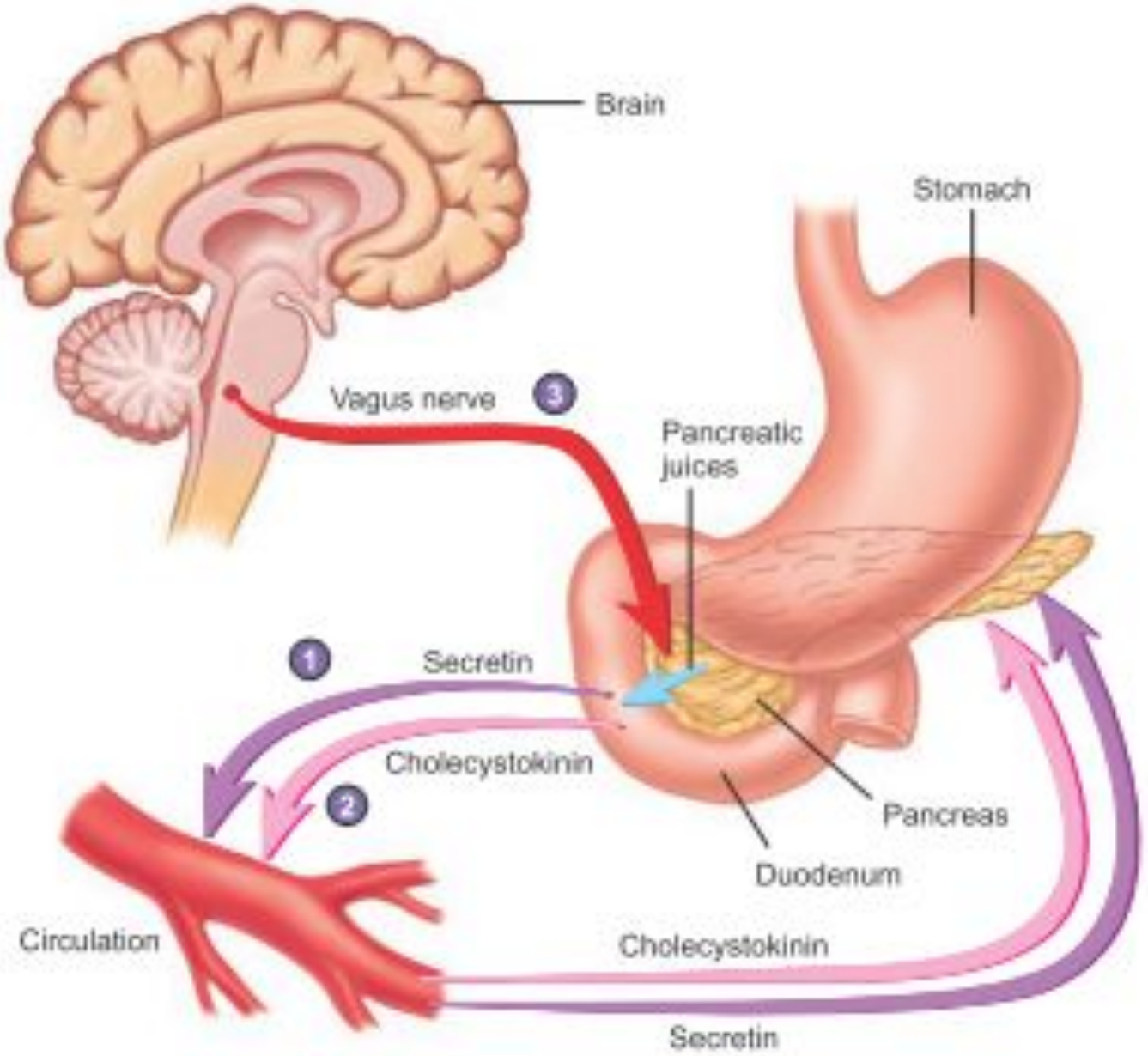
Характер действия	*Участок гидролитического расщепления*
Протеолитические	
Эндопептидазы	Внутренние пептидные связи между соседними аминокислотными остатками
Трипсин	Между остатками основных аминокислот
Химотрипсин	Между остатками ароматических аминокислот
Эластаза	Между остатками гидрофобных аминокислот в эластине
Экзопептидазы	Концевые пептидные связи
Карбоксипептидазы А и В	СООН-конец (А – неосновные аминокислоты, В – основные аминокислоты)
Аминопептидазы	N-конец
Амилолитические	
α-амилаза	α-1,4-Гликозидные связи в полимерах глюкозы
Липолитические	Эфирные связи
Липаза	В положениях 1 и 3 триглицеридов
Фосфолипаза A_2	В положении 2 фосфоглицеридов
Холестеролаза	В эфирах холестерола
Нуклеолитические	
Рибонуклеаза	Фосфодиэфирные связи между нуклеотидами в рибонуклеиновых кислотах


Duct lumen
Basolateral
$CO_2 + H_2O$
C.A
$HCO_3^- + H^+$
HCO_3^-
Cl^-/HCO_3^- Exchanger
Cl^-
CFTR
cAMP
H^+
NHE-1
Na^+
$2HCO_3^-$
NBC
Na^+
$3Na^+$
Na^+, K^+ ATPase
$2K^+$
K^+ channel

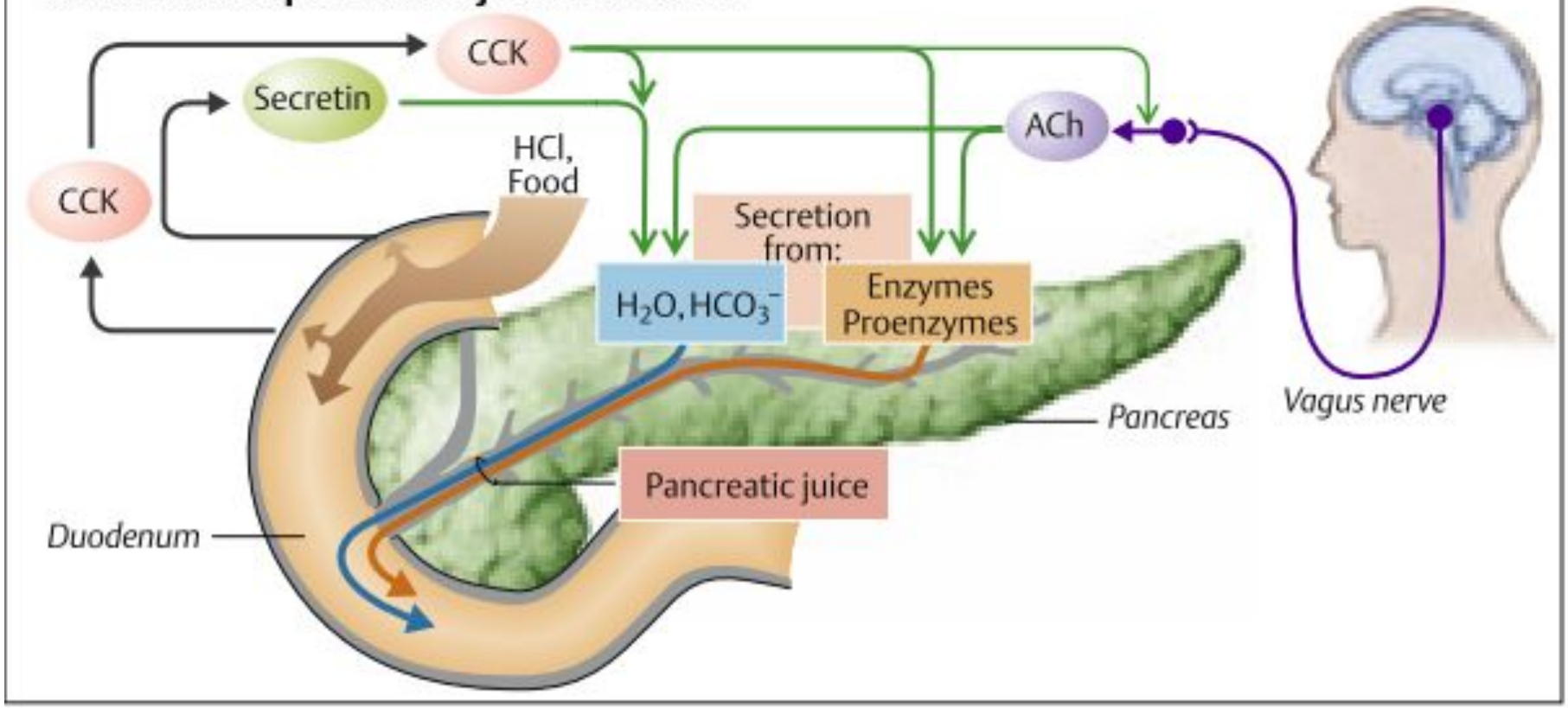

Lumen of the duct
Pancreatic duct cell
Interstitial space
Na^+ + H_2O
Na^+
2 HCO_3^-
Cl^-
HCO_3^-
CA
CO_2
CO_2
OH^-
H_2O
Cl^-
Na^+
H^+
H^+
ATP
Cl^-
Na^+
K^+
K^+
↑[cAMP]
Secretin
CaM kinase
PKC
M_3 receptor
↑[Ca^{2+}]
ACh
Na^+ + H_2O
1
Bicarbonate secretion into the lumen occurs via a Cl-HCO_3 exchange mechanism.
2
Some of the HCO_3^- that enters the lumen directly enters the cell across the basolateral membrane via an Na/HCO_3 cotransporter.
3
Additional intracellular HCO_3^- is generated by the activity of cytoplasmic carbonic anhydrase (CA), which catalyzes the formation of HCO_3^- from CO_2 and OH^-.
4
The OH^- needed by the CA arises from the splitting of H_2O. This reaction is driven by the extrusion of H^+ by both an Na–H exchanger and an H^+ pump.
5
The lumen-negative voltage pulls Na^+ into the lumen, via the tight junctions.
Cystic fibrosis transmembrane regulator (CFTR)
ATP receptor
Outward rectifying Cl^- channel (ORCC)
The most powerful stimulus for HCO_3^- secretion is secretin, which activates adenylyl cyclase, raises $[cAMP]_i$, stimulates protein kinase A, and phosphorylates CFTR.
ACh also stimulates HCO_3^- secretion. ACh activates Gq, which in turn stimulates PLC to release DAG (which stimulates PKC) and IP_3 (which releases Ca^{2+} from internal stores).


160
140
120
100
80
60
40
20
[Ion], (mEq/ liter)
Na^+
HCO_3^-
Cl^-
K^+
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
Secretory rate (mL/min)

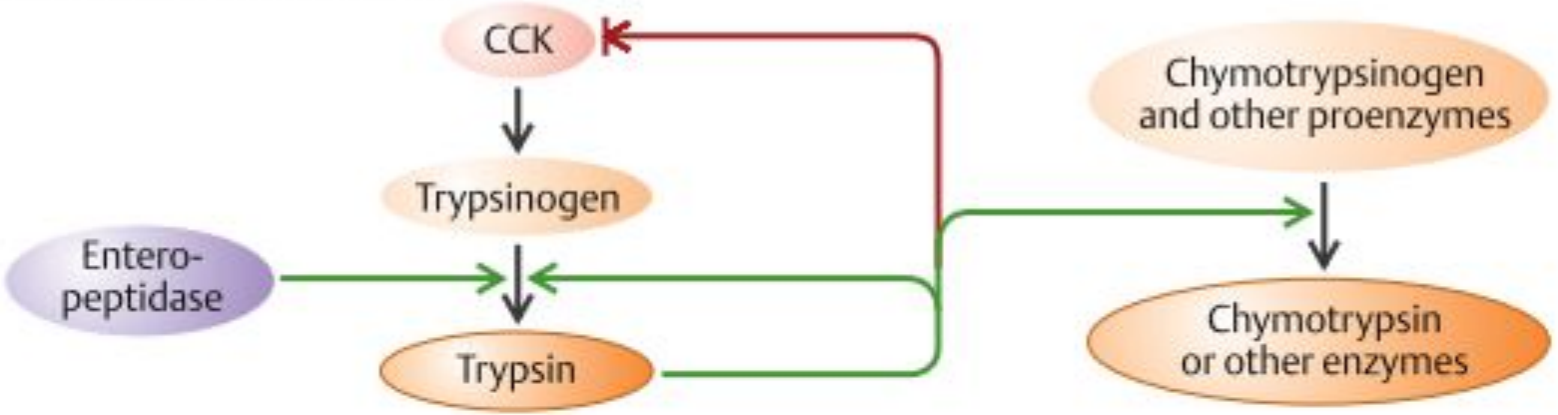
1. Secretin (*purple arrows*) released from the duodenum stimulates the pancreas to release a watery secretion rich in HCO_3^-.
2. Cholecystokinin (*pink arrows*) released from the duodenum causes the pancreas to release a secretion rich in digestive enzymes.
3. Parasympathetic stimulation from the vagus nerve (*red arrow*) causes the pancreas to release a secretion rich in digestive enzymes.

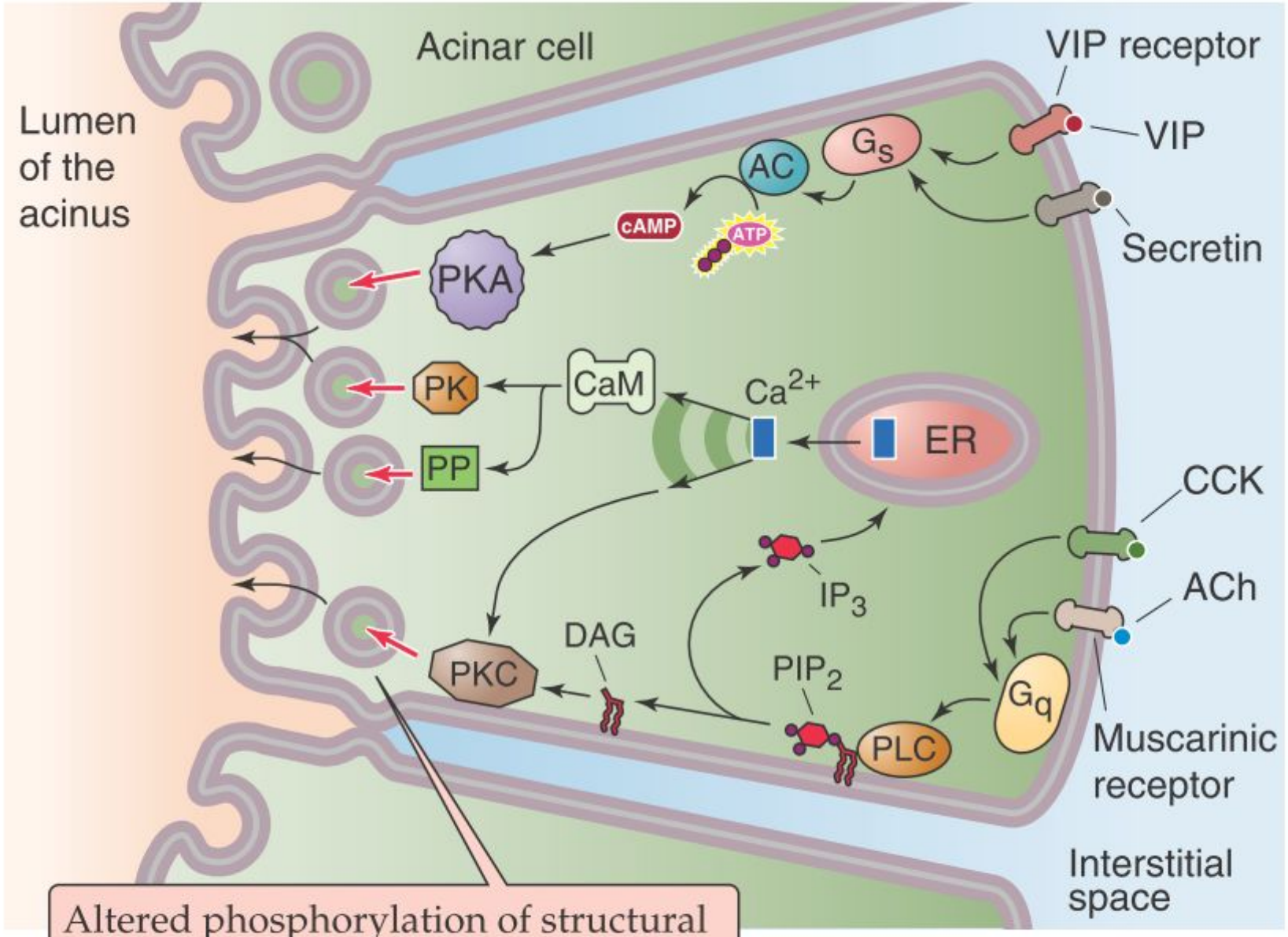


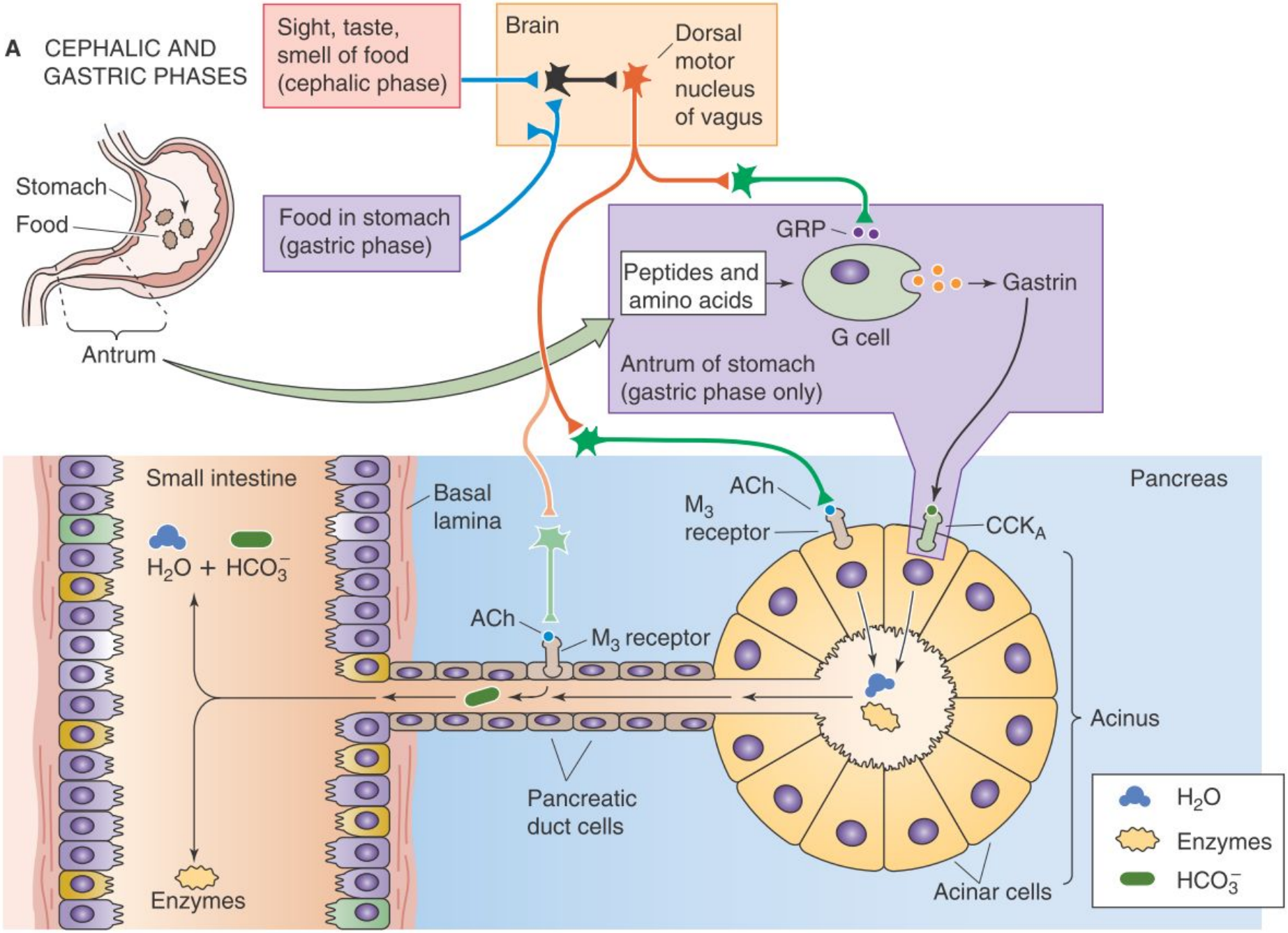
C. Control of pancreatic juice secretion

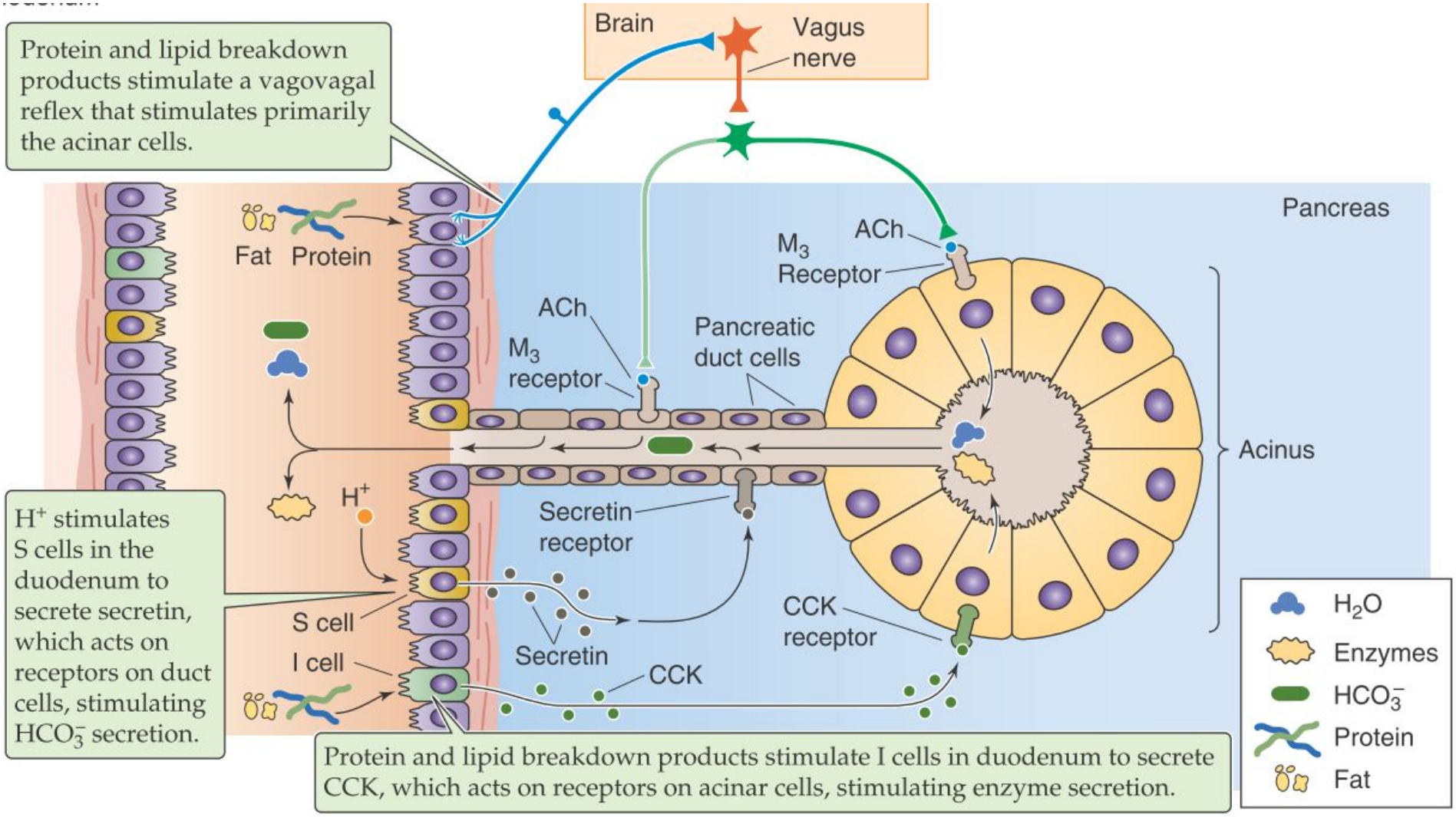


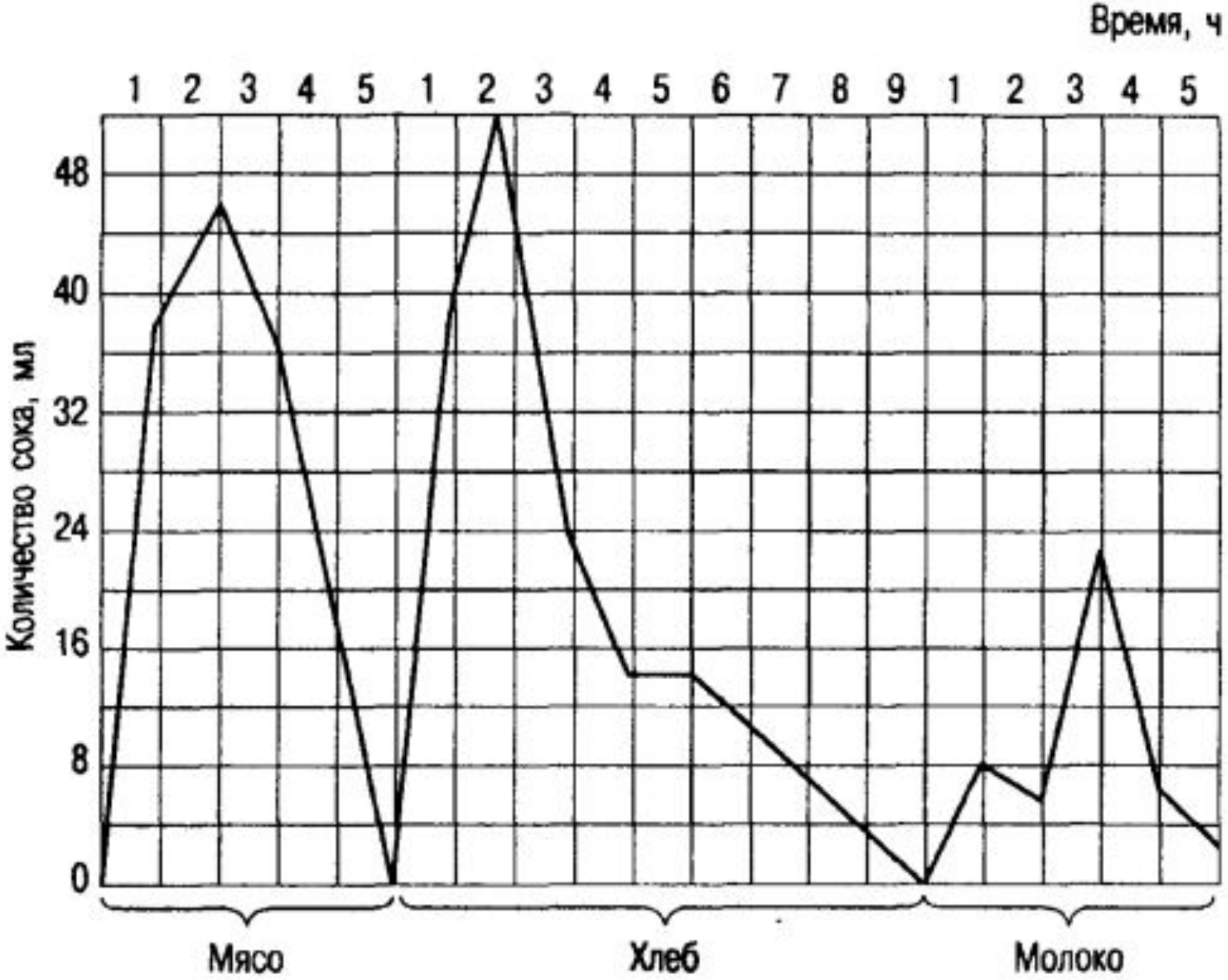
D. Trypsin: activation and effects



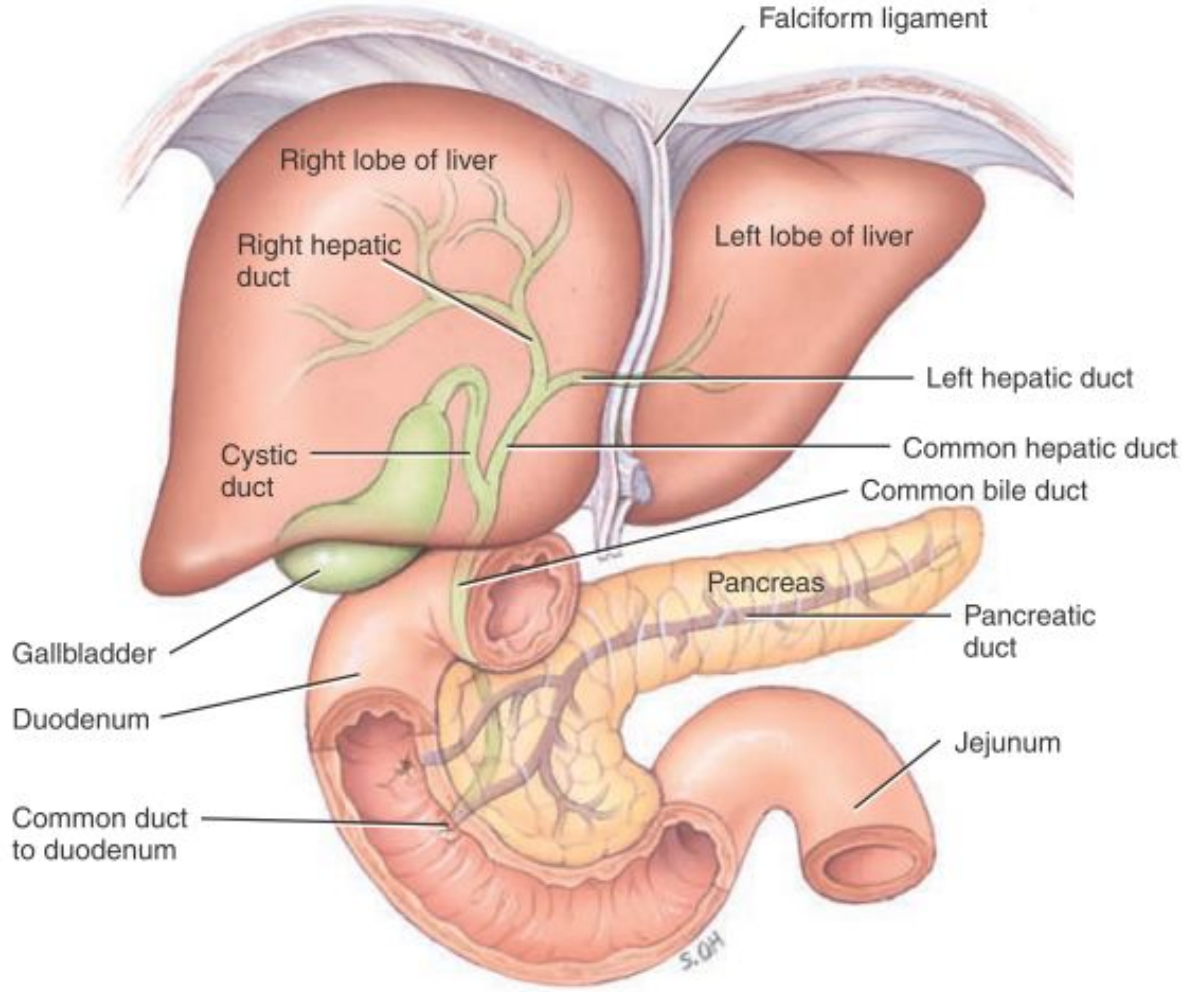

Acinar cell
Lumen of the acinus
VIP receptor
VIP
Secretin
G_s
AC
cAMP
ATP
PKA
PK
CaM
PP
Ca^{2+}
ER
CCK
ACh
IP_3
DAG
PKC
PIP_2
G_q
PLC
Muscarinic receptor
Interstitial space
Altered phosphorylation of structural and regulatory proteins leads to vesicle insertion and protein secretion.


A CEPHALIC AND GASTRIC PHASES
Sight, taste, smell of food (cephalic phase)
Brain
Dorsal motor nucleus of vagus
Stomach
Food
Food in stomach (gastric phase)
Antrum
GRP
Peptides and amino acids
Gastrin
G cell
Antrum of stomach (gastric phase only)
Small intestine
Basal lamina
Pancreas
ACh
M3 receptor
CCKA
H2O + HCO3−
ACh
M3 receptor
Acinus
Pancreatic duct cells
Enzymes
Acinar cells
H2O
Enzymes
HCO3−

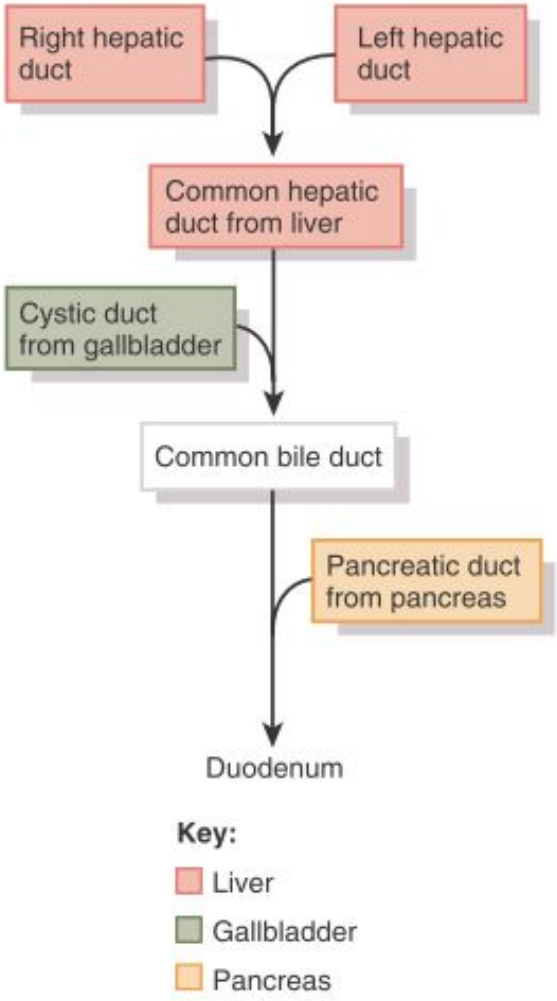

Protein and lipid breakdown products stimulate a vagovagal reflex that stimulates primarily the acinar cells.
Brain
Vagus nerve
Pancreas
Fat
Protein
ACh
M_3 Receptor
ACh
M_3 receptor
Pancreatic duct cells
Acinus
H^+
Secretin receptor
H^+ stimulates S cells in the duodenum to secrete secretin, which acts on receptors on duct cells, stimulating HCO_3^- secretion.
S cell
I cell
Secretin
CCK
CCK receptor
H_2O
Enzymes
HCO_3^-
Protein
Fat
Protein and lipid breakdown products stimulate I cells in duodenum to secrete CCK, which acts on receptors on acinar cells, stimulating enzyme secretion.

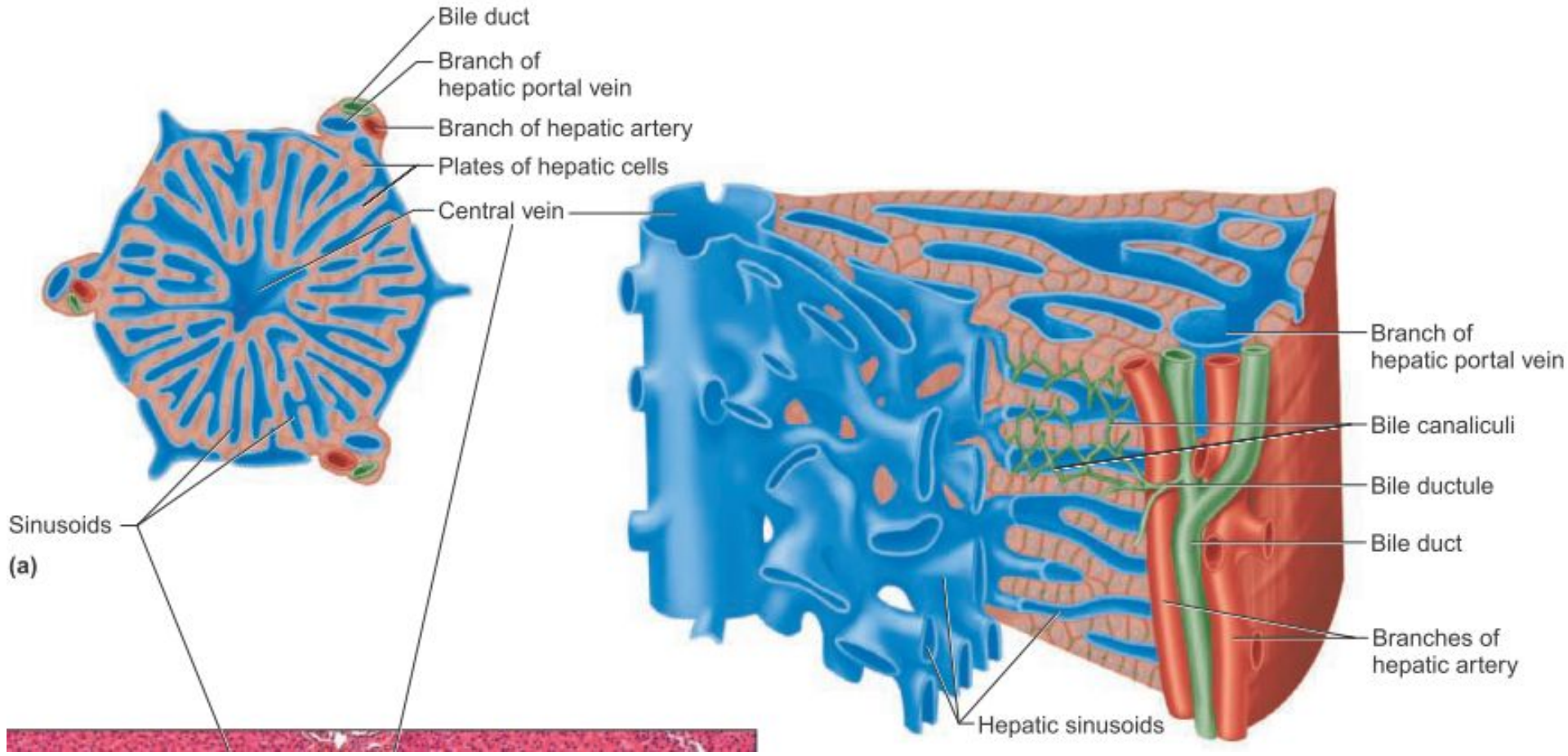

Время, ч
1 2 3 4 5 1 2 3 4 5 6 7 8 9 1 2 3 4 5
48
40
32
24
16
8
0
Количество сока, мл
Мясо
Хлеб
Молоко

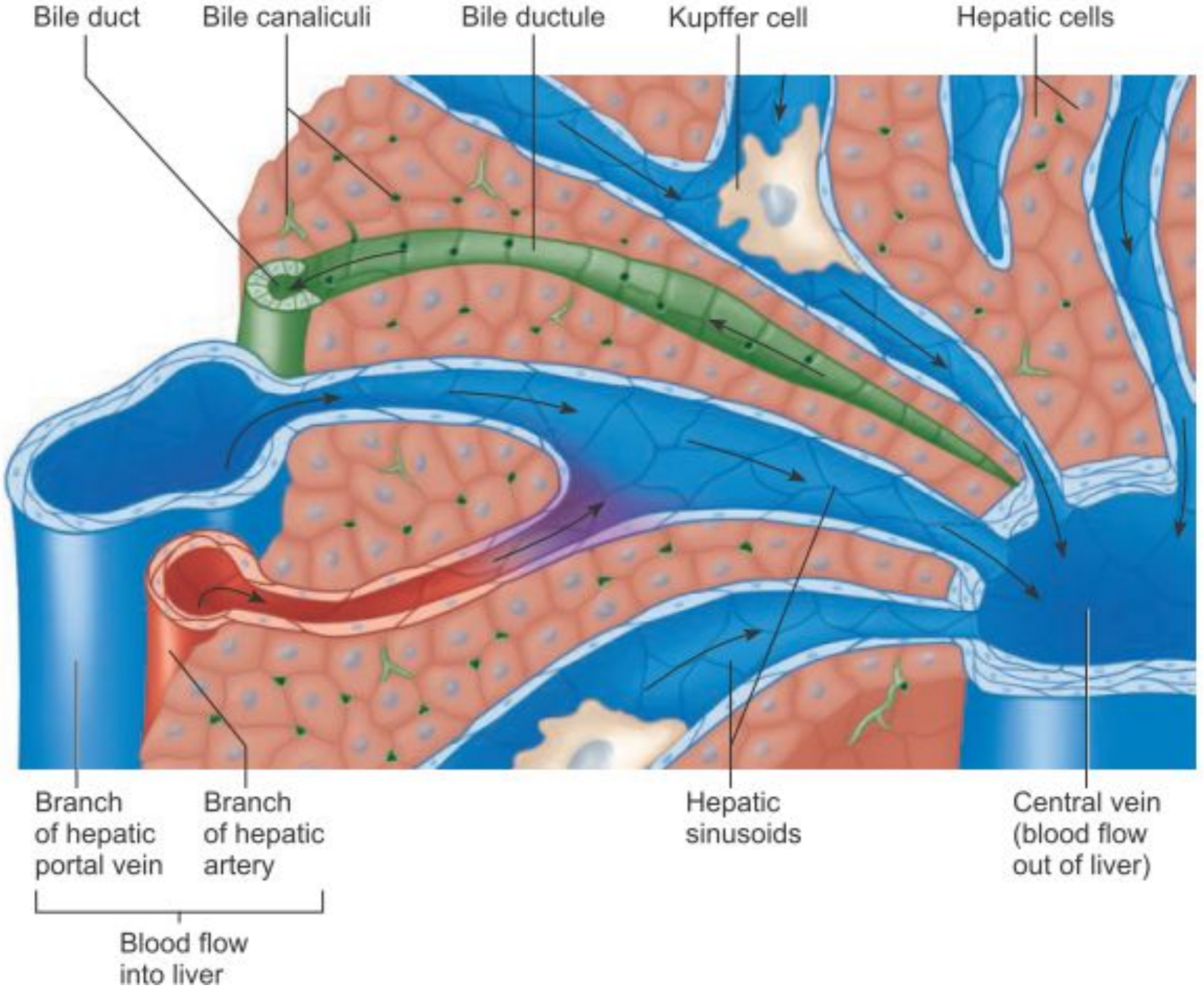
duodenum through the pancreatic duct.

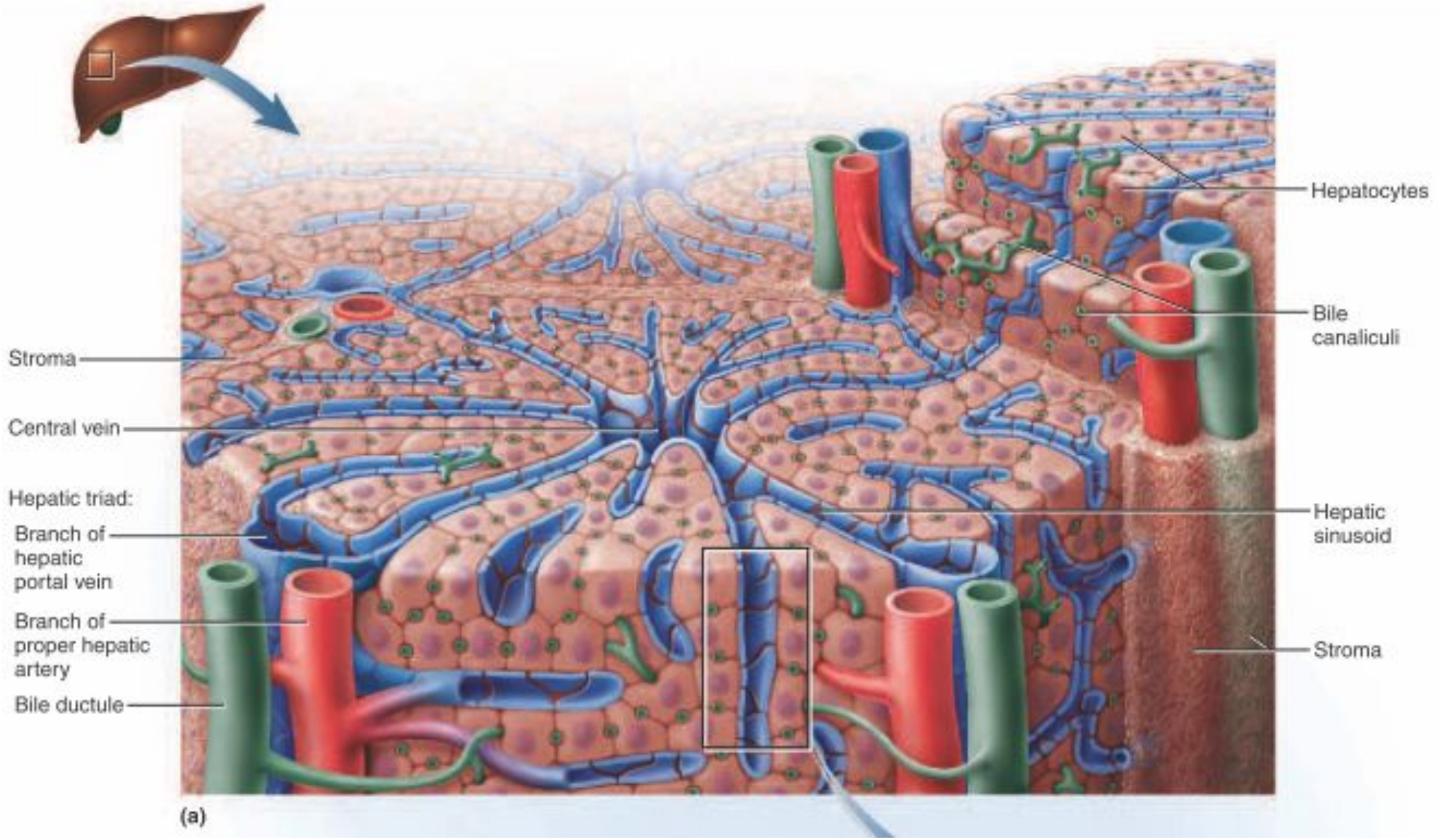


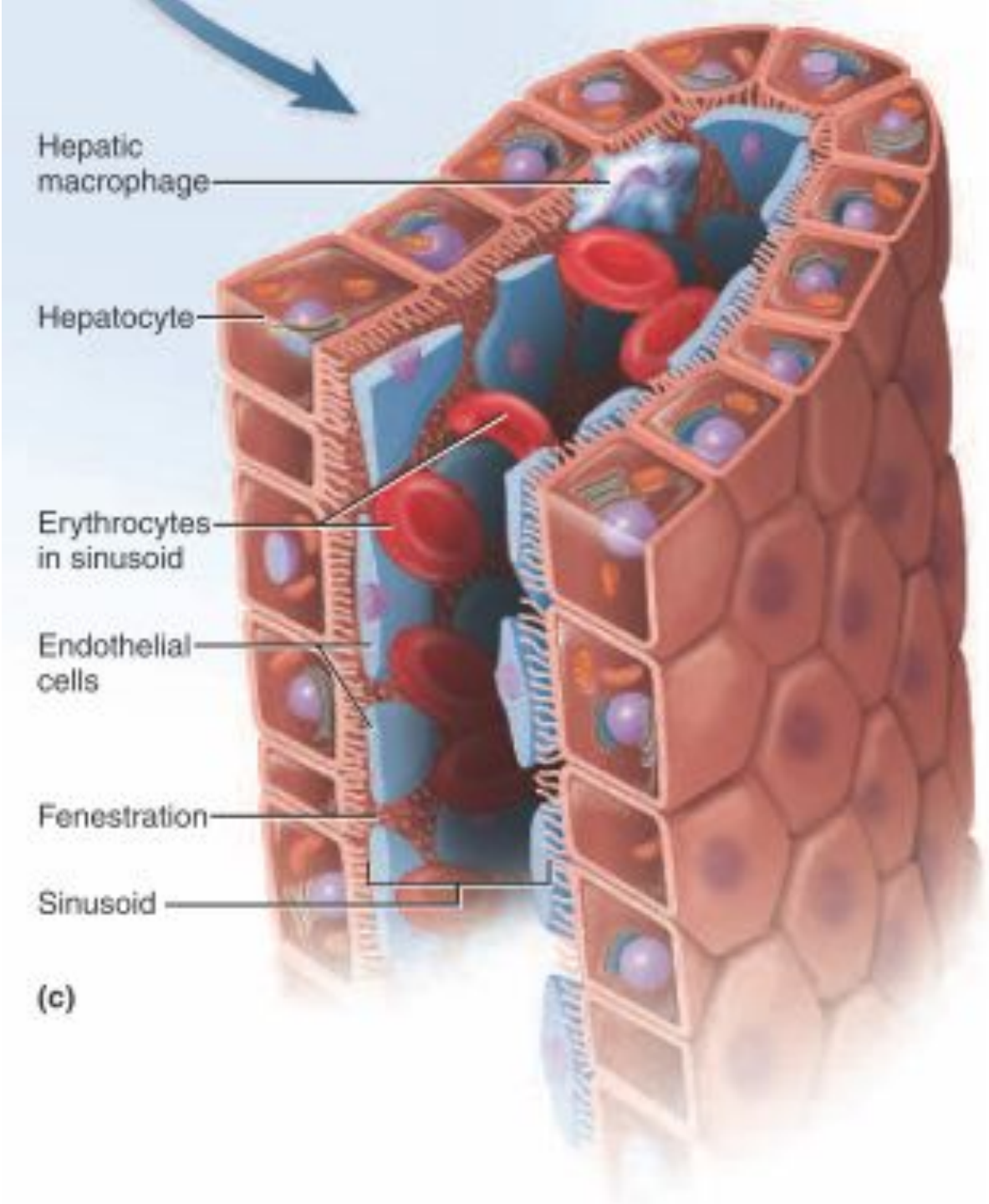
Anterior view

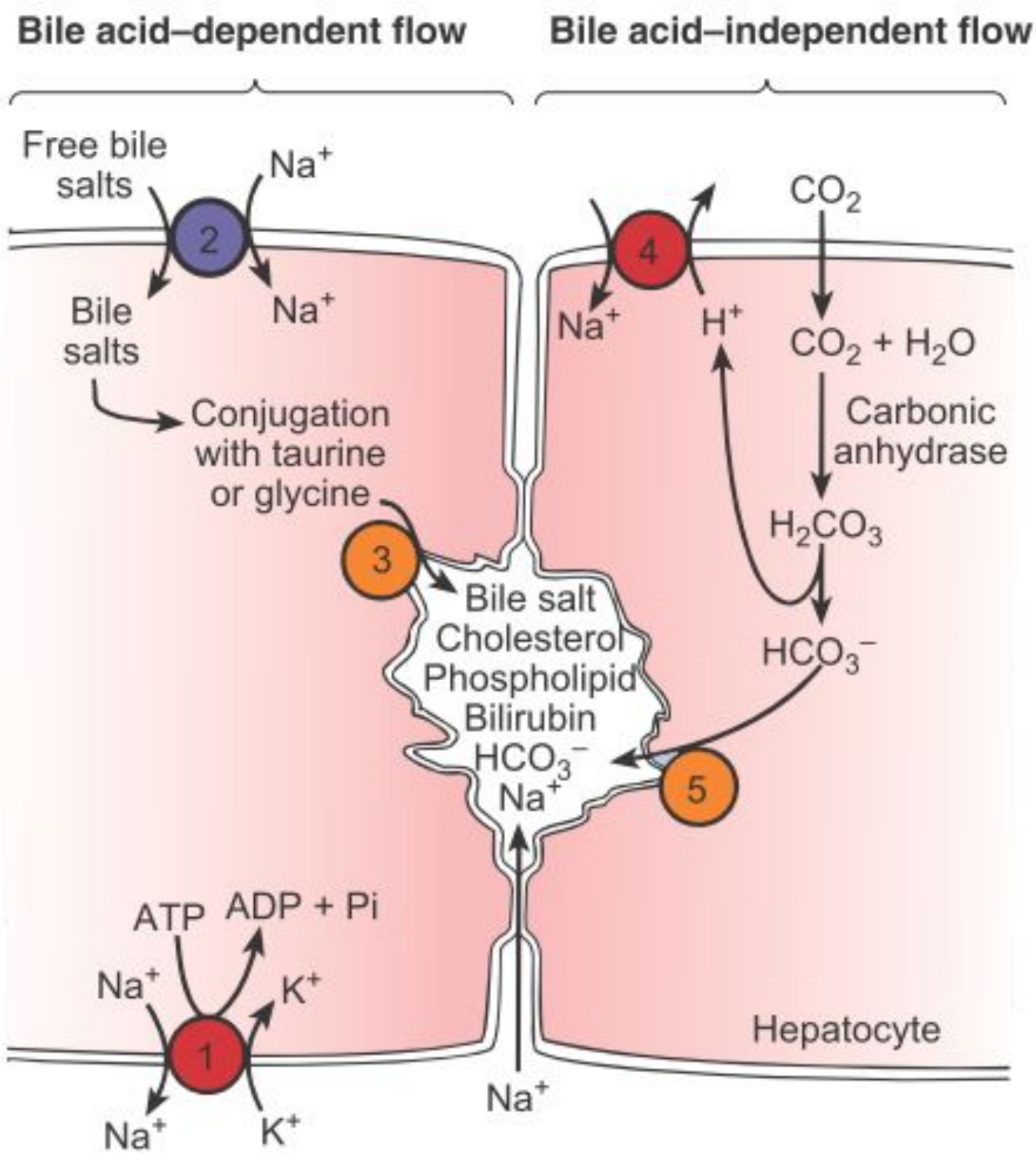


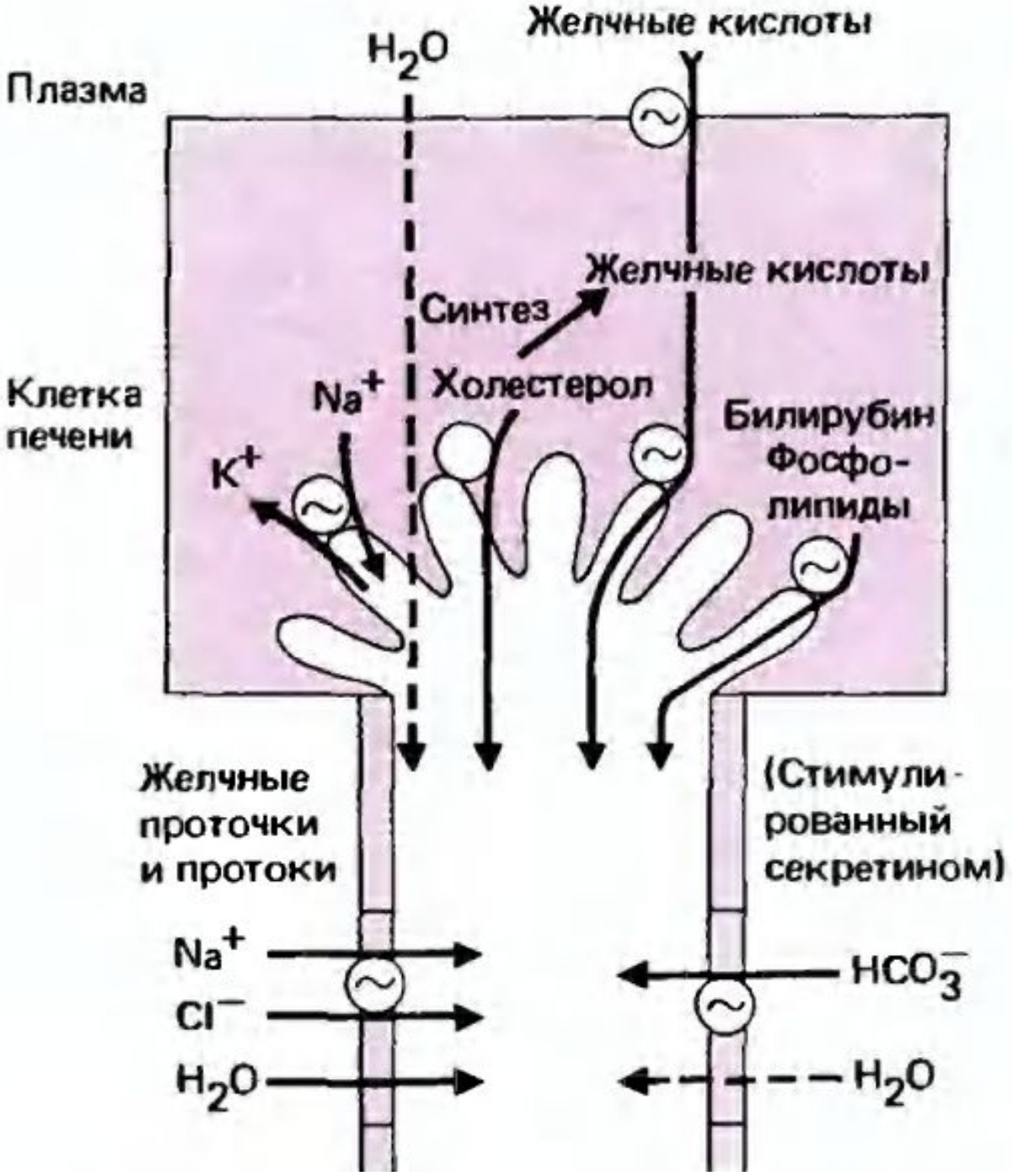

Bile duct
Branch of hepatic portal vein
Branch of hepatic artery
Plates of hepatic cells
Central vein
Sinusoids
(a)
Branch of hepatic portal vein
Bile canaliculi
Bile ductule
Bile duct
Branches of hepatic artery
Hepatic sinusoids

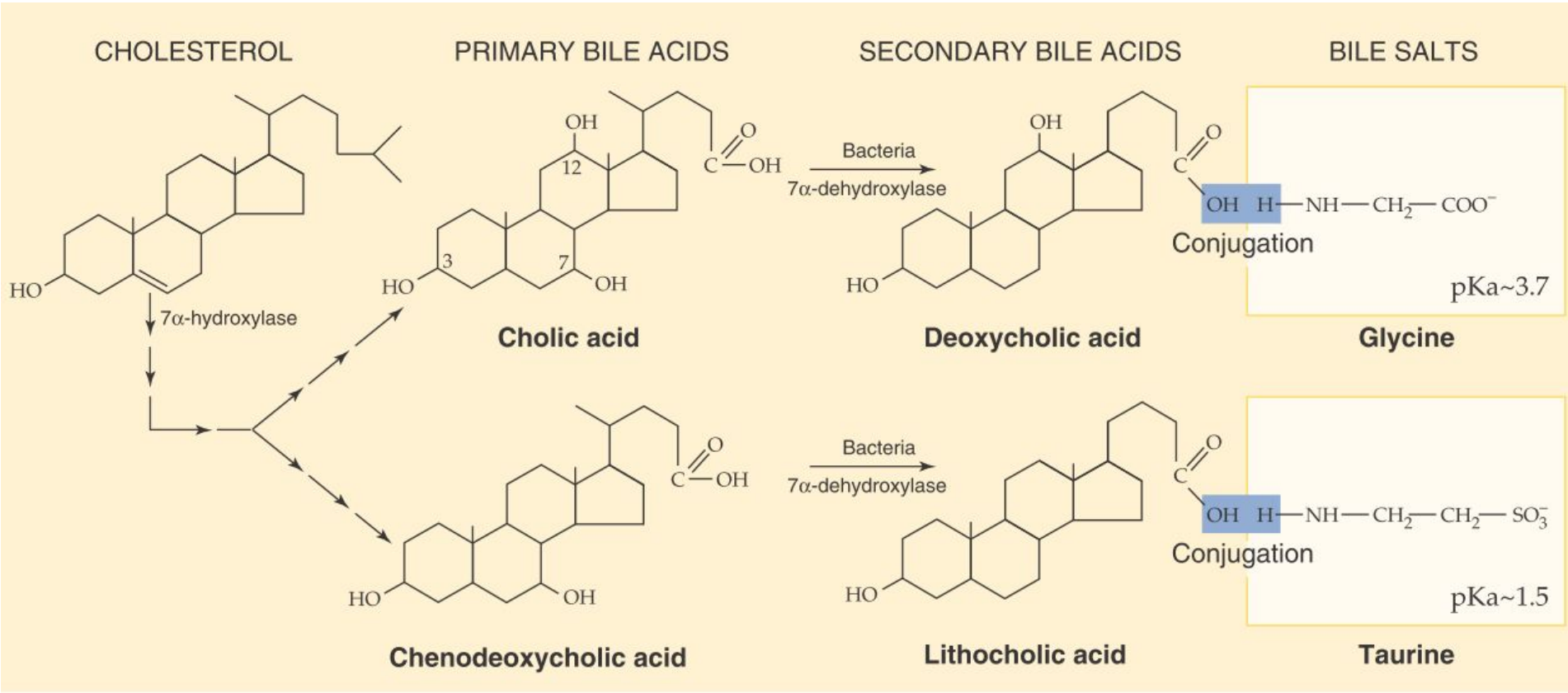

Bile duct
Bile canaliculi
Bile ductule
Kupffer cell
Hepatic cells
Branch of hepatic portal vein
Branch of hepatic artery
Blood flow into liver
Hepatic sinusoids
Central vein (blood flow out of liver)

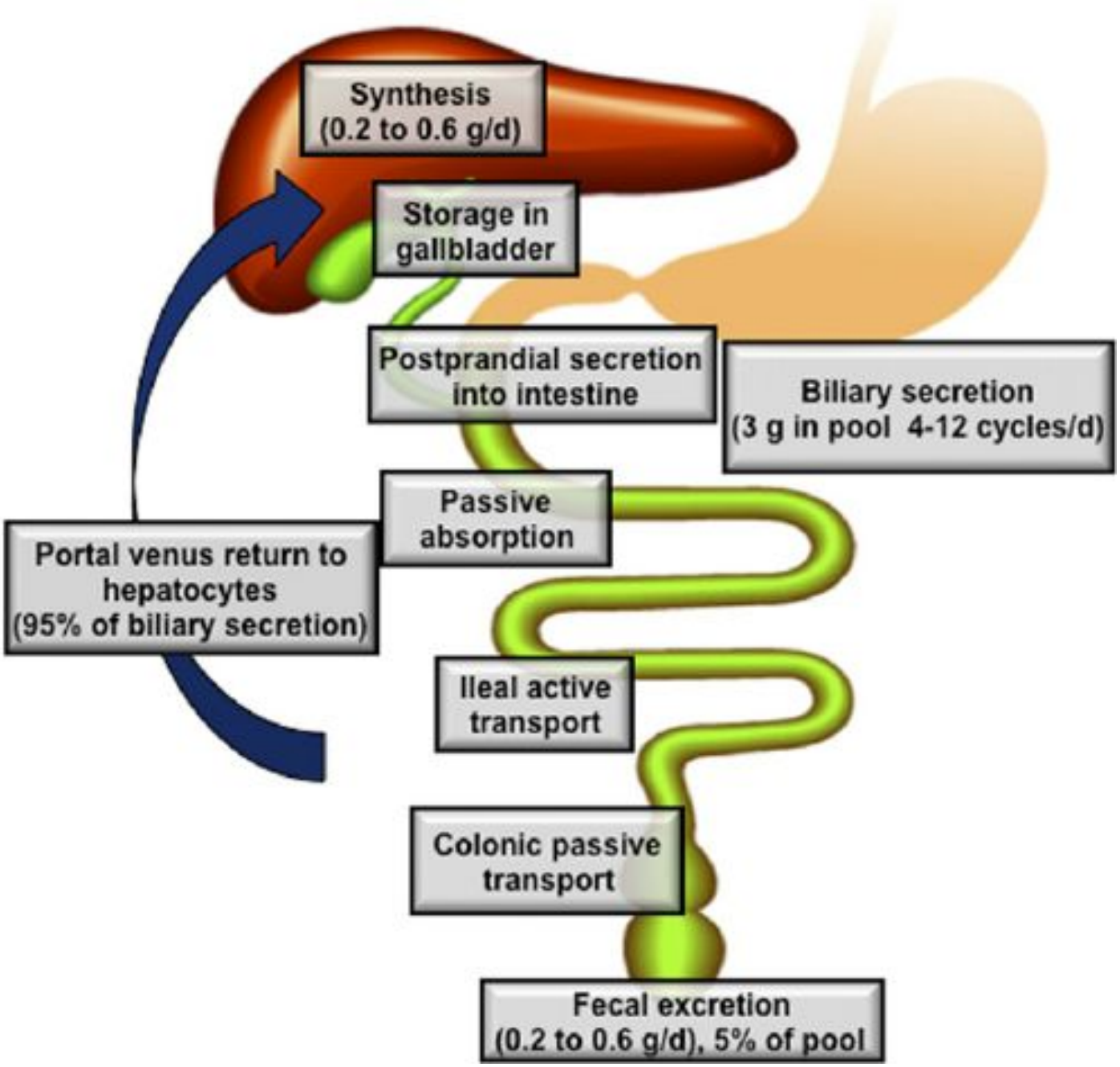

Hepatocytes
Bile canaliculi
Stroma
Central vein
Hepatic triad:
Branch of hepatic portal vein
Branch of proper hepatic artery
Bile ductule
Hepatic sinusoid
Stroma
(a)

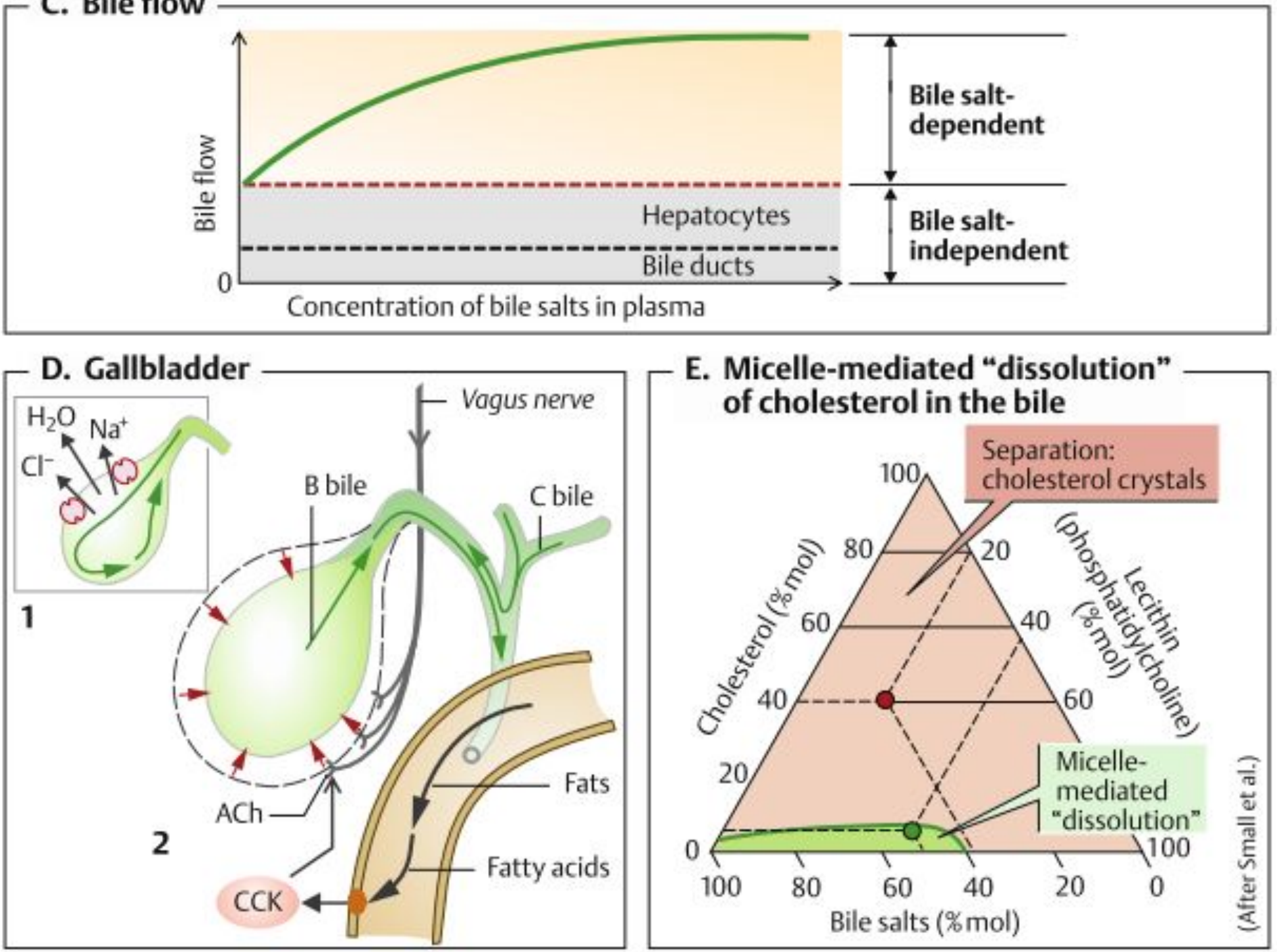

Hepatic macrophage
Hepatocyte
Erythrocytes in sinusoid
Endothelial cells
Fenestration
Sinusoid
(c)


Bile acid–dependent flow
Bile acid–independent flow
Free bile salts
Na+
2
Bile salts
Na+
Conjugation with taurine or glycine
3
Bile salt
Cholesterol
Phospholipid
Bilirubin
HCO3−
Na+
4
Na+
H+
CO2
CO2 + H2O
Carbonic anhydrase
H2CO3
HCO3−
5
ATP
ADP + Pi
Na+
K+
1
Na+
K+
Na+
Hepatocyte

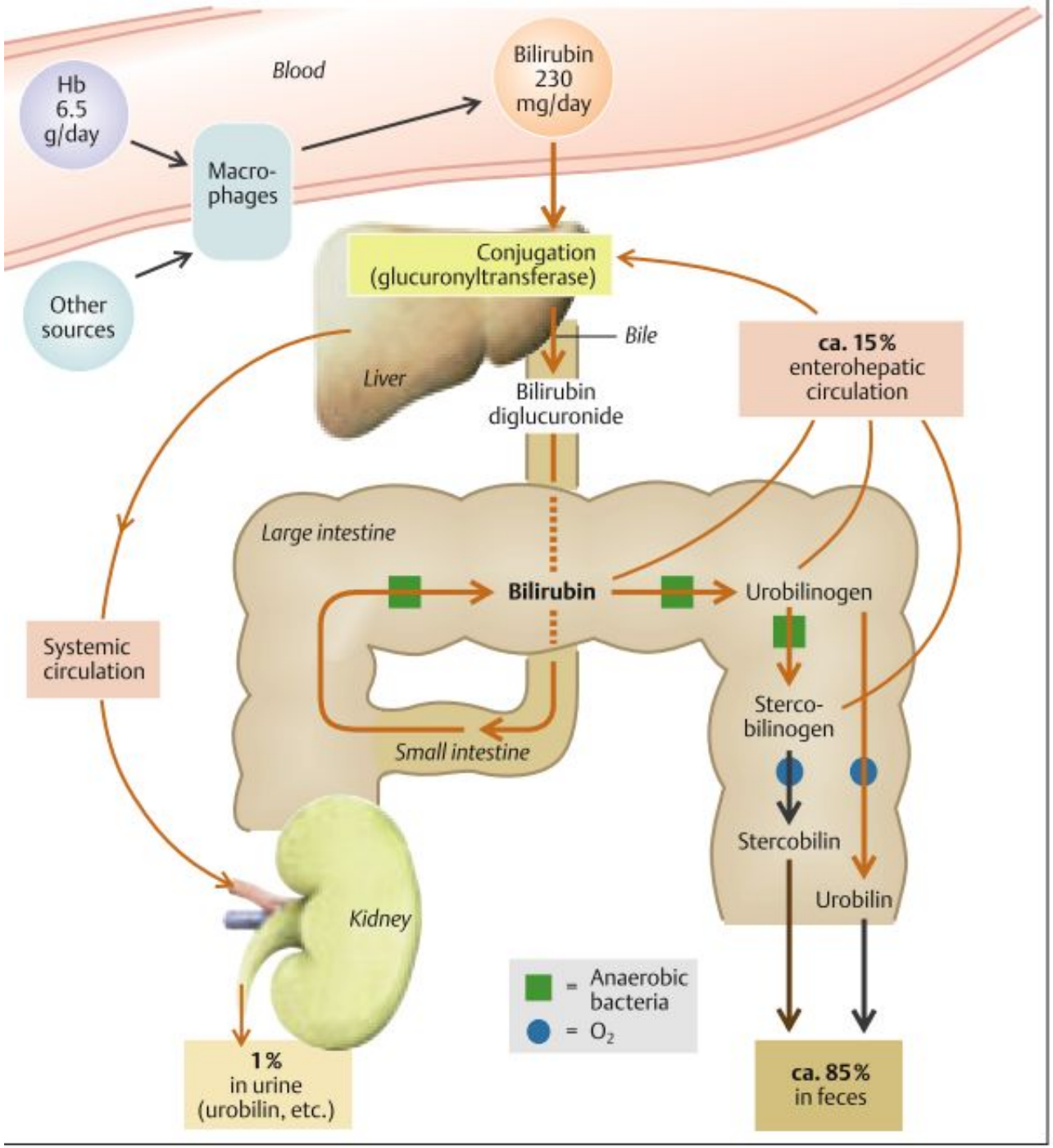

Желчные кислоты
H_2O
Плазма
Желчные кислоты
Синтез
Клетка печени
Na^+
Холестерол
Билирубин
Фосфо-липиды
K^+
Желчные проточки и протоки
(Стимули-рованный секретином)
Na^+
Cl^-
H_2O
HCO_3^-
H_2O

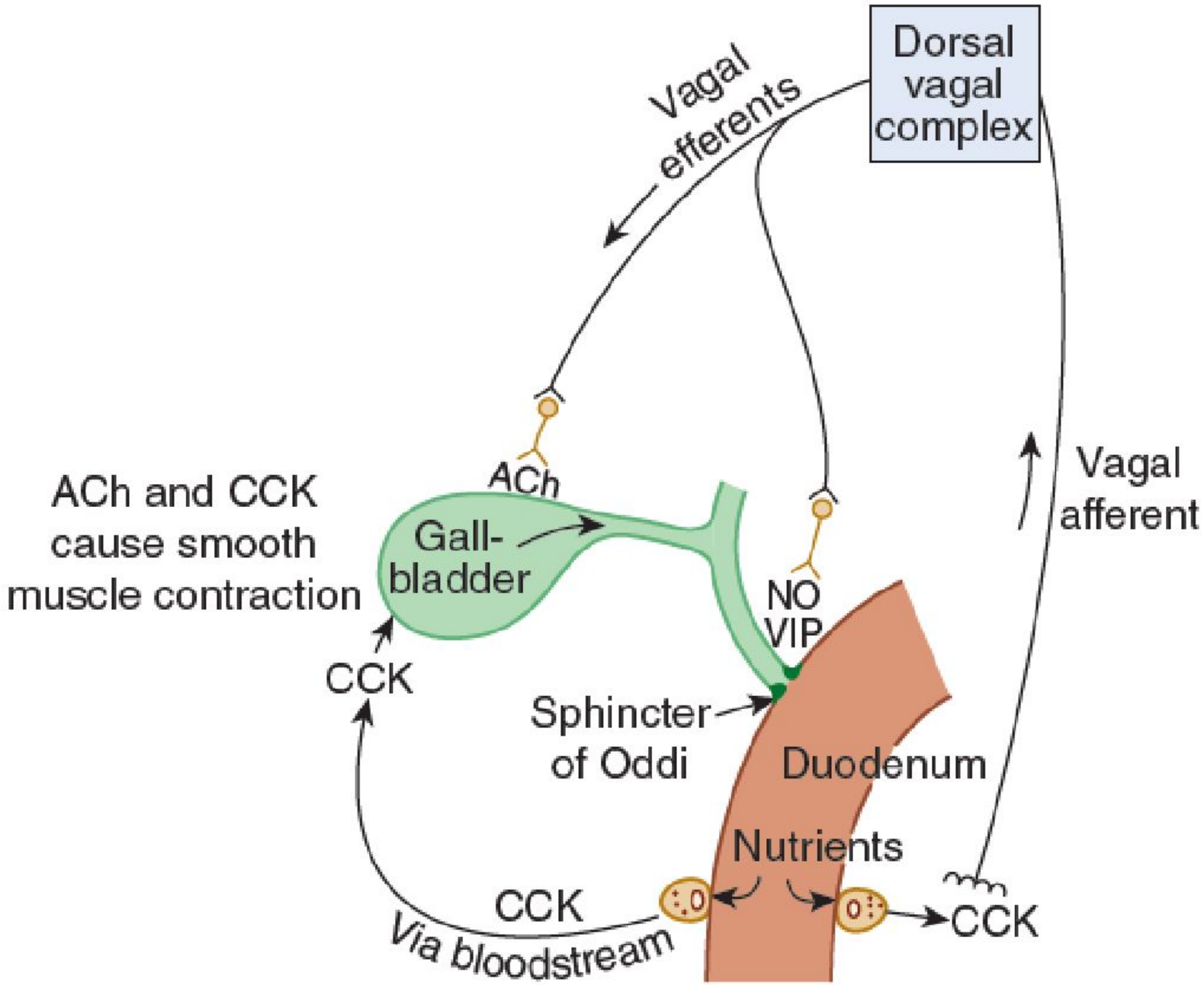

CHOLESTEROL
PRIMARY BILE ACIDS
SECONDARY BILE ACIDS
BILE SALTS
HO
7α-hydroxylase
OH
12
3
7
HO
OH
C
O
OH
Cholic acid
Bacteria
7α-dehydroxylase
OH
C
O
OH H NH CH2 COO⁻
Conjugation
pKa~3.7
HO
Deoxycholic acid
Glycine
C
O
OH
HO
OH
Chenodeoxycholic acid
Bacteria
7α-dehydroxylase
OH H NH CH2 CH2 SO3⁻
Conjugation
pKa~1.5
HO
Lithocholic acid
Taurine

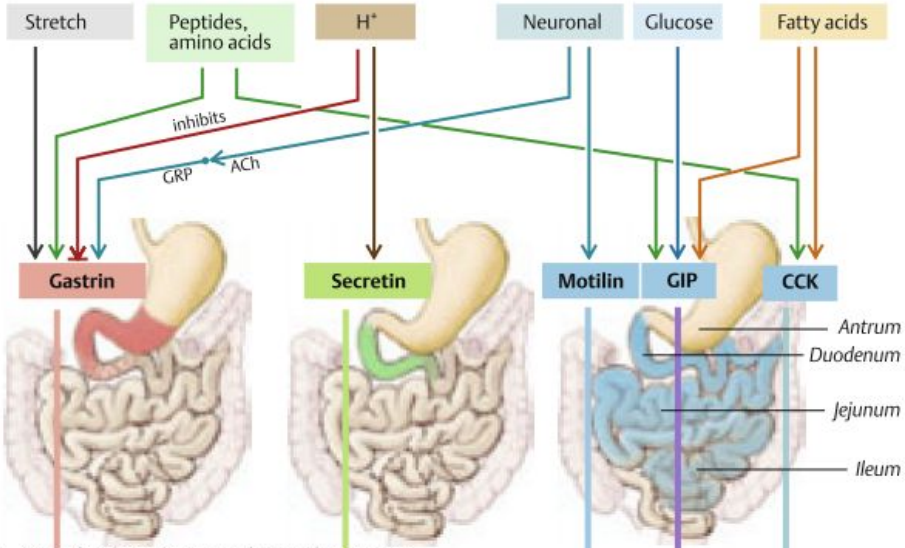

Synthesis
(0.2 to 0.6 g/d)
Storage in
gallbladder
Postprandial secretion
into intestine
Biliary secretion
(3 g in pool 4-12 cycles/d)
Passive
absorption
Portal venus return to
hepatocytes
(95% of biliary secretion)
Ileal active
transport
Colonic passive
transport
Fecal excretion
(0.2 to 0.6 g/d), 5% of pool


C. Bile flow
Bile flow
0
Hepatocytes
Bile ducts
Concentration of bile salts in plasma
Bile salt-dependent
Bile salt-independent
D. Gallbladder
H_2O
Na^+
Cl^-
1
Vagus nerve
B bile
C bile
ACh
2
Fats
Fatty acids
CCK
E. Micelle-mediated "dissolution" of cholesterol in the bile
Separation: cholesterol crystals
Micelle-mediated "dissolution"
Cholesterol (%mol)
Lecithin (phosphatidylcholine) (%mol)
Bile salts (%mol)
100
80
60
40
20
0
(After Small et al.)

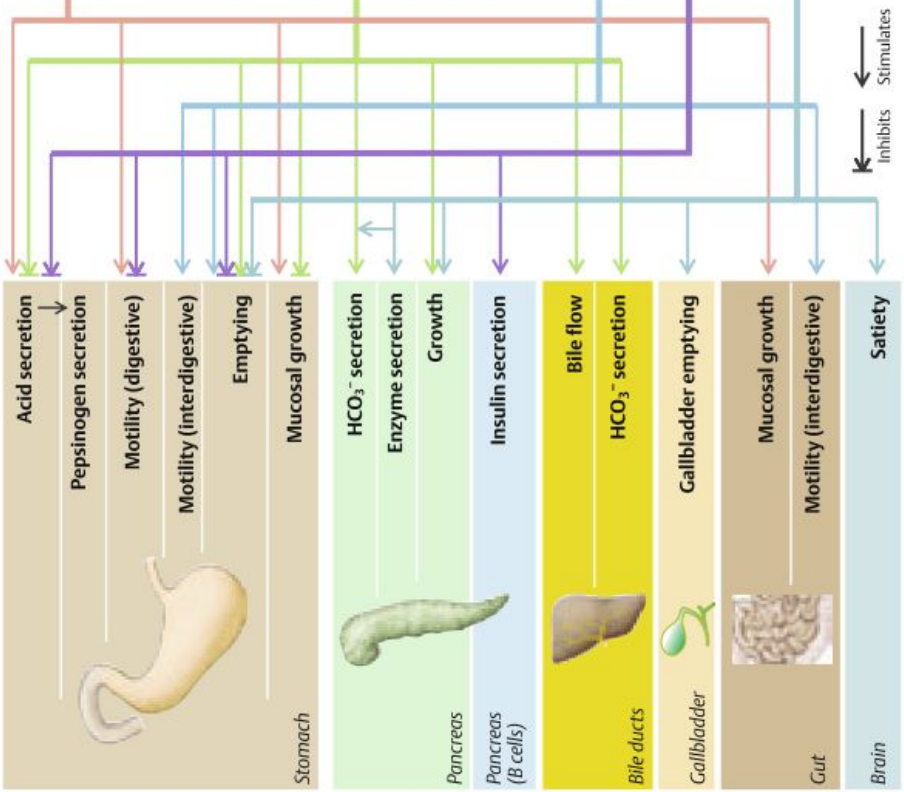
B. Bilirubin metabolism and excretion




Dorsal vagal complex
Vagal efferents
ACh
ACh and CCK cause smooth muscle contraction
Gall-bladder
NO
VIP
Vagal afferent
CCK
Sphincter of Oddi
Duodenum
Nutrients
CCK
Via bloodstream
CCK



1 Stimulus for release and site of secretion



2 Main effects of gastrointestinal hormones

(Partly after L. R. Johnson)