

# **Gastrointestinal Physiology**

## **Required Textbook**

**Textbook of Medical Physiology**

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# Lecture 1

Organization & General Principles of  
Gastrointestinal Physiology

By

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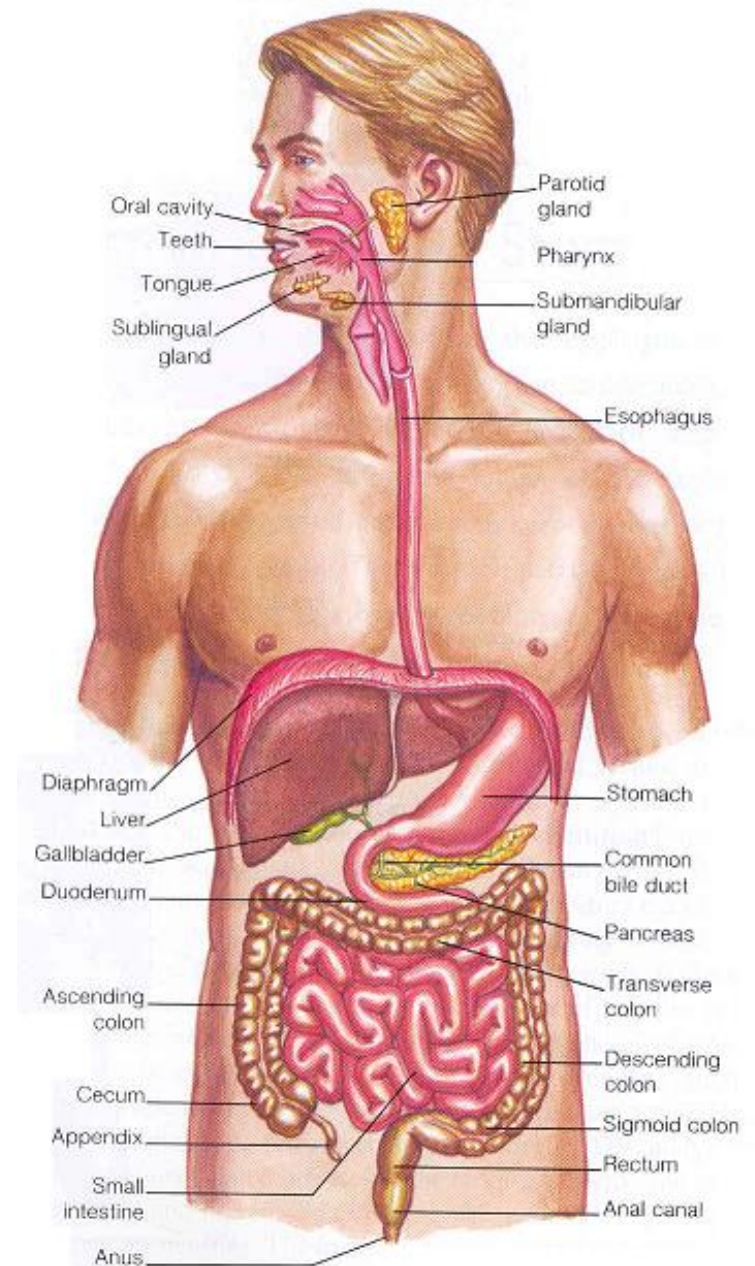


# LEARNING OBJECTIVES

- ❖ Physiologic Anatomy of the Gastrointestinal Wall
- ❖ The General and Specific Characteristics of Smooth Muscle
- ❖ Neural & Hormonal Control of Gastrointestinal Function
- ❖ Types of Neurotransmitters Secreted by Enteric Neurons
- ❖ Functional Types of Movements in the GIT
- ❖ Gastrointestinal Blood Flow "Splanchnic Circulation"
- ❖ Effect of Gut Activity and Metabolic Factors on GI Blood Flow



The gastrointestinal system consists of the gastrointestinal tract (GIT) and associated organs that produce secretions



**The organs of the digestive system**

# GASTROINTESTINAL FUNCTION

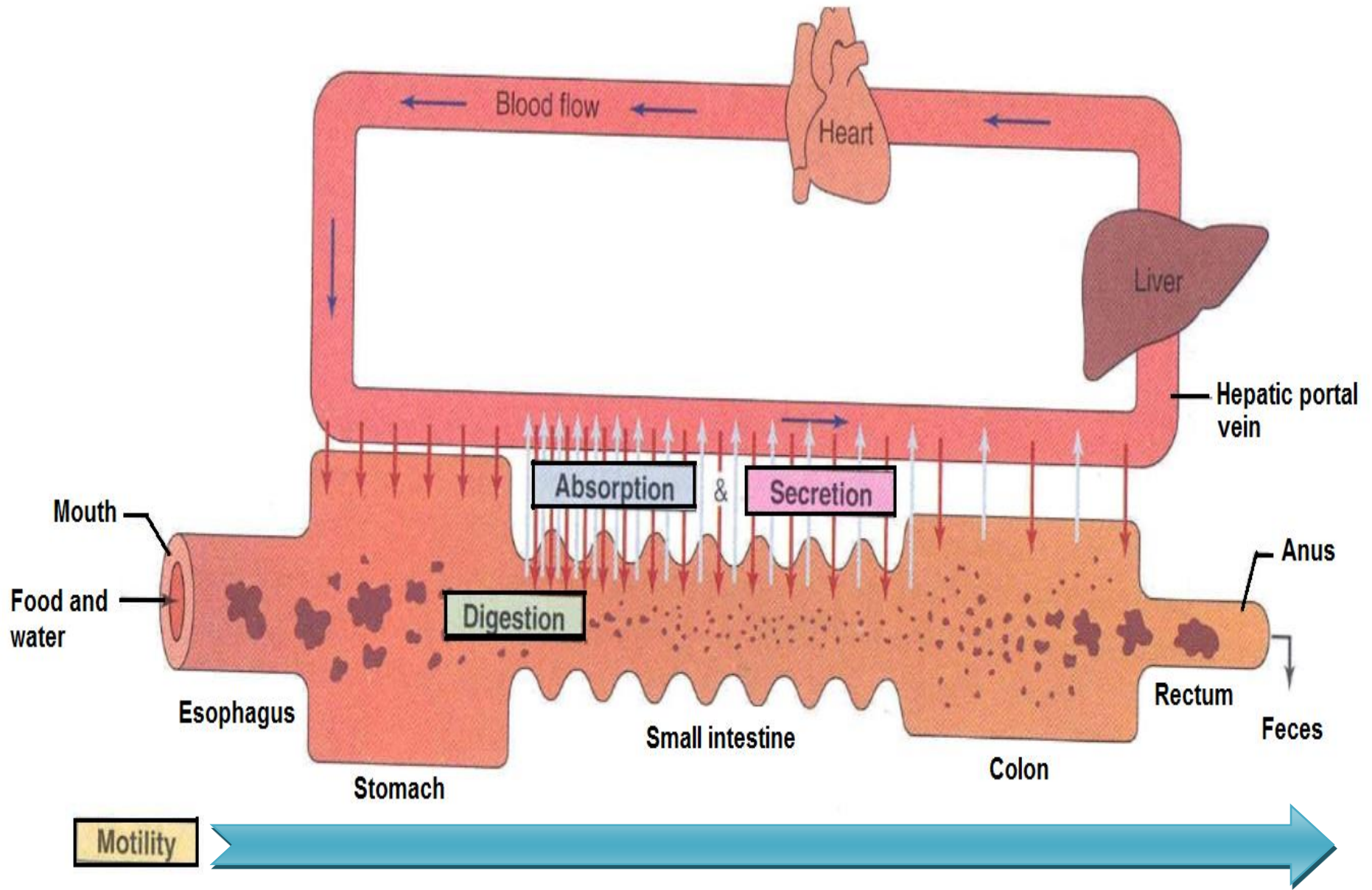
The alimentary tract provides the body with a continual supply of water, electrolytes, and nutrients.

To achieve this function, it requires

1. Movement of food through the alimentary tract (**motility**).
2. **Secretion** of digestive juices and **digestion** of the food
3. **Absorption** of water, various electrolytes, and digestive products
4. **Circulation** of blood through the gastrointestinal organs to carry away the absorbed substances

Control of all these functions is by local, nervous, and hormonal systems



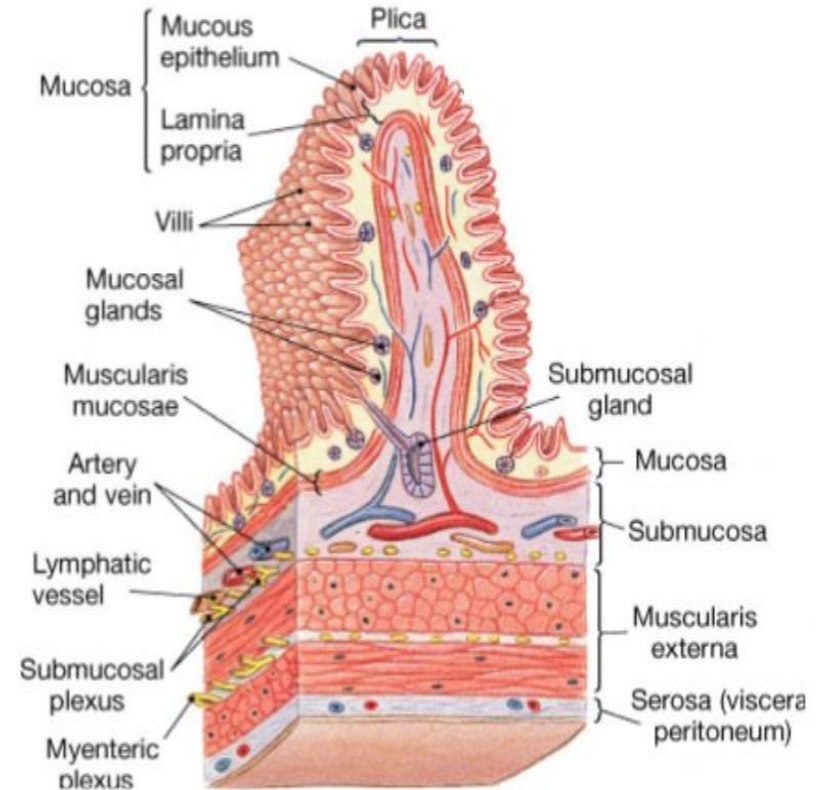


Four processes carried out by GIT, motility, secretion, digestion and absorption

# Physiologic Anatomy of the Gastrointestinal Wall

The following layers structure the GI wall from inner surface outward:

- ✓ The mucosa
- ✓ The submucosa
- ✓ Circular muscle layer
- ✓ longitudinal muscle layer
- ✓ The serosa.



In addition, sparse bundles of smooth muscle fibers, the *mucosal muscle*, lie in the deeper layers of the mucosa.



# THE GENERAL CHARACTERISTICS OF SMOOTH MUSCLE

## 1- Two smooth muscle classification

### ➤ Unitary type

- Contracts spontaneously in response to stretch and in the absence of neural or hormonal influence (such as in stomach and intestine)
- Cells are electrically coupled via gap junctions

### ➤ Multiunit type

- Contracts spontaneously in response to neural input, but not in response to stretch (such as in esophagus & gall bladder)





## 2- Types of contraction

### ✓ Phasic contractions (rhythmical)

- Periodic contractions followed by relaxation
- In esophagus, gastric antrum and small intestine.

### ✓ Tonic contractions

- Maintained contraction without relaxation
- In orad region of the stomach, lower esophageal, ileocecal and internal anal sphincters.



### 3- Two main smooth muscle layers

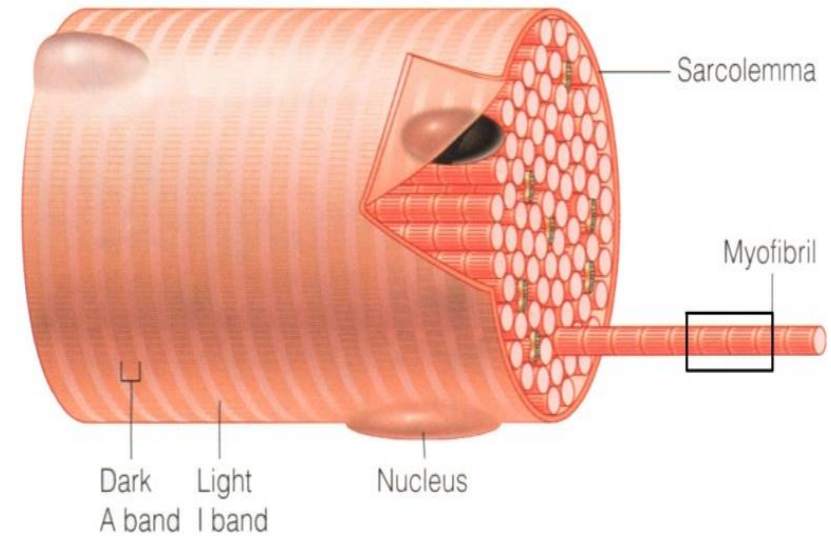
<b>Longitudinal</b>	<b>Circular</b>
Thinner and less powerful	Thicker and more powerful
Less gap junctions	More gap junctions
Contraction shortens the segment of the intestine and expands the lumen	Contraction reduces the diameter of the lumen and increases its length
Innervated by enteric nervous system (ENS), mainly by excitatory motor neurons	Innervated by ENS, both excitatory and inhibitory motor neurons
Ca <sup>++</sup> influx from outside is more important	Intracellular release of Ca <sup>++</sup> is more important



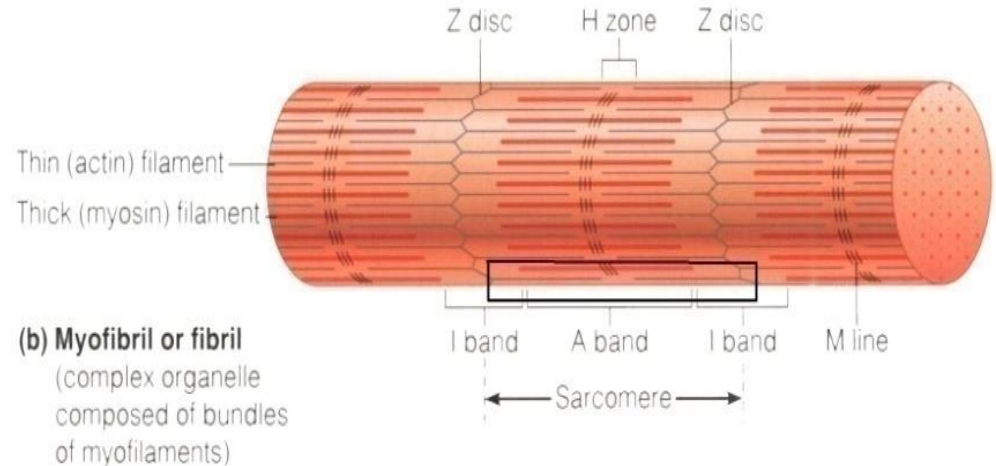
# THE SPECIFIC CHARACTERISTICS OF SMOOTH MUSCLE

## 1. Gastrointestinal Smooth Muscle Functions as a Syncytium:

- The smooth muscle fibers are arranged in bundles of as many as 1000 parallel fibers.
- They are 200 to 500  $\mu\text{m}$  in length and 2 to 10  $\mu\text{m}$  in diameter.



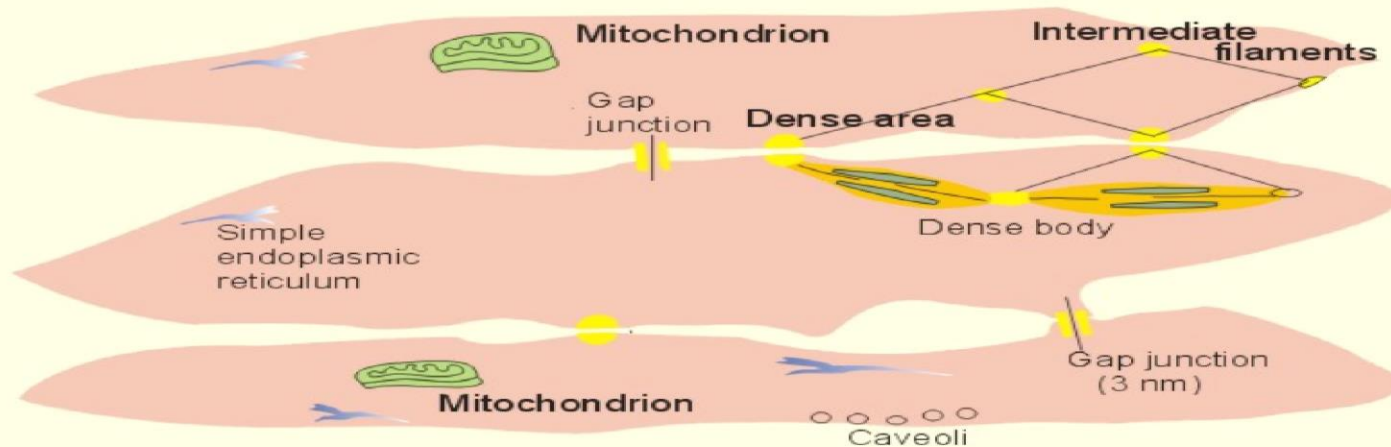
(a) Segment of a muscle fiber (cell)



(b) Myofibril or fibril  
(complex organelle  
composed of bundles  
of myofilaments)

- Within each bundle, the muscle fibers are electrically connected with one another through large numbers of *gap junctions* .

Structure of Visceral Smooth Muscle Cells



Electrical syncytium by Gap junctions

- Each bundle of smooth muscle fibers is partly separated from the next by loose connective tissue but they fuse with one another at many points, so each muscle layer represents a branching latticework of smooth muscle bundles.
- Each muscle layer functions as a *syncytium*; when an action potential is elicited anywhere within the muscle mass, it generally travels in all directions in the muscle.



## 2. Electrical Activity of Gastrointestinal Smooth Muscle:

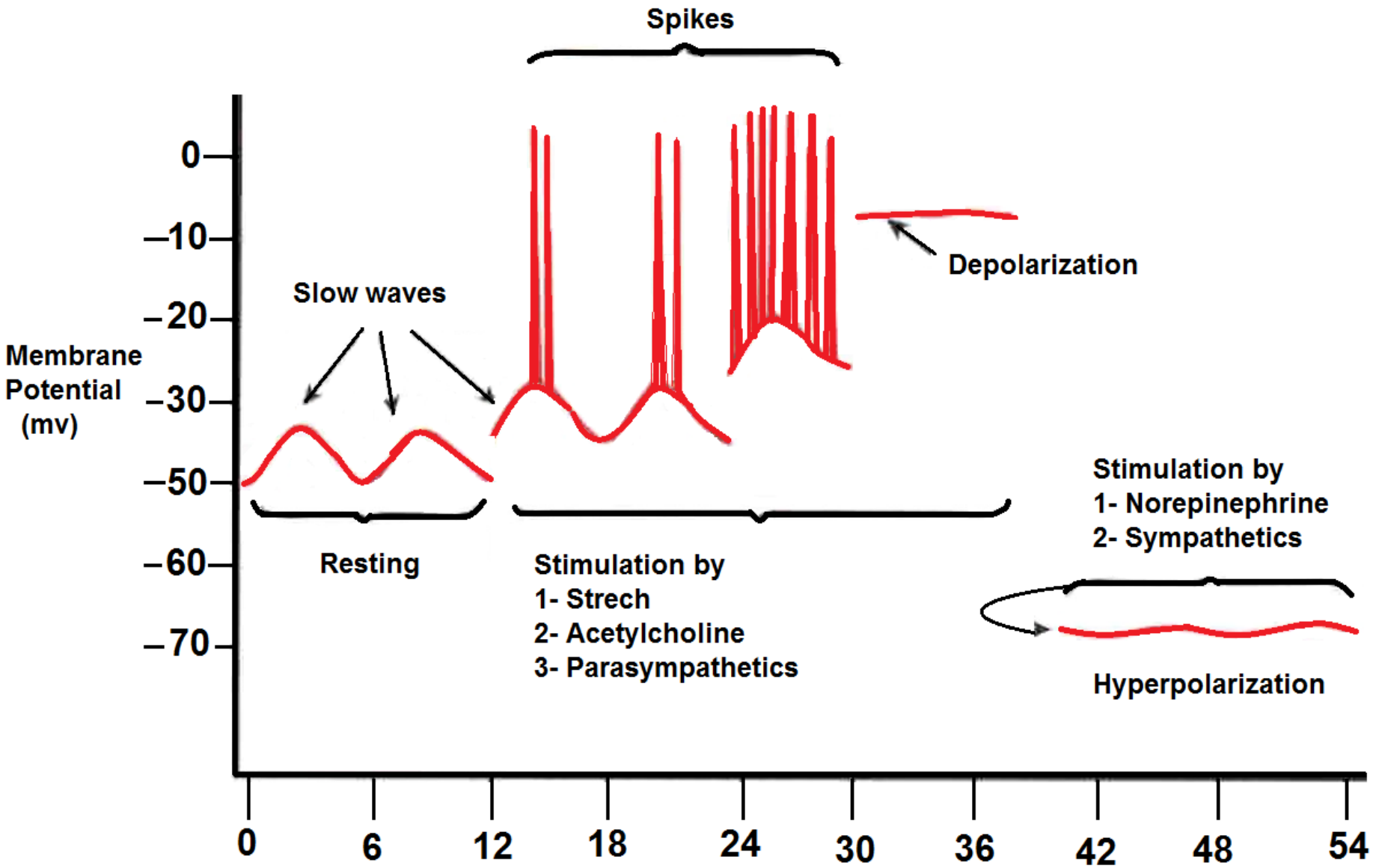
- The smooth muscle of the gastrointestinal tract is excited by almost continual slow, intrinsic electrical activity along the membranes of the muscle fibers.
- This activity has two basic types of electrical waves:
  - (a) *Slow waves*
  - (b) *Spikes.*



## A- The slow waves- basic electrical rhythm

- They are slow spontaneous change in RMP (cyclic waves of depolarization & repolarization).
- Their intensity varies between 5-15 mv.
- Their frequency ranges between **3/min**. in stomach body to **12/min** in duodenum and change to **8/min**. in terminal ileum.
- They do not directly cause contraction.
- Spikes of action potential are superimposed on the depolarization phase of slow waves followed by contraction



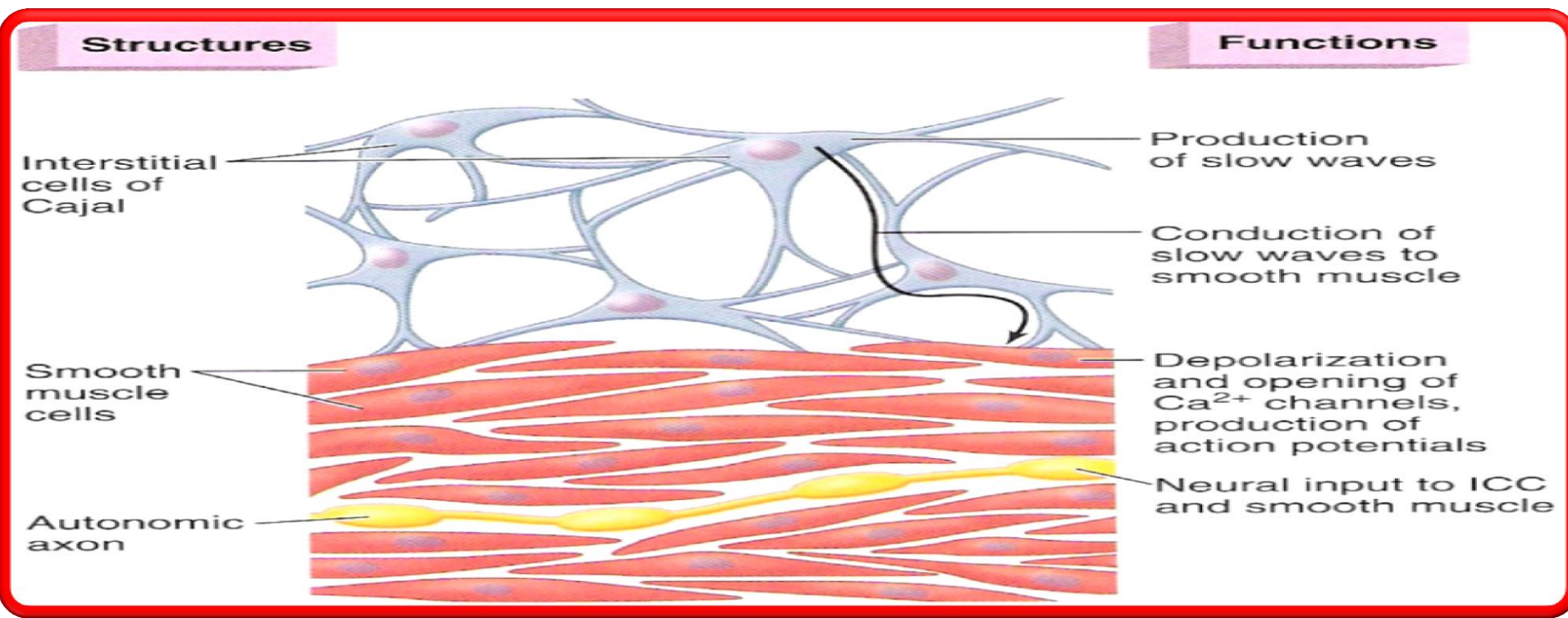


**Membrane potentials in intestinal smooth muscles**



\* They are generated by **interstitial cells of Cajal, ICC** (the GI pacemaker), located between the longitudinal & circular muscle layers. These form a network with each other and are interposed between the smooth muscle layers, with synaptic-like contacts to smooth muscle cells.

\* Parasympathetic  $\uparrow$  the amplitude and frequency of slow waves. Sympathetic  $\downarrow$  their amplitude and frequency.



## *B- THE SPIKE POTENTIALS*

- \* They are true action potentials that occur when RMP rises above -40 mv [RMP= -50- (-60) mv].
- \* They are more prolonged than those of skeletal muscles.
- \* The rising phase of AP is caused by  $\text{Ca}^{++}$  and  $\text{Na}^{+}$  inflow through the channels that allow especially large numbers of  $\text{Ca}^{++}$  to enter along with smaller numbers of  $\text{Na}^{+}$  ( $\text{Ca}^{++}$ - $\text{Na}^{+}$  channels). They open slowly.  $\text{Ca}^{++}$  that enters cells helps to initiate contraction.  
(N.B: slow waves do not cause  $\text{Ca}^{++}$  entry).
- \* They usually do not propagate more than a few mm. Instead slow waves are propagated & spike potentials occur at the peak of slow waves.
- \* The higher the slow wave potential rises, the greater the frequency of the spike potentials, usually ranging between 1 and 10 spikes per second.



### 3. Changes in Voltage of the Resting Membrane Potential.

The resting membrane potential ranges from (-50) to (-60) mv but multiple factors can change this level:-

- When the membrane potential becomes less negative (*depolarization*), the muscle fibers become more excitable.
- When the membrane potential becomes more negative (*hyperpolarization*), the fibers become less excitable.



### **Factors that depolarize the membrane (more excitable):**

- (1) Stretching of the muscle.
- (2) Stimulation by Ach.
- (3) Stimulation by parasympathetic nerves that secrete Ach at their endings.
- (4) Stimulation by several specific GI hormones.

### **Factors that hyperpolarize the membrane (less excitable):**

- (1) Norepinephrine or epinephrine
- (2) Stimulation of the sympathetic nerves that secrete mainly norepinephrine at their endings.

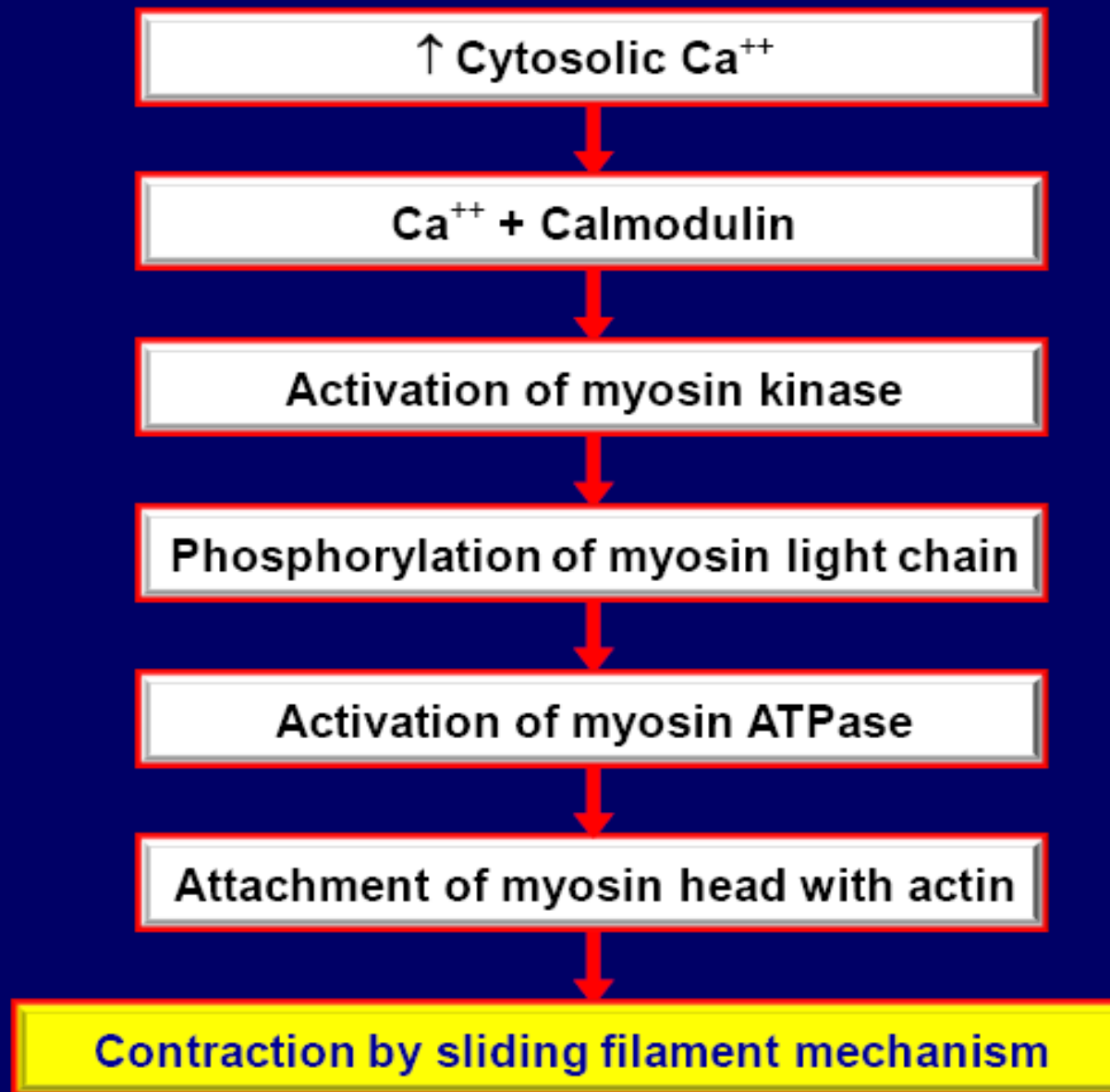


## 4. Calcium Ions and Muscle Contraction.

- ❖ Smooth muscle contraction occurs in response to entry of  $\text{Ca}^{++}$  into the muscle fiber.
- ❖ The slow waves do not cause  $\text{Ca}^{++}$  to enter the smooth muscle fiber (only  $\text{Na}^+$ ). Therefore, the slow waves by themselves usually cause no muscle contraction.
- ❖ Instead, it is during the spike potentials, generated at the peaks of the slow waves, that significant quantities of  $\text{Ca}^{++}$  do enter the fibers and cause most of the contraction.



# Mechanism of smooth muscle contraction



## 5. Tonic Contraction of Some GI Smooth Muscle.

- It is continuous, **not associated with the basic electrical rhythm of the slow waves** but often lasting several minutes or even hours.
- It is sometimes caused by:
  1. Continuous repetitive spike potentials.
  2. Hormones.
  3. Continuous entry of  $\text{Ca}^{++}$  into the interior of the cell brought about in ways not associated with changes in membrane potential.



# **CONTROL OF GIS FUNCTIONS**

## **I- Neural control**

- \* Autonomic (extrinsic) nervous system
- \* The enteric nervous system

## **II- Hormonal control**





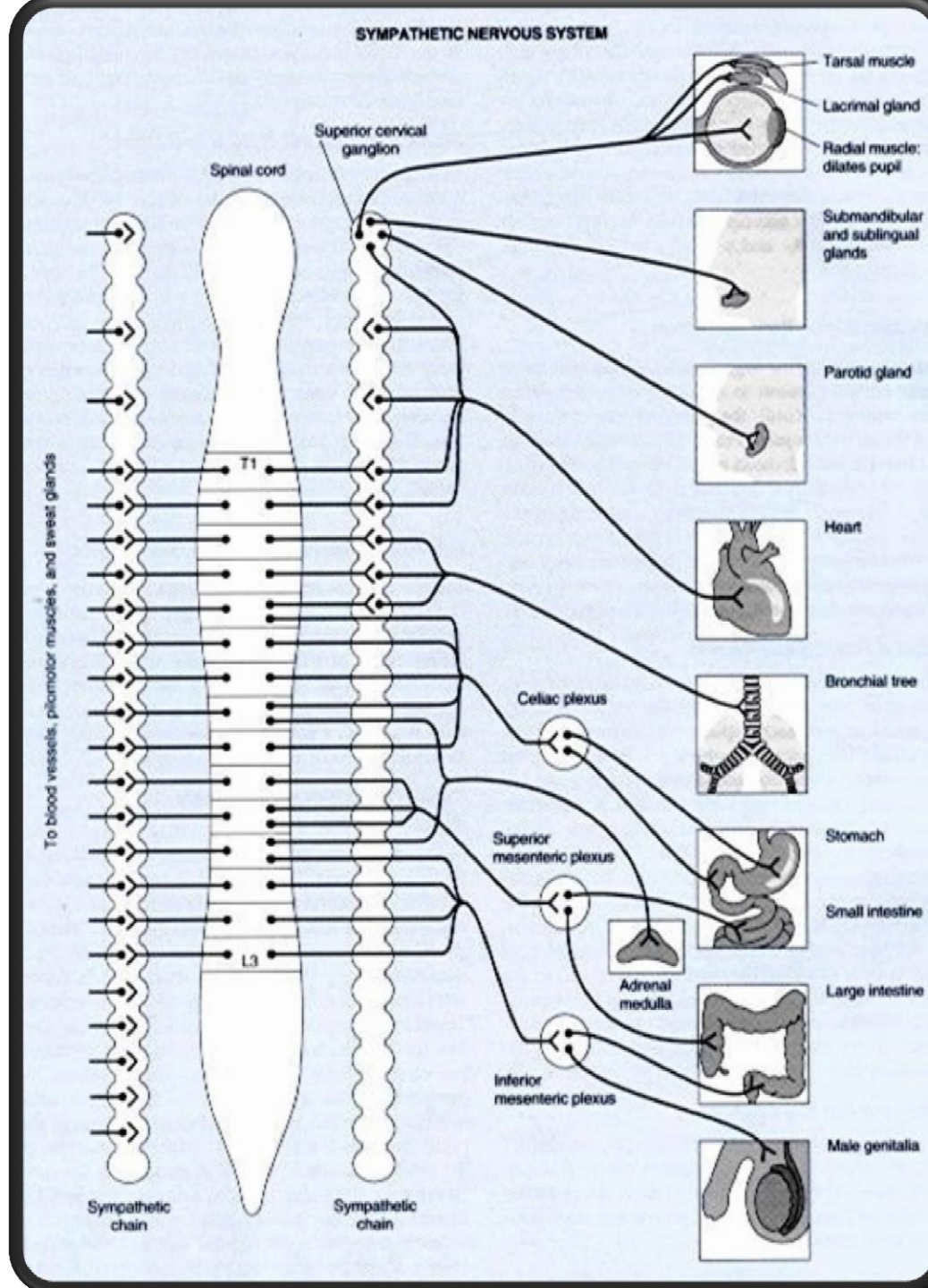
# I- Autonomic control (the extrinsic nervous system):

A- Sympathetic (What is its function?)

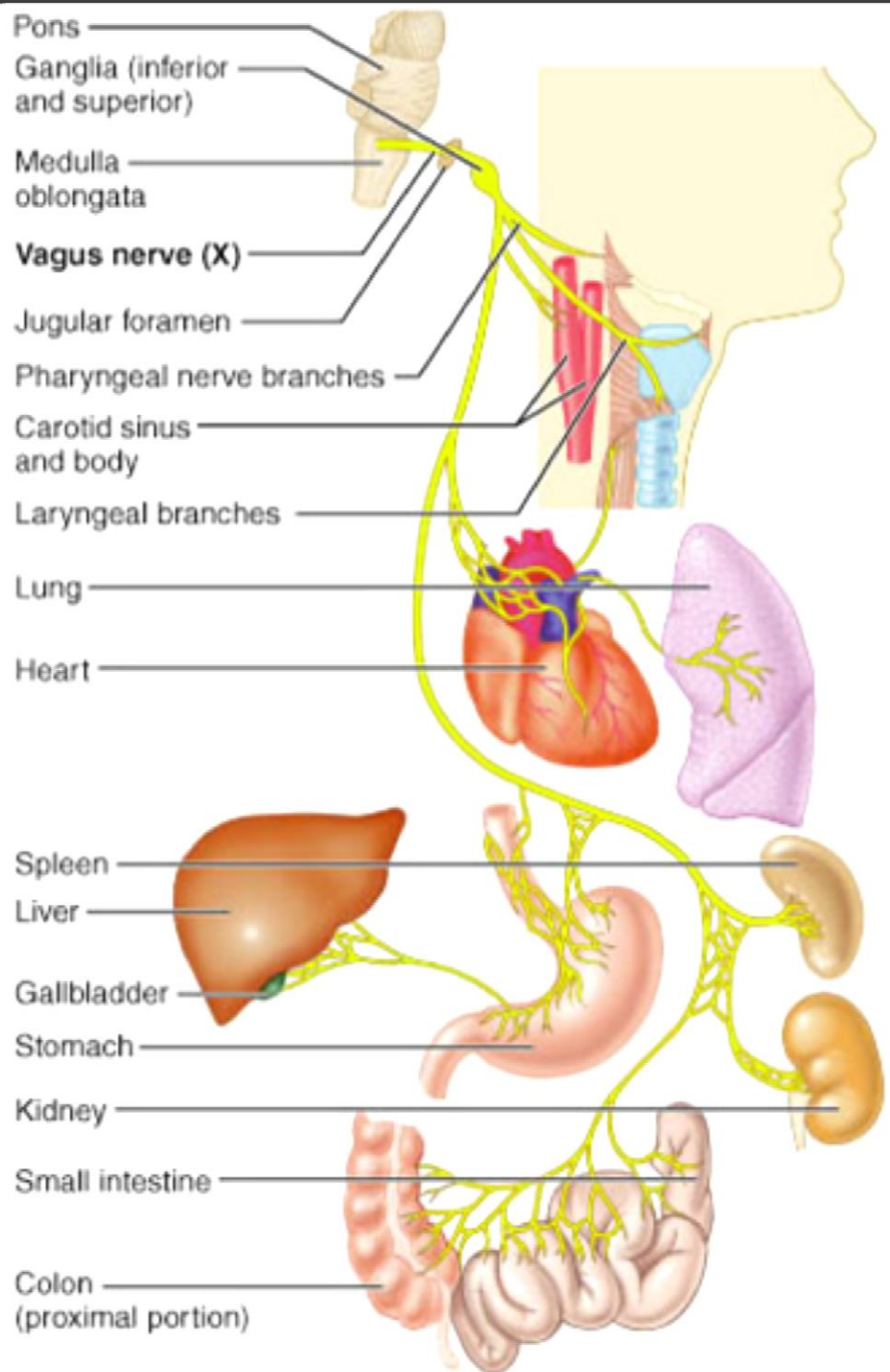
B- Parasympathetic (What is its function?)



# SYMPATHETIC INNERVATION



# PARASYMPATHETIC INNERVATION



# ENTERIC NERVOUS SYSTEM

- *Enteric Nervous System* is the nervous system of GI tract.
- It lies entirely in the wall of the gut, beginning in the esophagus and extending all the way to the anus.
- It has as many neurons as spinal cord (about 100 million).



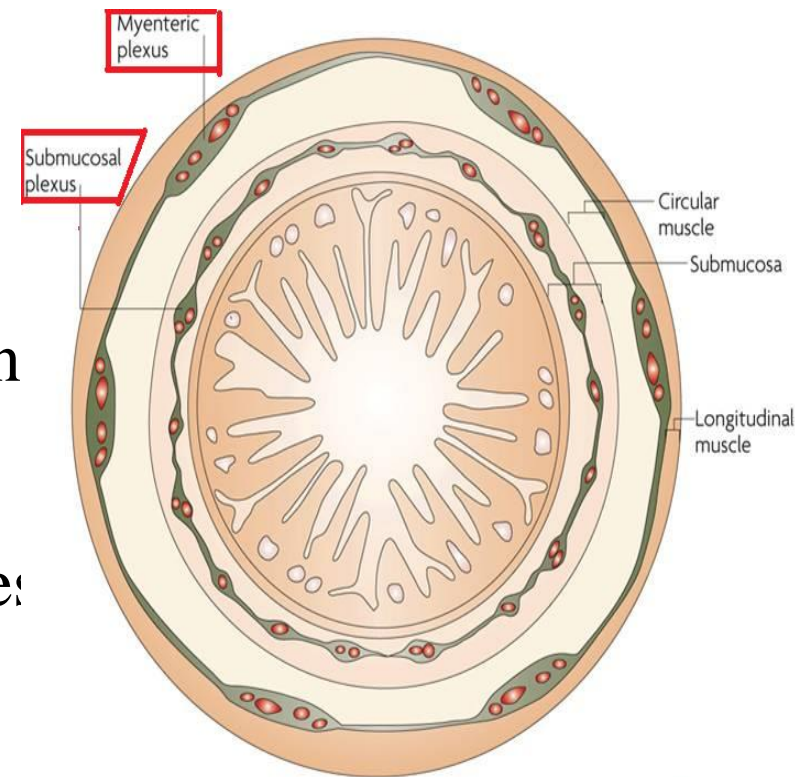
# ENTERIC NERVOUS SYSTEM

It is composed mainly of two plexuses:

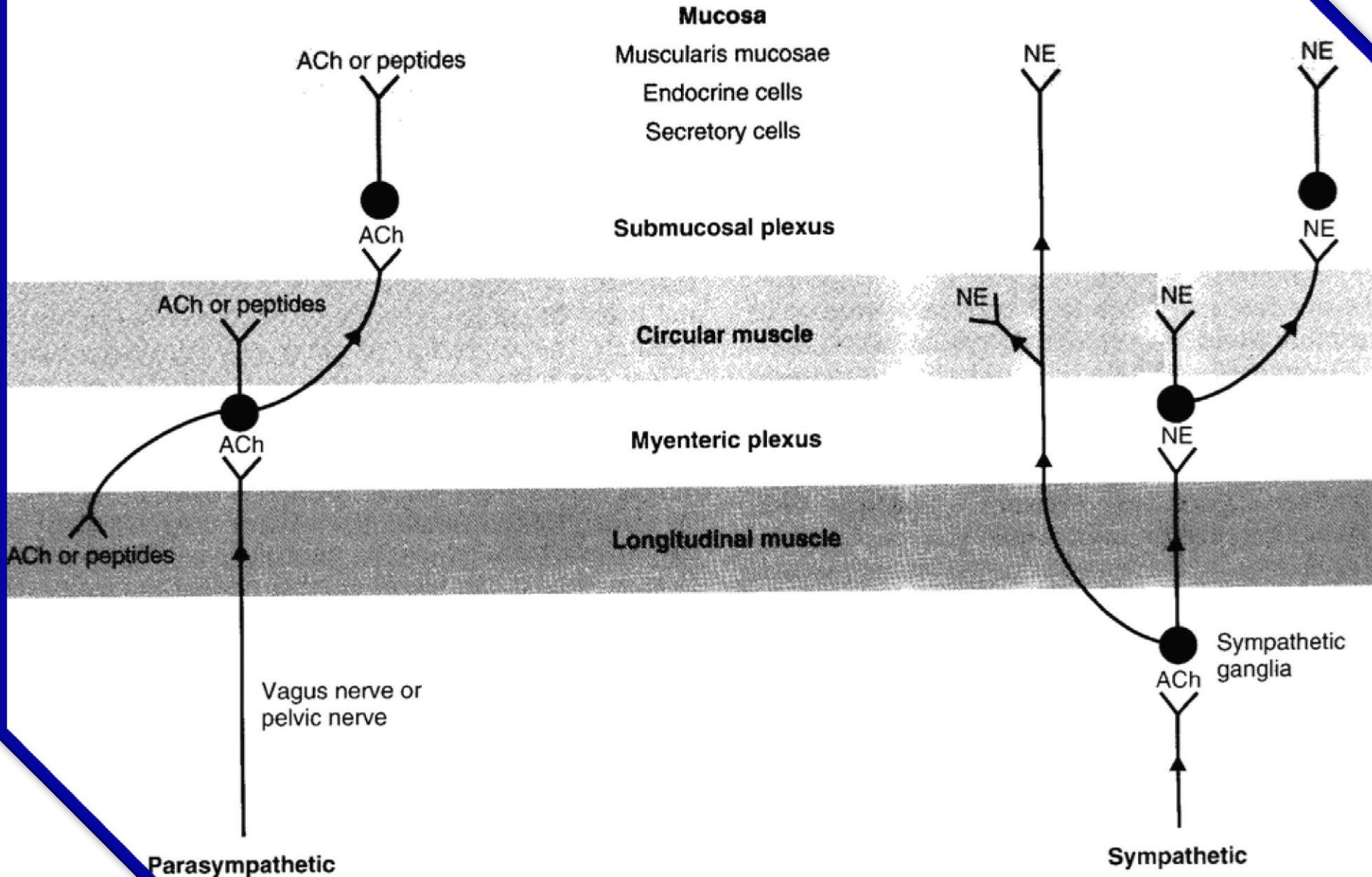
(1) The *myenteric (Auerbach's)* plexus lies between the longitudinal and circular muscle layers.

(2) The *submucosal (Meissner's)* plexus lies in the submucosa.

The enteric nervous system can function on its own, independently of the parasympathetic and sympathetic systems, however, these extrinsic nerves can greatly enhance or inhibit gastrointestinal functions.



# EXTRINSIC NERVOUS SYSTEM



## Mucosa

Muscularis mucosae  
Endocrine cells  
Secretory cells

## Submucosal plexus

## Circular muscle

## Myenteric plexus

## Longitudinal muscle

Parasympathetic

Sympathetic

## DIFFERENCES BETWEEN THE MYENTERIC AND SUBMUCOSAL PLEXUSES

### The *myenteric plexus*

- When it is stimulated, its principal effects are:
  - (1) Increased tonic contraction
  - (2) Increased intensity of the rhythmical contractions
  - (3) Increased rate of the rhythm of contraction
  - (4) Increased velocity of conduction of excitatory waves along gut wall
- It has *excitatory* and *inhibitory* motor neurons (fiber endings secrete an inhibitory transmitter, e.g., *vasoactive intestinal polypeptide*)

### The *submucosal plexus*

- Controls local *intestinal secretion*, local *absorption*, and local *contraction of the submucosal muscle* that causes various degrees of infolding of the gastrointestinal mucosa.



# TYPES OF NEUROTRANSMITTERS SECRETED BY ENTERIC NEURONS

- The specific functions of many of GI neurotransmitters are not well known, but some research workers have discovered the effects of some of these substances as following:

## **1. Excitatory Motor Neurons Evoke Muscle Contraction & Intestinal Secretion:**

### **A. Neurotransmitters of motor neurons:**

- i. Substance P
- ii. Ach

### **B. Neurotransmitters of secretomotor neurons (releasing of water, electrolytes and mucus from crypts of Lieberkuhn):**

- i. Ach
- ii. VIP
- iii. Histamine





## 2. Inhibitory Motor Neurons Suppress Muscle Contraction:

Neurotransmitters:

i. ATP

ii. NO

iii. VIP



**TABLE 8-1. Neurotransmitters and Neuromodulators in the Enteric Nervous System**

Substance	Source	Actions
Acetylcholine (ACh)	Cholinergic neurons	Contraction of smooth muscle in wall Relaxation of sphincters ↑ Salivary secretion ↑ Gastric secretion ↑ Pancreatic secretion
Norepinephrine (NE)	Adrenergic neurons	Relaxation of smooth muscle in wall Contraction of sphincters ↑ Salivary secretion
Vasoactive intestinal peptide (VIP)	Neurons of mucosa and smooth muscle	Relaxation of smooth muscle ↑ Intestinal secretion ↑ Pancreatic secretion
Gastrin-releasing peptide (GRP) or bombesin	Neurons of gastric mucosa	↑ Gastrin secretion
Enkephalins (opiates)	Neurons of mucosa and smooth muscle	Contraction of smooth muscle ↓ Intestinal secretion
Neuropeptide Y	Neurons of mucosa and smooth muscle	Relaxation of smooth muscle ↓ Intestinal secretion
Substance P	Cosecreted with ACh	Contraction of smooth muscle ↑ Salivary secretion

## II- THE HORMONAL CONTROL (THE GUT AS AN ENDOCRINE ORGAN)

- ❖ Endocrine cells are located in the pancreas, in the mucosa and submucosa of the stomach and intestine.
- ❖ They produce hormones that act on the secretory cells located in the wall of GIT, in the pancreas or in the liver to alter the rate or composition of their secretion.
- ❖ Other hormones act on smooth muscle cells or on sphincters.
- ❖ All the GI hormones are peptide such as gastrin, secretin and cholecystokinin.



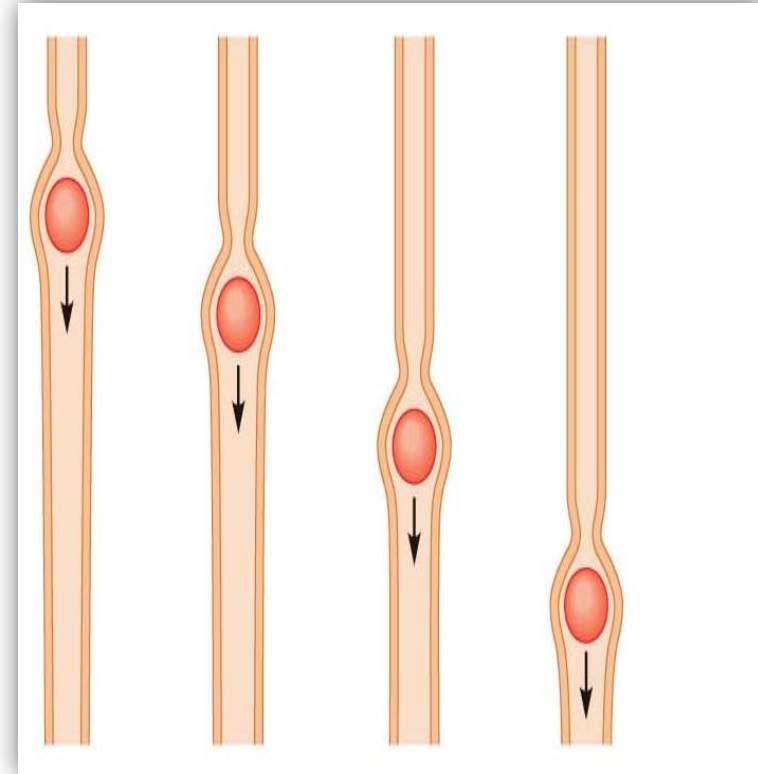
<b>Hormone</b>	<b>Site of Secretion</b>	<b>Stimuli for Secretion</b>	<b>Actions</b>
<b>Gastrin</b>	"G" cells of the stomach	Small peptides and amino acids Distention of the stomach Vagal stimulation (GRP)	↑ Gastric H <sup>+</sup> secretion Stimulates growth of gastric mucosa
<b>Cholecystokinin (CCK)</b>	"I" cells of the duodenum and jejunum	Small peptides and amino acids Fatty acids	↑ Pancreatic enzyme secretion ↑ Pancreatic HCO <sub>3</sub> <sup>-</sup> secretion Stimulates contraction of the gallbladder and relaxation of the sphincter of Oddi Stimulates growth of the exocrine pancreas and gallbladder Inhibits gastric emptying
<b>Secretin</b>	"S" cells of the duodenum	H <sup>+</sup> in the duodenum Fatty acids in the duodenum	↑ Pancreatic HCO <sub>3</sub> <sup>-</sup> secretion ↑ Biliary HCO <sub>3</sub> <sup>-</sup> secretion ↓ Gastric H <sup>+</sup> secretion Inhibits trophic effect of gastrin on gastric mucosa
<b>Glucose-Dependent Insulinotropic Peptide (GIP)</b>	"K" cells of the Duodenum and jejunum	Fatty acids Amino acids Oral glucose	↑ Insulin secretion from pancreatic β cells ↓ Gastric H <sup>+</sup> secretion
<b>Motilin</b>	"M" cells of the stomach	Fat, Acid, Nerve	Stimulates Gastric motility

# FUNCTIONAL TYPES OF MOVEMENTS IN GIT

- Two types of movements occur in the GIT:

## 1) *Propulsive movements (peristalsis)*

- Organizes propulsion of material over variable distances within the GI lumen
- A contraction ring appears around gut, then moves forward.
- Usual stimulus is distention. Other stimuli include chemical or physical irritation of the epithelial lining in the gut.
- Myenteric plexus is important
- Atropine (cholinergic blocker) depresses propulsion.



# Peristaltic Reflex and the "Law of the Gut."

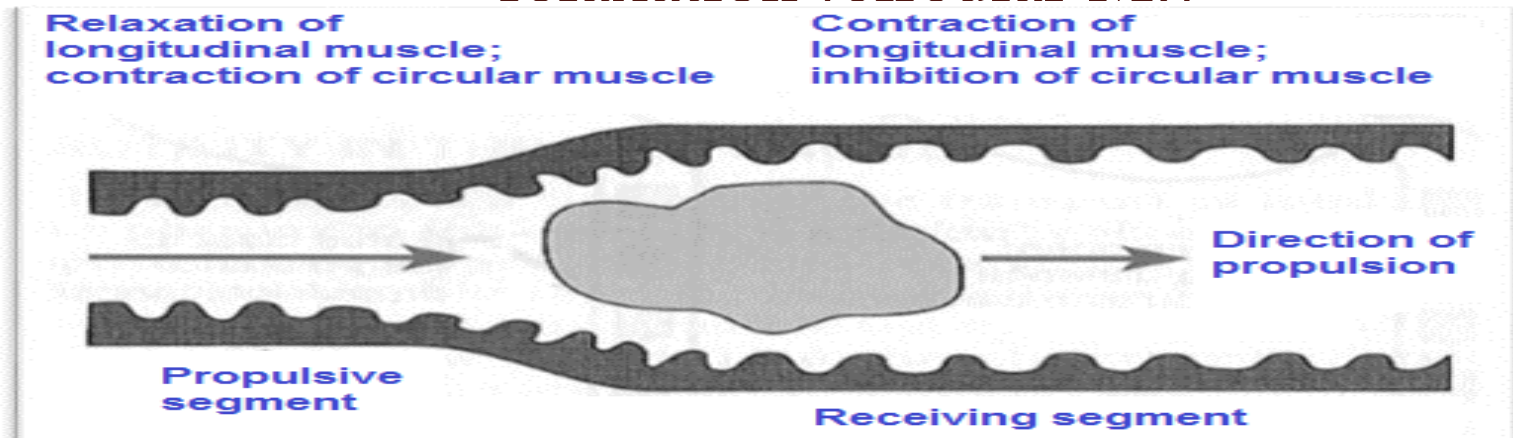
When a segment of the intestinal tract is excited by distention and thereby initiates peristalsis, the contractile ring normally begins on the orad side of the distended segment and moves toward the distended segment, pushing the intestinal contents in the anal direction for 5 to 10 cm. before dying out.

Propulsive segment---contraction (circular M.)

----relaxation (longitudinal M.)

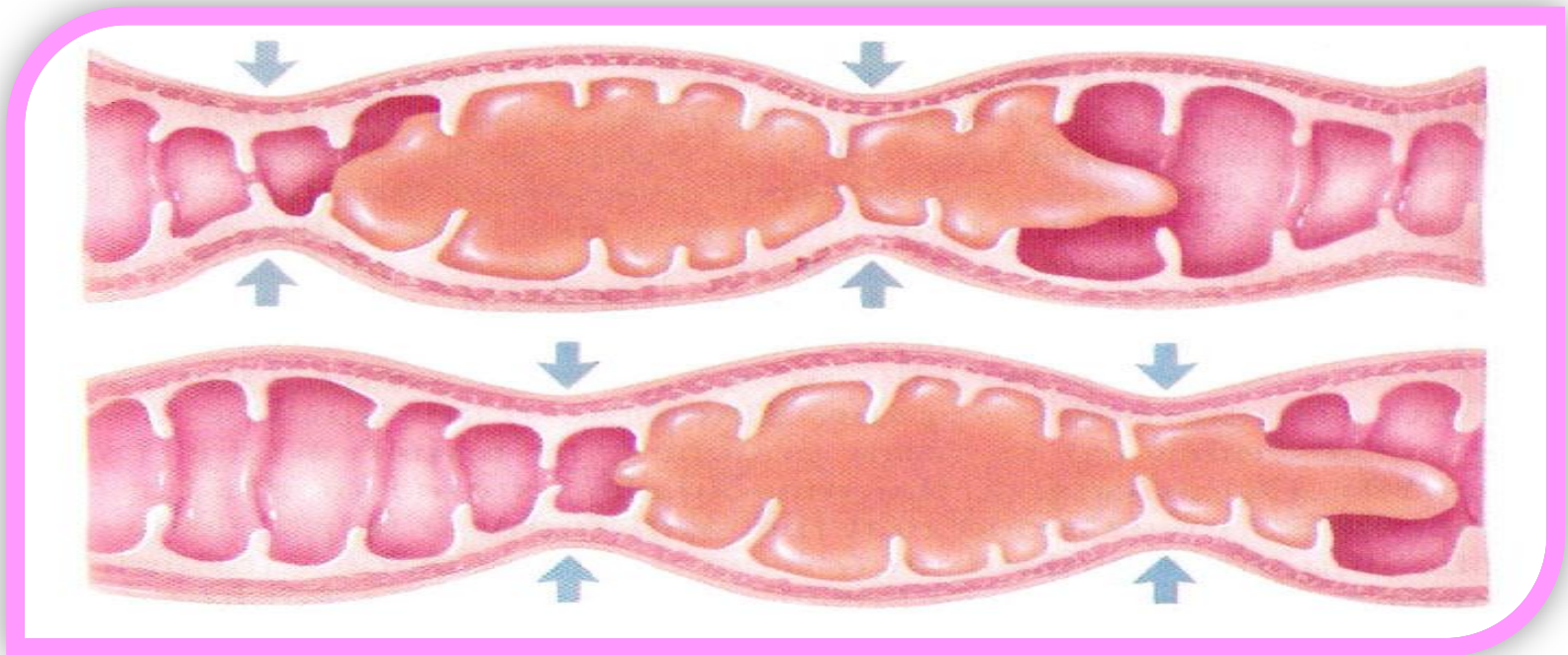
Receiving segment---contraction (longitudinal M.)

---relaxation (circular M.)



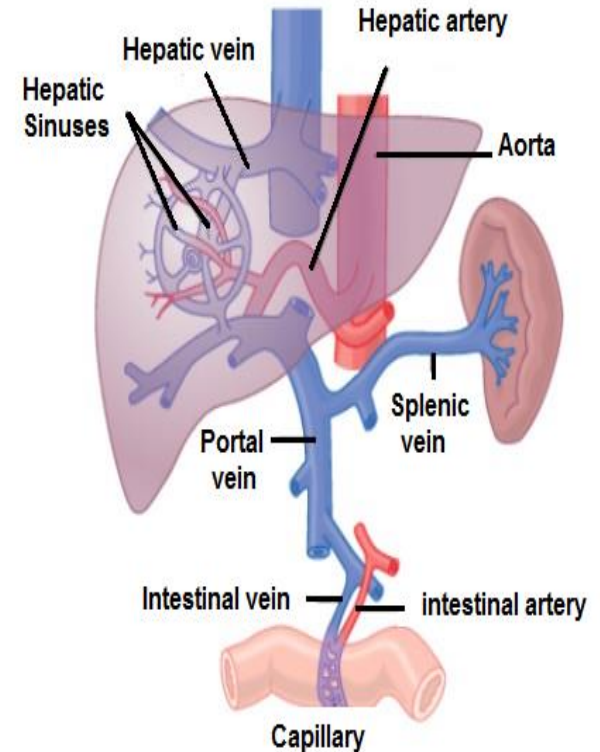
## 2) Mixing movements (segmentation)

- Blend different juices with the chyme
- Bring products of digestion in contact with absorptive surfaces



# GASTROINTESTINAL BLOOD FLOW- "SPLANCHNIC CIRCULATION"

- It includes the blood flow through the gut itself, the spleen, pancreas, and liver.
- All blood then flows into the liver by way of the *portal vein*
- In the liver, the blood passes through *liver sinusoids* and finally leaves the liver by way of *hepatic veins* that empty into the vena cava of the general circulation.





# EFFECT OF GUT ACTIVITY AND METABOLIC FACTORS ON GASTROINTESTINAL BLOOD FLOW

Causes of the increased blood flow during GI activity

1. Most of the peptide hormones, including *cholecystokinin*, *vasoactive intestinal peptide*, *gastrin*, and *secretin*.
2. Kinins (*kallidin* and *bradykinin*) released into the gut wall from some of the GI glands.
3. *Decreased oxygen concentration* in the gut wall (increase blood flow 50 to 100 %).



# NERVOUS CONTROL OF GASTROINTESTINAL BLOOD FLOW

- Parasympathetic stimulation increases local blood flow and glandular secretion.
- Sympathetic stimulation to causes intense vasoconstriction with greatly decreased blood flow. But the local metabolic vasodilator mechanisms override the sympathetic vasoconstriction effects, returning the normal blood flow to GI muscle and glands.



THANK YOU

