HUMAN PHYSIOLOGY (normal)

LECTURE 15. The Physiology of Digestion

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Introduction

Digestion is defined as the process by which **food is broken down** into **simple chemical substances** that can be **absorbed** and used as nutrients by the body

Functions of digestive system:

- Ingestion or **consumption** of food substances
- **Mechanical processing** (by muscles contraction) and **chemical** (enzymatic) **breakdown** of food
- **Secretion** of necessary enzymes and other substances for digestion
- **Absorption** of the digestive products (nutrients)
- **Excretion** - removal of waste products from body

Control of Digestive Function

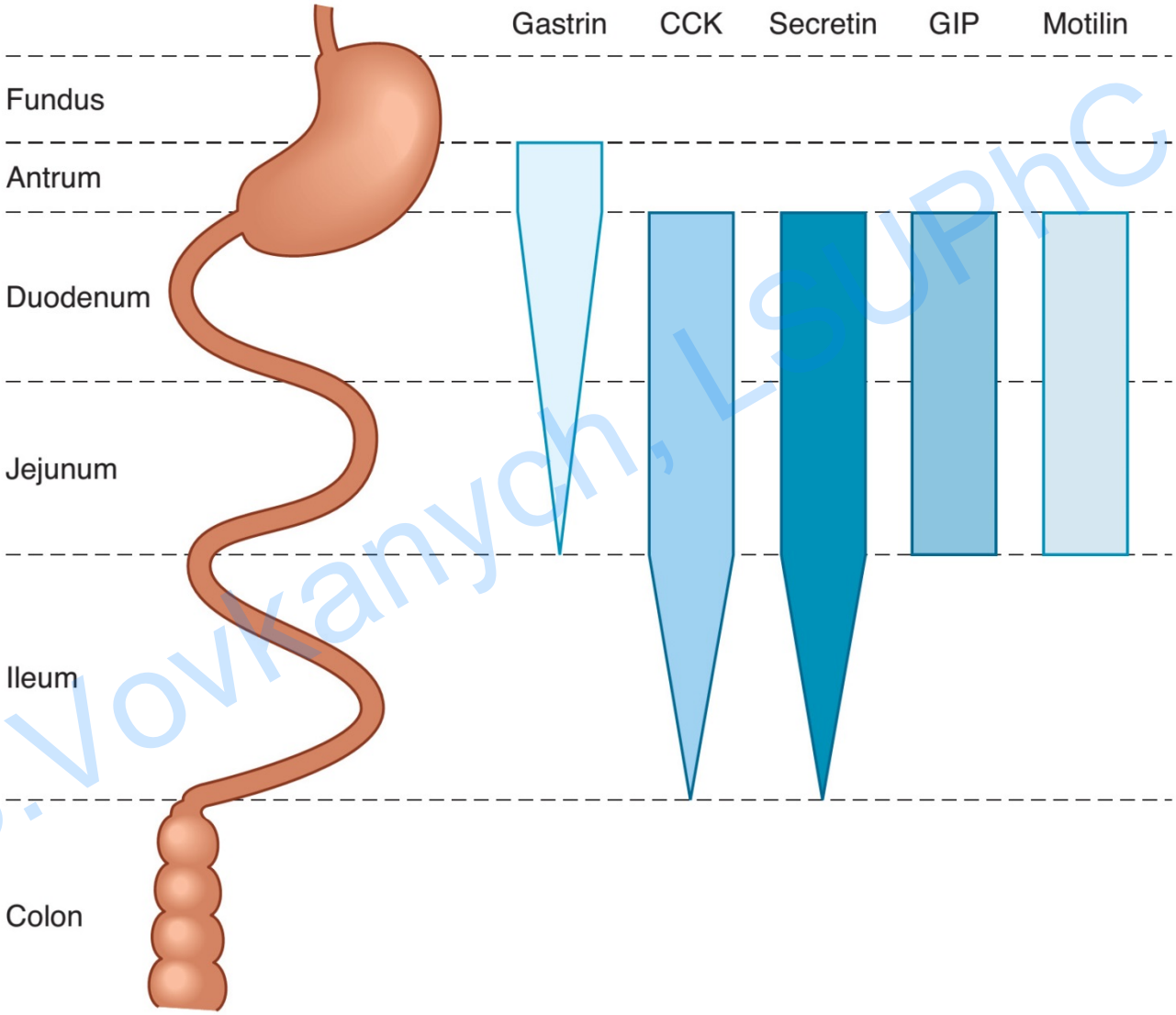
Neural mechanisms control

- **short reflexes** are responsible for local reflexes (stretch receptors and chemoreceptors), control small segments of digestive tract, operate entirely outside of CNS control
- **long reflexes** - higher level control of digestive and glandular activities, control large-scale peristaltic waves, involve interneurons and motor neurons in CNS

Hormonal mechanisms

- at least **18 peptide hormones** that affect most aspects of digestive function
- are produced by **enteroendocrine cells** in digestive tract
- reach **target organs** after distribution in bloodstream

Some Hormones of GI Tract



Nerve Supply to Gastrointestinal Tract

Enteric nervous system (contain nerve cell bodies) is present within the wall of gastrointestinal tract, formed by

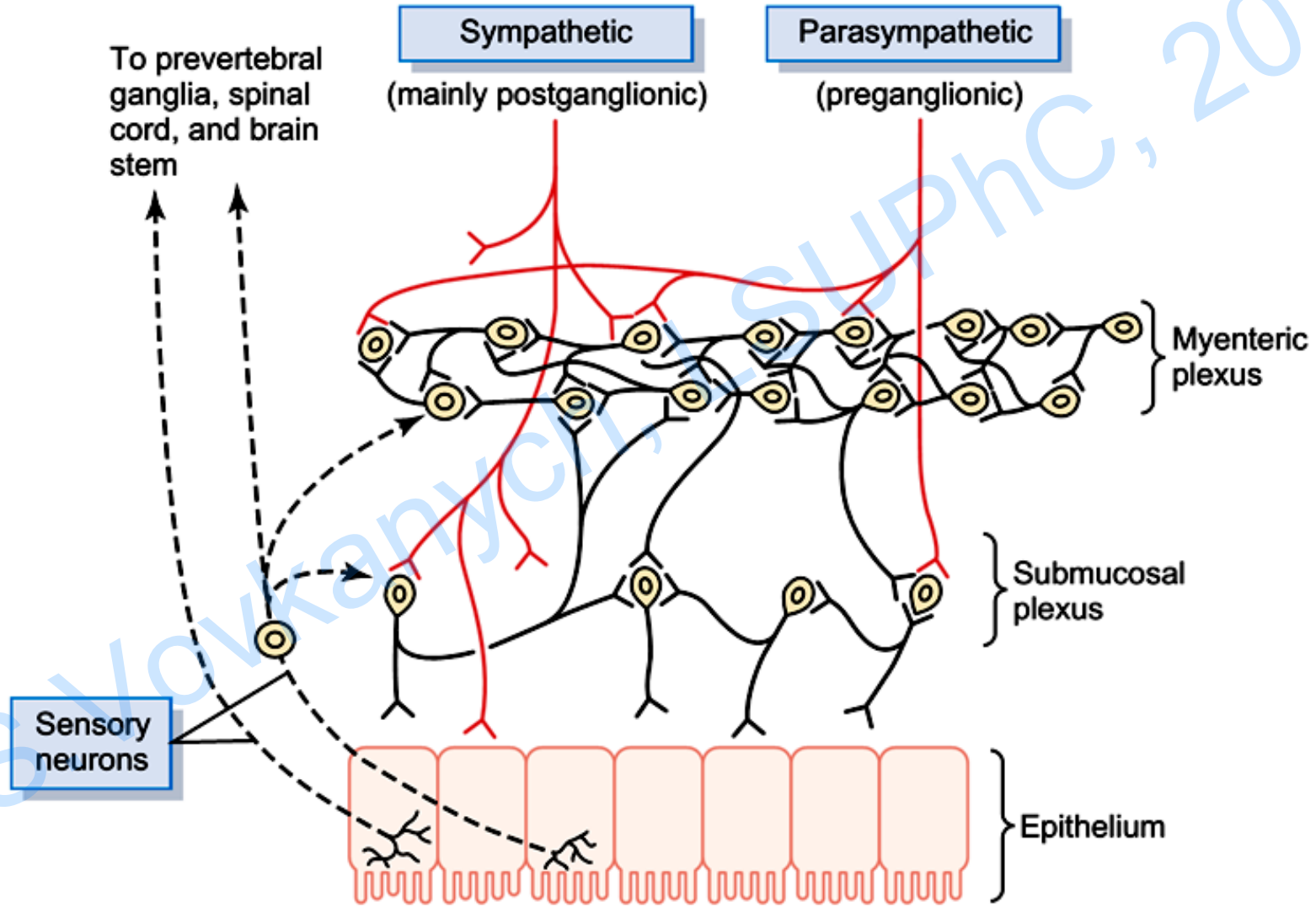
- **Myenteric** (Auerbach) plexus – mainly regulate the movements of GI tract.
- **Submucosal** (Meissner) plexus – mainly regulate the secretory functions of GI tract

- Enteric nervous system is controlled by extrinsic nerves from **autonomic nervous system**

Nerve Supply to Gastrointestinal Tract

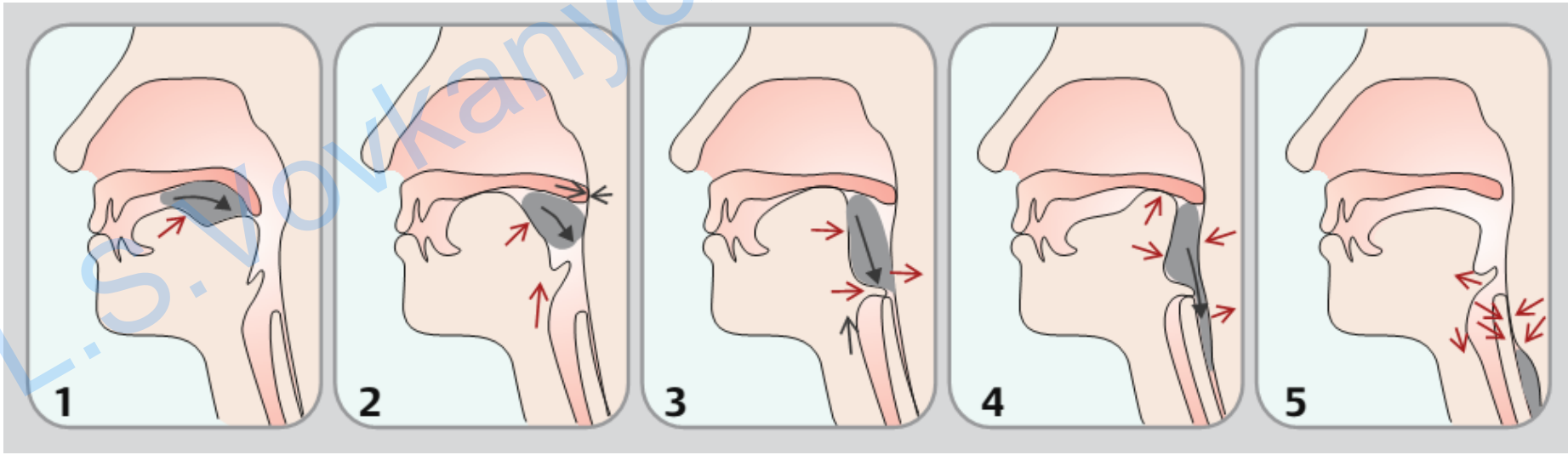
- **Preganglionic sympathetic** nerve fibers to GI tract arise from T5 to L2, terminate in the celiac and mesenteric ganglia.
- **Postganglionic fibers** from these ganglia are distributed throughout the GI tract
- Sympathetic nerve fibers **inhibit** the **movements** and **decrease** the **secretions** of GI tract
- **Preganglionic parasympathetic** nerve fibers to mouth and salivary glands pass through **facial** and **glossopharyngeal** nerves
- **Preganglionic** parasympathetic nerve fibers to **esophagus**, **stomach**, **small intestine** and **upper part of large intestine** pass through **vagus** nerve
- **Preganglionic** nerve fibers to **lower part of large intestine** arise from S2-S4
- **Parasympathetic** nerve fibers **accelerate** the **movements** and **increase** the **secretions** of GI tract

Neural Control of the GI Tract



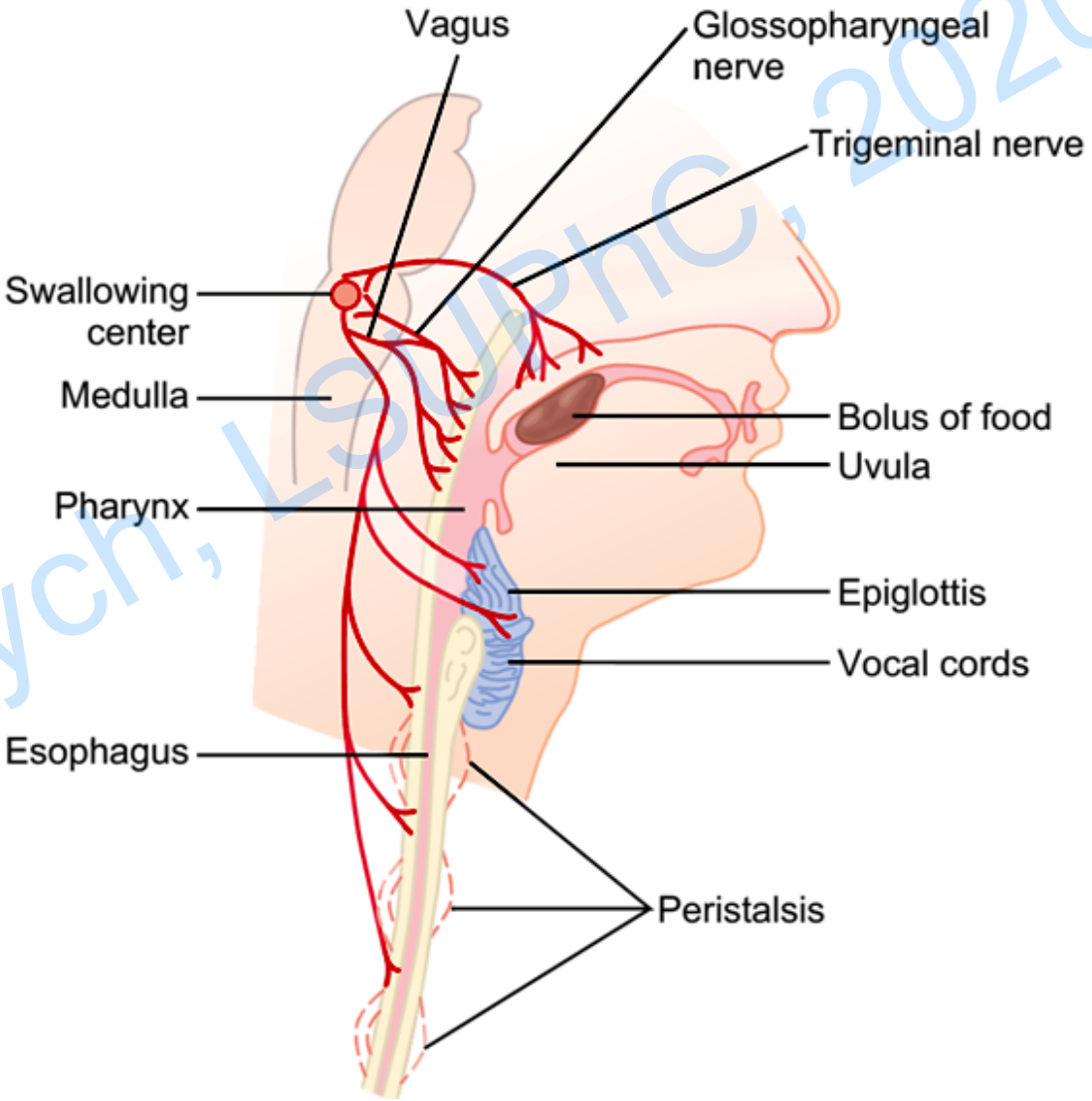
Mechanical processing

- In the mouth, food is **mixed** with saliva and **propelled** into the esophagus
- **Chewing** (mastication) breaks up large food particles and mixes the food with the secretions of the salivary glands – the **bolus** is formed
- **Swallowing** (deglutition) is a reflex starts with a wave of involuntary contraction in the pharyngeal muscles that pushes the material into the esophagus



Swallowing

- **Voluntary** stage, which initiates the swallowing process
- **Pharyngeal** (involuntary) stage - passage of food through the pharynx into the esophagus
- **Esophageal** stage, involuntary phase that transports food from the pharynx to the stomach



The Movement of Digestive Materials

Movements (motility) are performed by muscular layers of digestive tract, which consist of **visceral smooth muscle** tissue (except for the oral cavity, pharynx and external sphincter of rectum)

Along digestive tract smooth muscles has rhythmic cycles of activity controlled by **pacesetter** cells, located in muscularis mucosae and muscularis externa

The smooth muscles are controlled by **Enteric Nervous System** (ENS), mainly by the **myenteric plexus** (plexus of Auerbach)

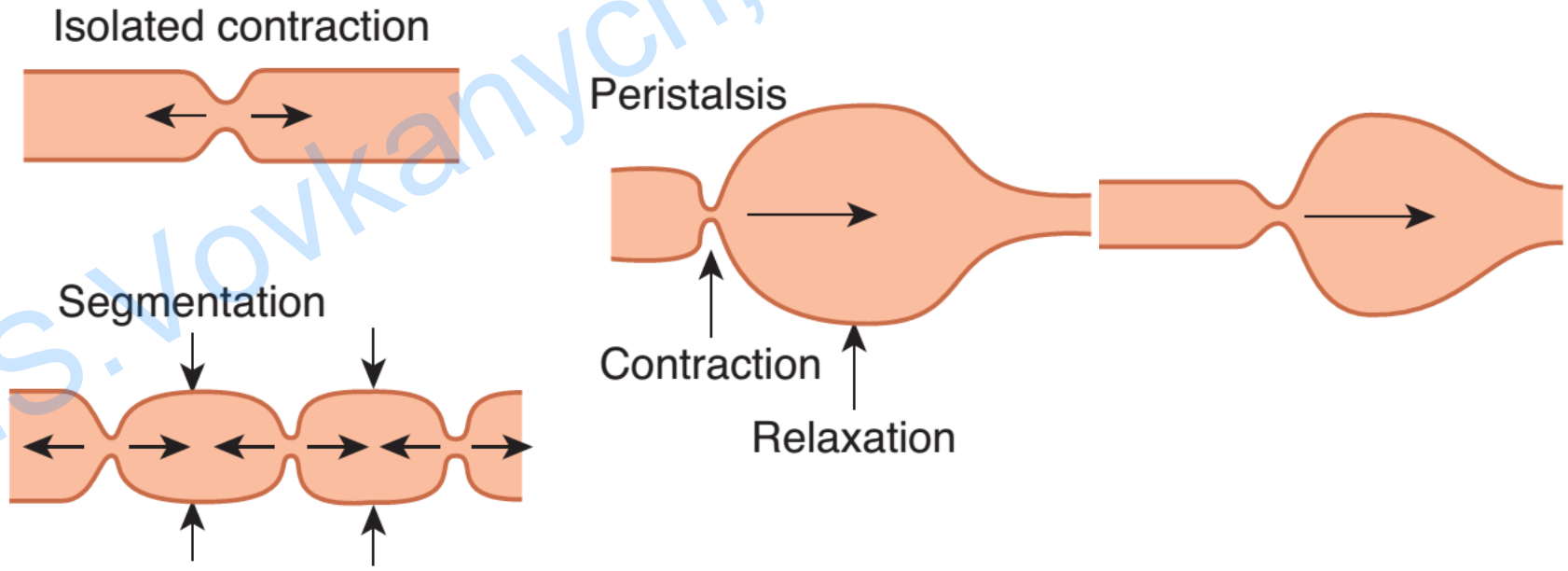
ENS is **innervated** primarily by **parasympathetic** division of ANS

Patterns of gastrointestinal motility (in GI tract):

- **Isolated contraction**
- **Segmentation**
- **Peristalsis**

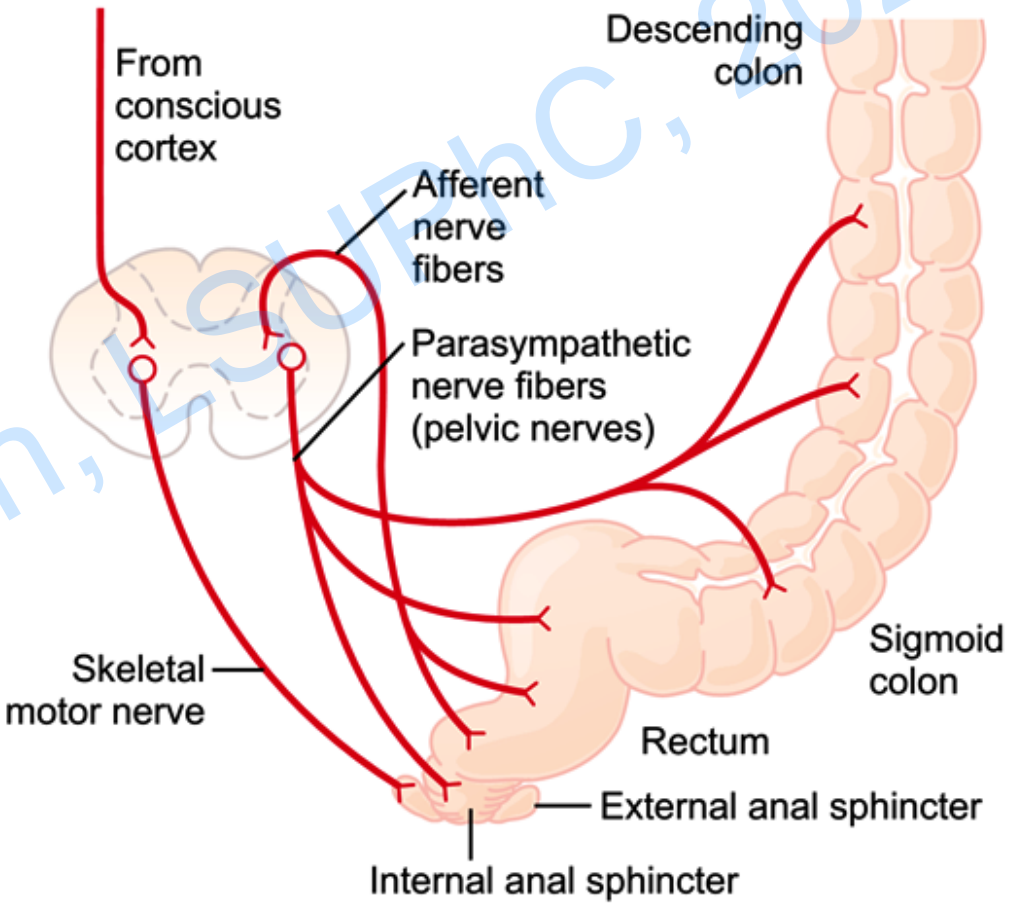
The Movement of Digestive Materials

- **Isolated contractions** separates some parts of contents, is typical for sphyncters
- **Segmentation** cycles of contraction fragment the bolus or chyme, mix contents with intestinal secretions
- **Peristalsis** consists of waves of muscular contractions, which move a bolus or chyme along the length of the digestive tract

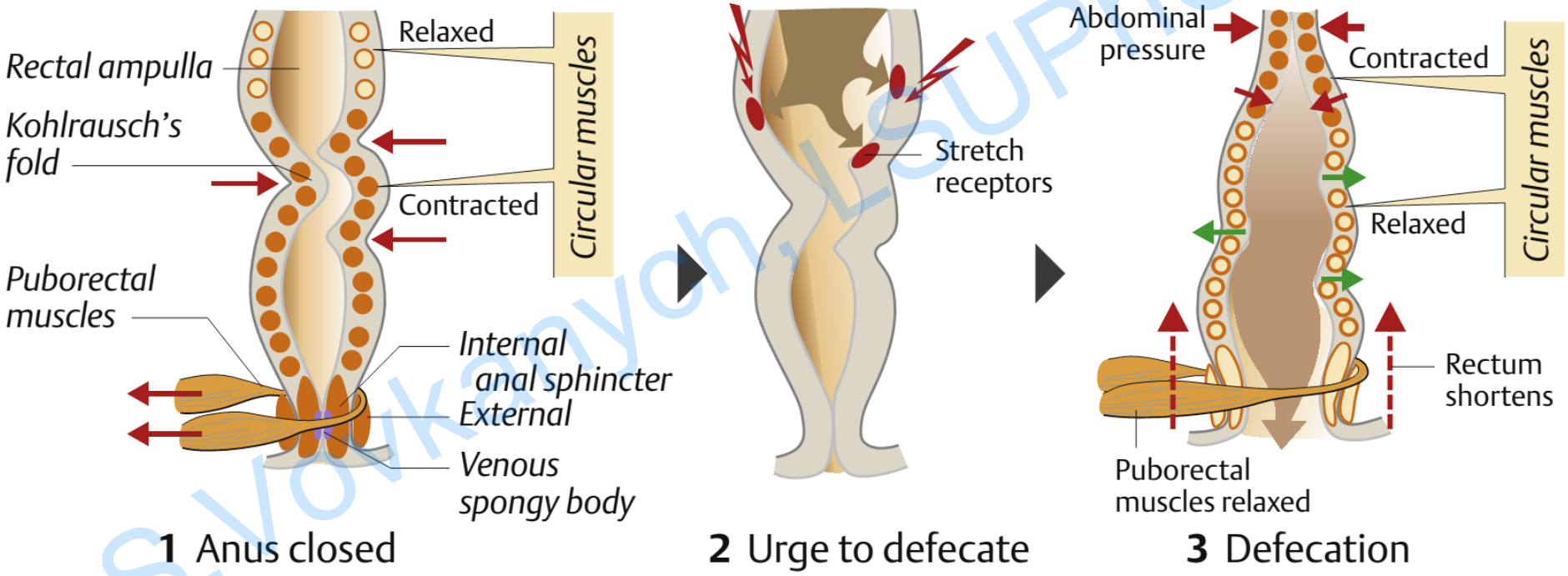


Defecation

- Is initiated by **defecation reflexes**
- **Intrinsic reflex** mediated by the local enteric nervous system
- It usually must be intensified by a **parasympathetic defecation reflex** (sacral segments of the spinal cord)
- It greatly **intensifies** the peristaltic waves as well as relaxes the internal anal sphincter
- **External anal sphincter** is relaxed by centers of spinal cord, controlled by higher centers of brain



Defecation stages



Secretion

Active process of **synthesis**, **transport** and **excretion** into lumen the components of secretory product, which form the secretions

It is the result of the **secretory glands activity**

The **main components** of secretes (digestive juices) are:

- **water**
- **organic** substances
  - **digestive enzymes** in most areas of the alimentary tract, from the mouth to the distal end of the ileum
  - **mucous** from the mouth to the anus, necessary for lubrication and protection of all parts of the alimentary tract
- **inorganic** compounds (ions)

Most digestive secretions are formed only **in response** to the presence of food in the alimentary tract

The quantity secreted in each segment of the tract is almost exactly the amount needed for proper digestion

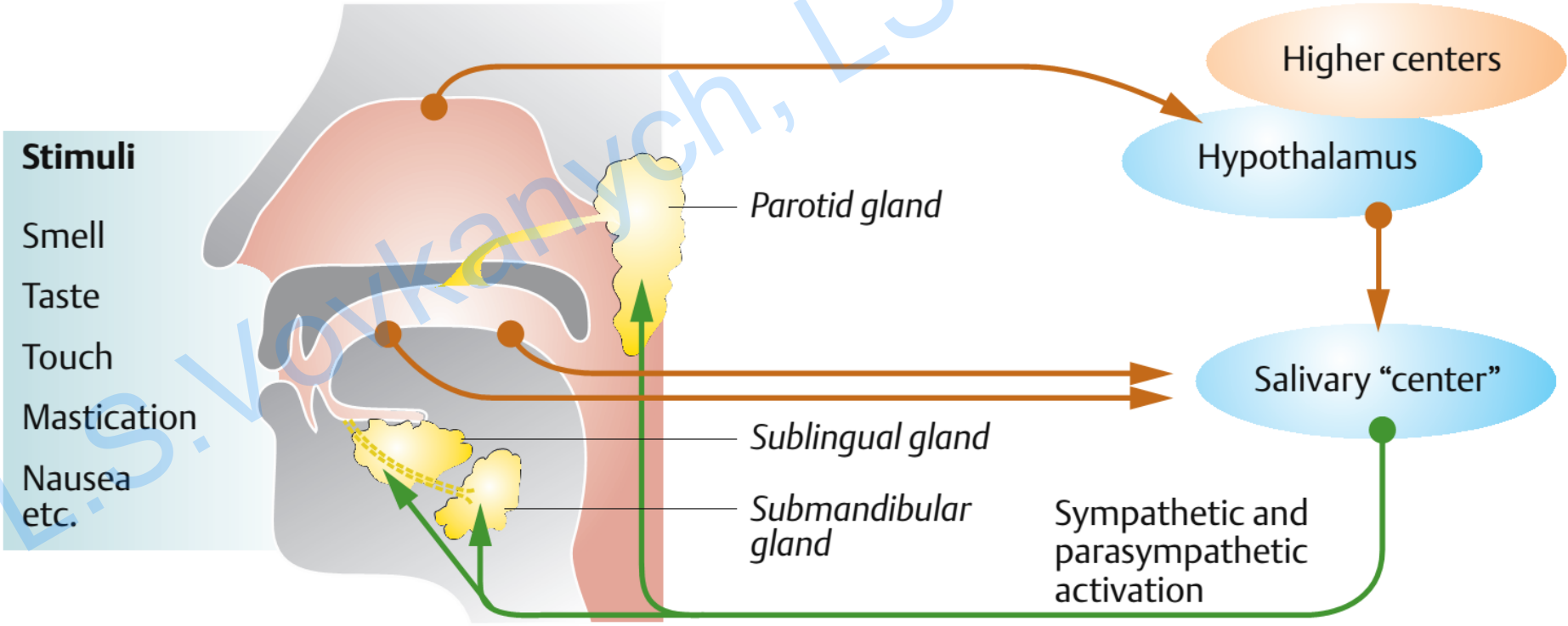
Properties and Composition of Saliva

- The saliva is secreted by three pairs of major (larger) **salivary glands** and some minor (small) salivary glands
- **Volume**: 1.0-1.5 L per day
- pH is **alkaline**
- Has **antimicrobial** properties (lysozyme, Immunoglobulin IgA, etc.)
- **Mucin** - protects the mouth by lubricating the mucus membrane of mouth

Enzyme	Source of secretion	Activator	Action
Salivary amylase	All salivary glands	Cl^-	Converts starch into maltose
Maltase	Major salivary glands	Cl^-	Converts maltose into glucose
Lingual lipase	Lingual glands		Triglycerides of milk fat into fatty acids and diacylglycerol

Nerve Regulation of Salivary Glands

- Stimulation of **parasympathetic** fibers of salivary glands causes secretion of saliva with large quantity of **water**
- Stimulation of **sympathetic** fibers causes secretion of saliva, which is thick and rich in **organic constituents**



Functions of Stomach

- **Mechanical** Function
  - **storage** function (for 3 to 4 hours)
  - formation of **chyme** (by peristaltic movements)
- **Digestive** Function (gastric juice)
- **Protective** Function (gastric juice)
- **Gastric juice** is a mixture of secretions from different **gastric glands**

Types of Gastric Glands

Type of gland	Localization	Type of cells	Secretory products
Fundic glands	body and fundus	Chief cells (CC)	Pepsinogen Rennin Lipase Gelatinase
		Parietal cells	Hydrochloric acid
		Mucus cells (MC)	Mucin
		Enterochromaffin cells (EC)	Serotonin
Pyloric glands	pyloric part	MC, EC	Mucin Serotonin
		G cells	Gastrin
Cardiac glands	cardiac region	CC, MC, EC	see above

Gastric Juice

- **Volume**: 1.2-1.5 L/day
- **Reaction**: highly acidic (pH of 0.9 to 1.2 during food digestion)

Enzyme	Activator	Substrate	Action
Pepsin	Hydrochloric acid	Proteins	Proteoses, peptones and polypeptides
Gastric lipase	Acid medium	Triglycerides of butter	Fatty acids and glycerols
Gastric amylase	Acid medium	Starch	Dextrin and maltose (negligible action)
Gelatinase	Acid medium	Gelatin and collagen of meat	Peptides

Mucin:

- protects the stomach wall from irritation or mechanical injury
- prevents the digestive action of pepsin on the wall of the stomach

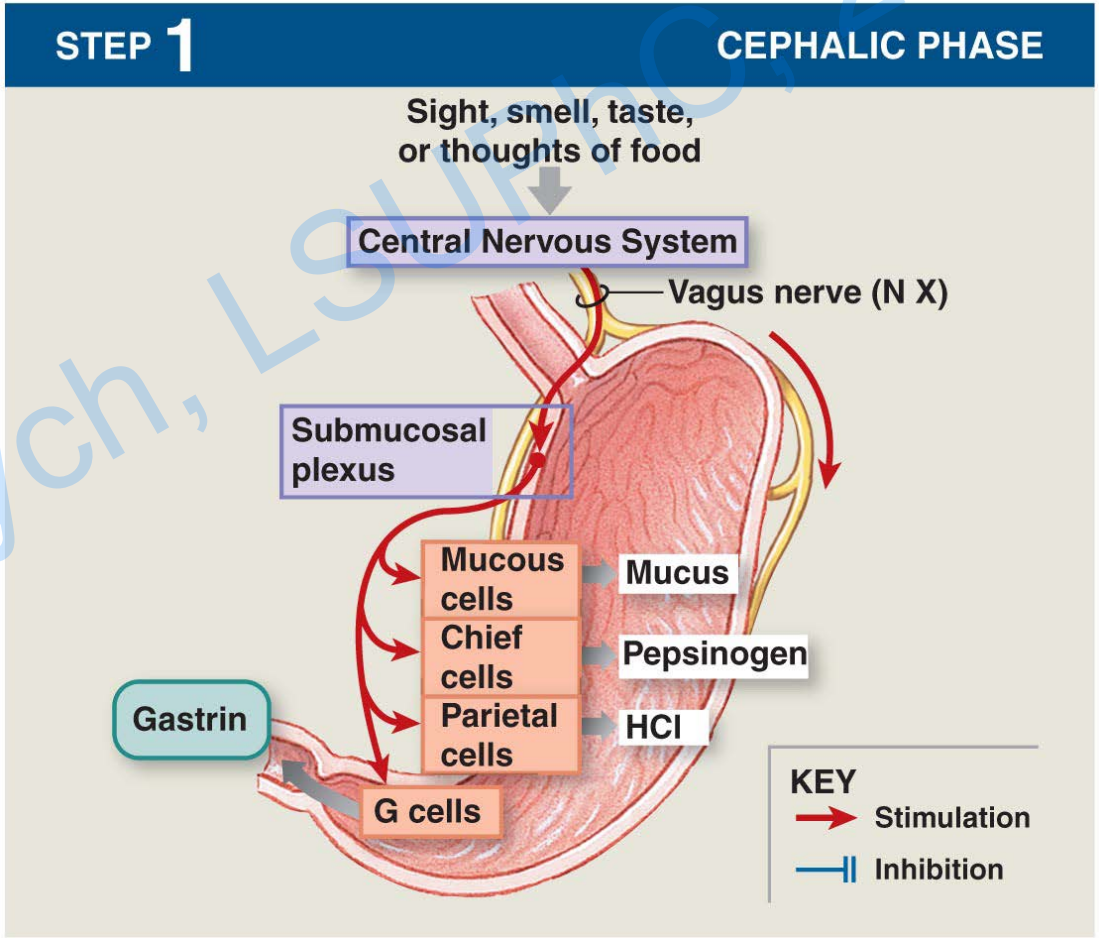
Regulation of Gastric Secretion

Gastric secretion occurs in **three** different phases:

- **Cephalic** phase
- **Gastric** phase
- **Intestinal** phase

Cephalic phase

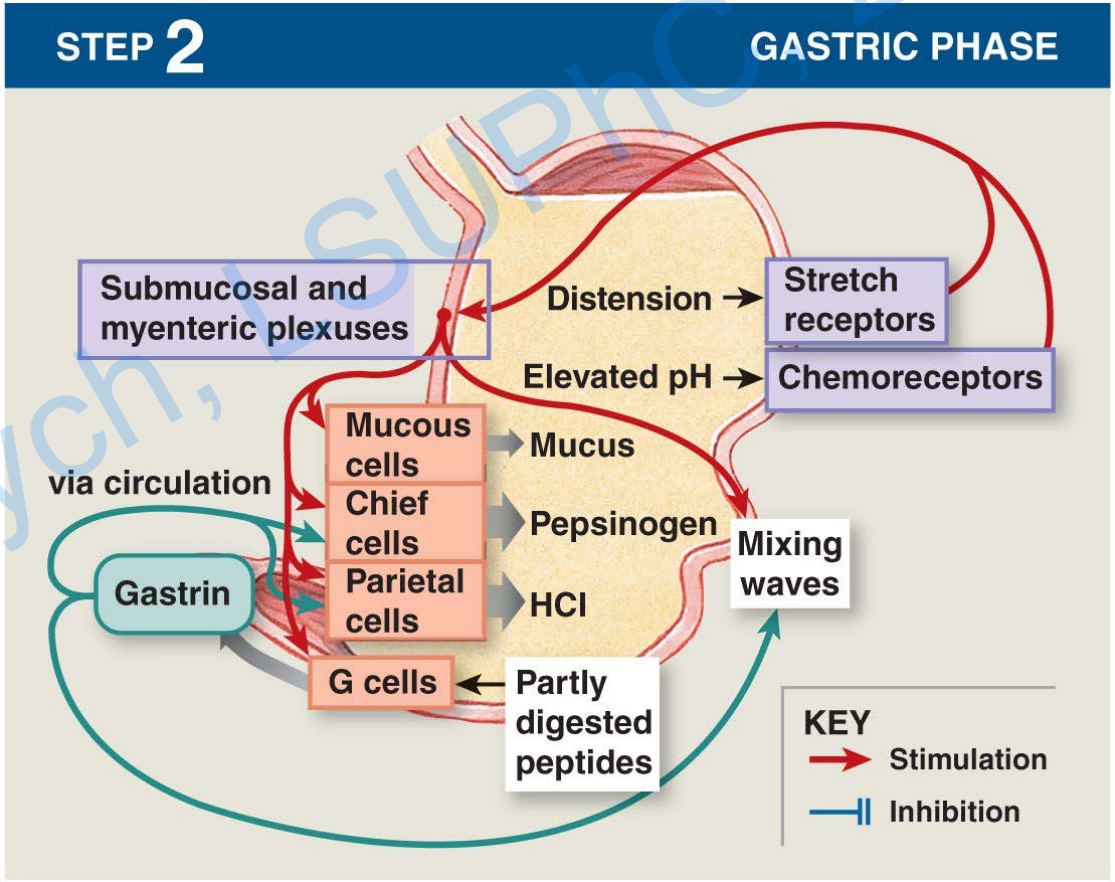
- **short** phase (minutes)
- **neural** mechanism involved vagus nerve and submucosal plexus
- **hormonal** stimulation by **gastrin**
- **stimulation** of secretion



Regulation of Gastric Secretion

Gastric phase

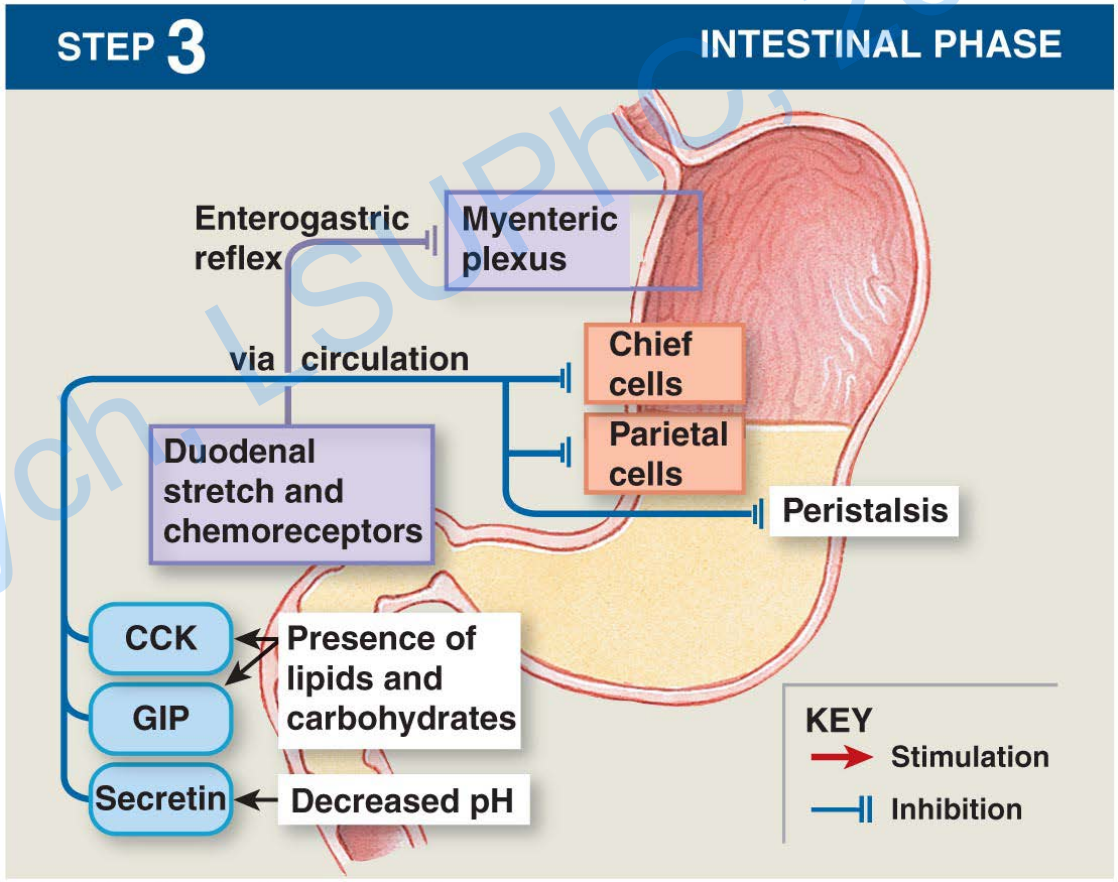
- **long** phase (3-4 hr)
- **neural local** mechanisms, activated by stretch receptors and chemoreceptors
- **hormonal** stimulation by gastrin
- **increase secretion** of HCl and pepsinogen;
- **increased motility**



Regulation of Gastric Secretion

Intestinal phase

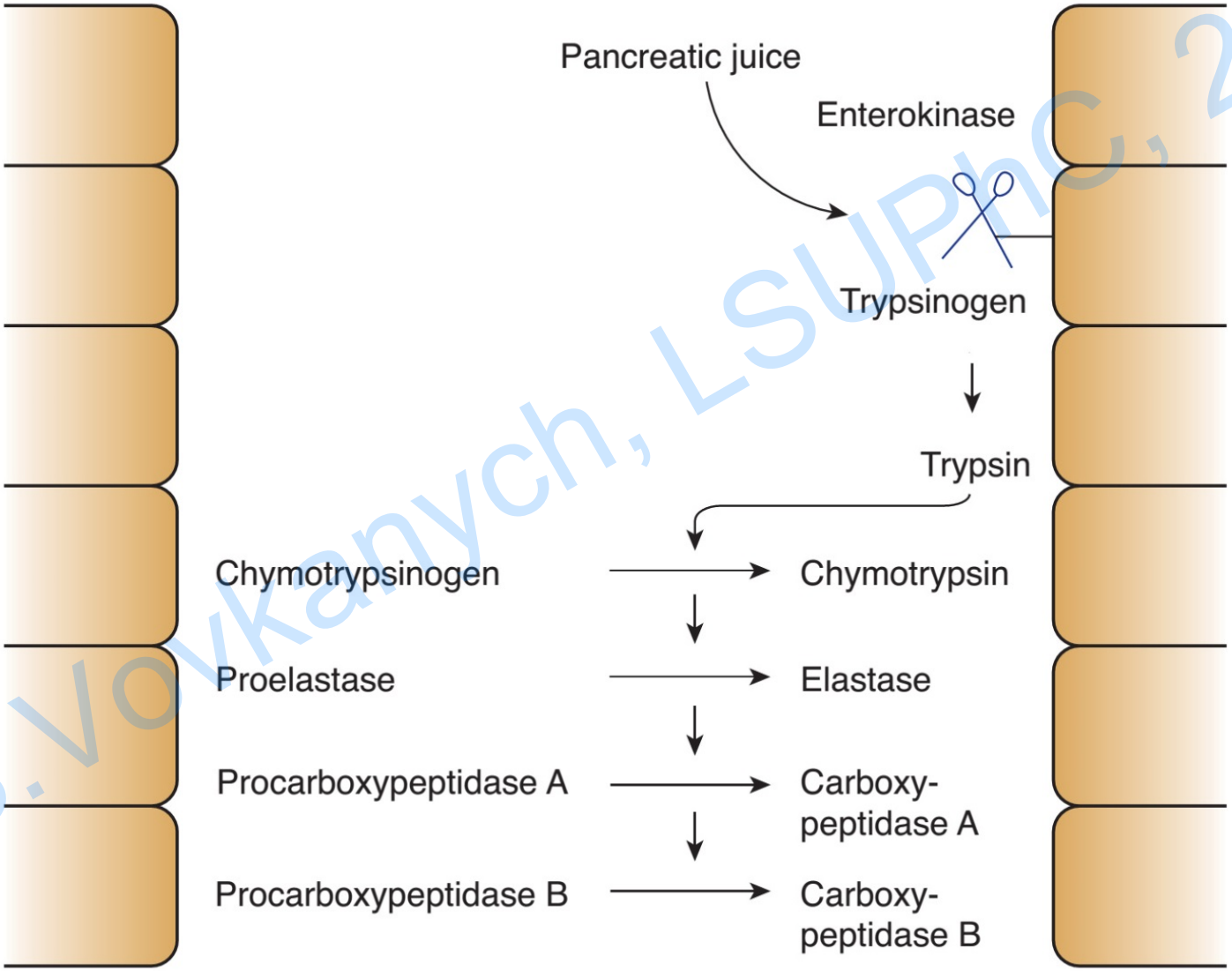
- **long** (3-4 hr)
- **neural local** reflexes stimulated by distention of **duodenum**
- **hormonal** – **inhibition** of **gastric secretion** by Secretin, Cholecystokinin (CCK) and Gastric inhibitory peptide (GIP)
- **inhibition** of HCL and pepsinogen production;
- **reduction of motility**



Properties and Composition of Pancreatic Juice

- **Volume**: 0.5 to 0.8 L/day
- **Reaction**: highly alkaline (pH of 8 to 8.3)
- **Bicarbonate** content is very high in pancreatic juice
- Plays an important role in the digestion of **proteins** and **lipids**, nucleases are also present, has mild digestive action on carbohydrates
- Major proteolytic enzymes of pancreatic juice are **trypsin** and **chymotrypsin**
- **Trypsin** is secreted as **inactive** trypsinogen, **activated** by enterokinase (secreted by the brushbordered cells of duodenal mucus membrane)
- Many other enzymes also are secreted as **proenzymes** (**inactive)** and are activated in the lumen

Activation of Pancreatic Proenzymes



Digestive Enzymes of Pancreatic Juice

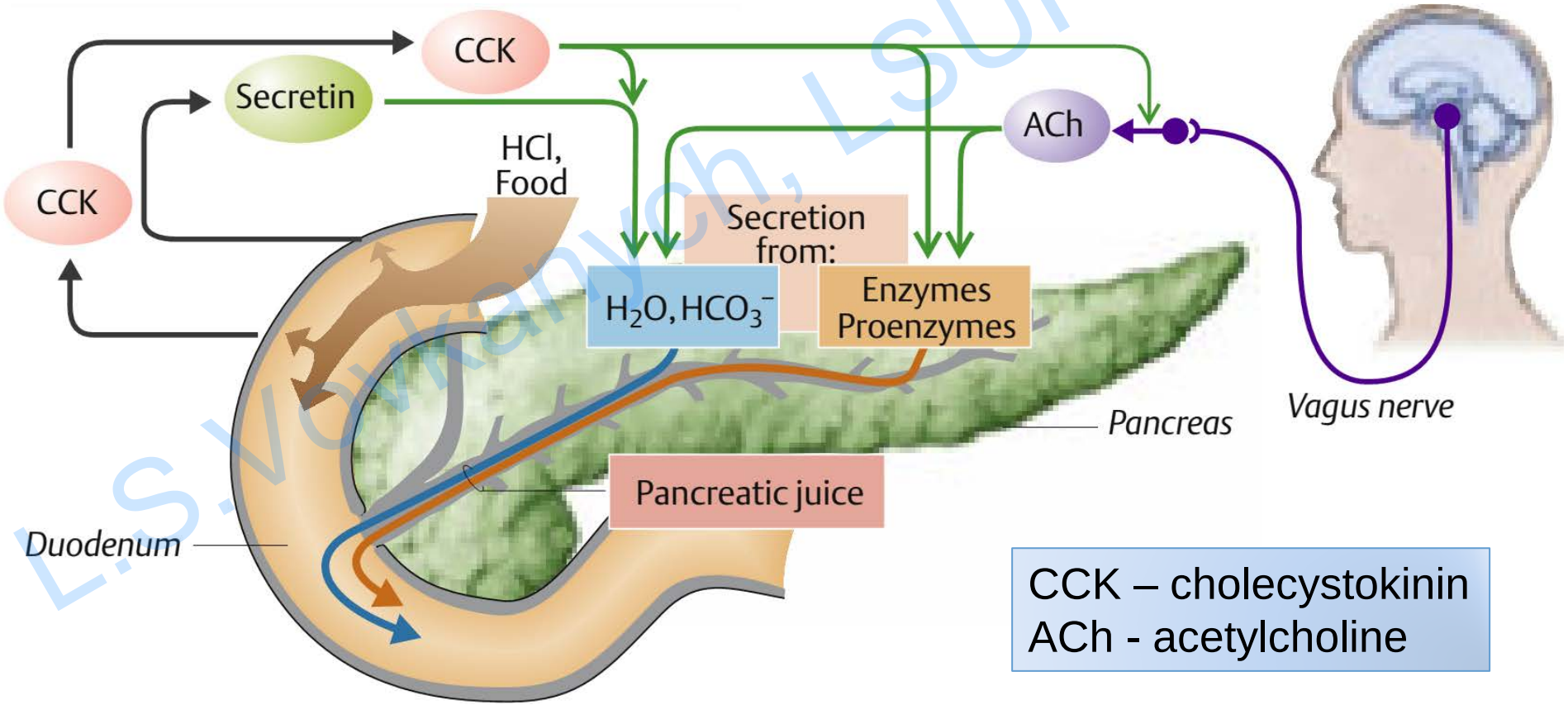
Enzyme	Activator	Substrate	End products
Proteolytic enzymes			
Trypsin	Enterokinase Trypsin	Proteins	Polypeptides
Chymotrypsin	Trypsin	Proteins	Polypeptides
Carboxypeptidases	Trypsin	Polypeptides	Amino acids
Elastase	Trypsin	Elastin	Amino acids
Collagenase	Trypsin	Collagen	Amino acids
Nucleolytic enzymes			
Nucleases	Trypsin	RNA and DNA	Mononucleotides

Digestive Enzymes of Pancreatic Juice

Enzyme	Activator	Substrate	End products
Lypolitic enzymes			
Pancreatic lipase	Alkaline medium	Triglycerides	Monoglycerides and fatty acids
Cholesterol ester hydrolase	Alkaline medium	Cholesterol ester	Cholesterol and fatty acids
Phospholipase A	Trypsin	Phospholipids	Lysophospholipids
Phospholipase B	Trypsin	Lysophospholipids	Phosphoryl choline and free fatty acids
Amylolytic enzymes			
Pancreatic amylase	--	Starch	Dextrin and maltose

Regulation of pancreatic secretion

- Secretion of pancreatic juice is regulated by both **nervous** and **hormonal** factors



CCK – cholecystokinin
ACh - acetylcholine

Regulation of Pancreatic Secretion

Stages (**phases**) of pancreatic secretion

- **Cephalic** phase (stimulation by vagal nerve endings)
- **Gastric** phase
  - when food enters the stomach, **gastrin** is secreted from stomach, it **stimulates** the pancreatic secretion
- **Intestinal** phase
  - when the chyme enters the intestine **many hormones** are released
  - some hormones **stimulate** the pancreatic secretion (Secretin, Cholecystokinin) and some hormones **inhibit** the (Pancreatic polypeptide, Somatostatin) pancreatic secretion

Bile Secretion (Liver and Gallbladder)

- **Properties** of bile
- **Volume**: 0.8 to 1.2 L/day
- **Reaction**: Alkaline (pH 8 to 8.6)
- Bile is secreted by **hepatocytes**
- It contains large quantity of **bile acids**, **bile pigments**, **cholesterol**, **lecithin** and **fatty acids**
- **Sodium**, **bicarbonate** and **water** are added to bile when it passes through the ducts
- Most of the bile from liver **enters the gallbladder**, where it is **stored**
- During the storage, the **volume** of bile decrease, the **concentration** of substances increase, **mucin** is added into bile

Main Organic Components of Bile

Bile salts are required for **digestion** and **absorption** of **fats** in the intestine

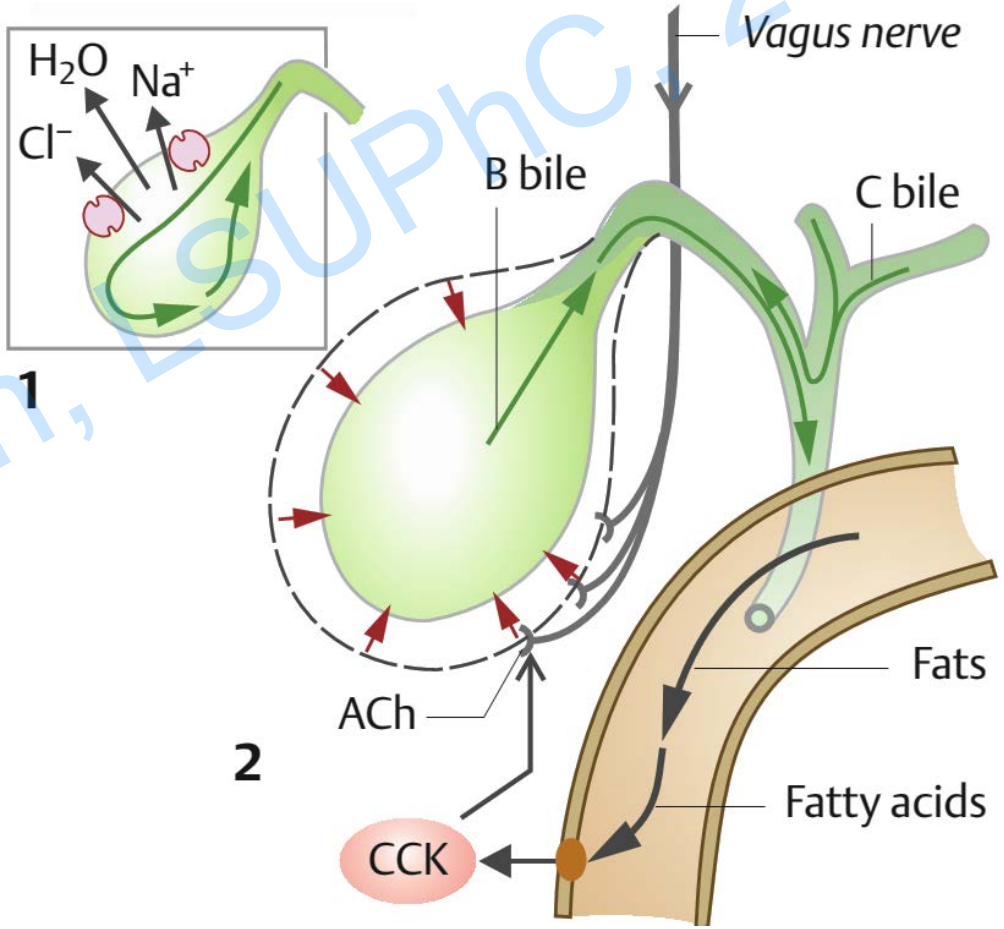
- **Emulsification** of fats (bile salts emulsify the fats by reducing the surface tension due to their detergent action, in emulsion fats can be easily digested by lipolytic enzymes)
- **Absorption** of fats (bile salts combine with fats and make complexes of fats called micelles)
- **Stimulation** of the secretion of bile from liver

Bile pigments (bilirubin and biliverdin) are the excretory products in bile

- Bile pigments are formed during the breakdown of **hemoglobin**

Regulation of Bile Secretion and Ejection from Gallbladder

- Bile secretion is a **continuous process**
- Substances which **increase** the secretion: Acetylcholine, Secretin, Cholecystokinin etc.
- Contraction of gallbladder is stimulated by **parasympathetic** nerve (vagus) and cholecystokinin (CCK, secreted in intestine)
- Increases the **release** of bile: Bile salts, Fatty acids, Amino acids etc.



Secretion of Small Intestine

Volume: 1.8-2.0 L/day

Reaction: alkaline (pH 8.3)

- Intestinal juice (Succus entericus) has strong **enzymatic activity**:
- **Peptidases** convert peptides into amino acids
- **Amylolytic enzymes** convert the disaccharides (lactose, sucrose and maltose) into two molecules of monosaccharides
- **Intestinal lipase** acts on triglycerides and converts them into fatty acids
- **Enterokinase** activates trypsinogen into trypsin

Mucus present in the succus entericus protects the intestinal wall from the acid chyme

Defensins secreted by paneth cells of intestinal glands are the antimicrobial peptides

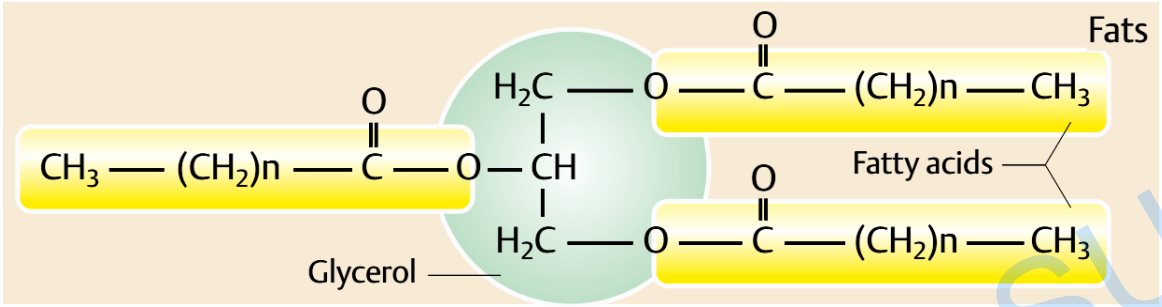
Digestive Enzymes of Intestinal Juice

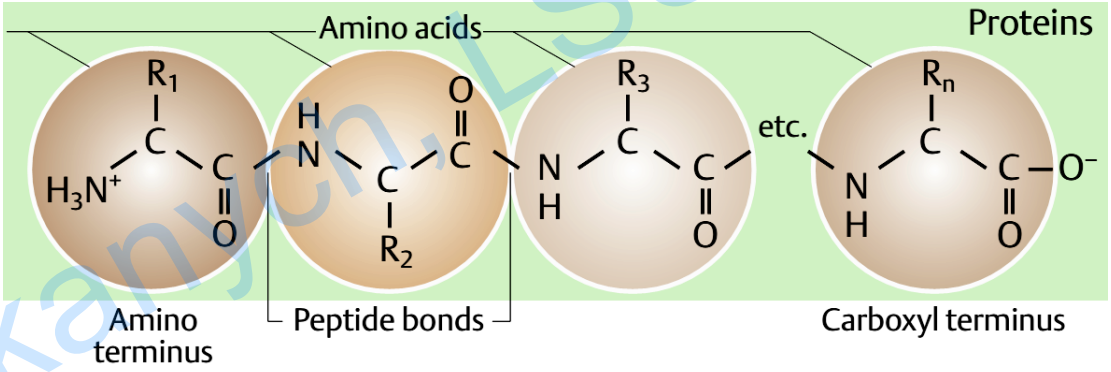
Enzyme	Substrate	End products
Enterokinase	Trypsinogen	Trypsin
Aminopeptidases	Polypeptides	Free terminal amino acid
Carboxypeptidases		Free terminal amino acid
Endopeptidases		Two amino acids
Maltase	Maltose, maltotriose, α-dextrins	Glucose
Lactase	Lactose	Galactose and glucose
Sucrase	Sucrose	Fructose and glucose
Nucleases	Nucleic acids	Pentoses and purine and pyrimidine bases
Intestinal lipase	Triglycerides	Fatty acids

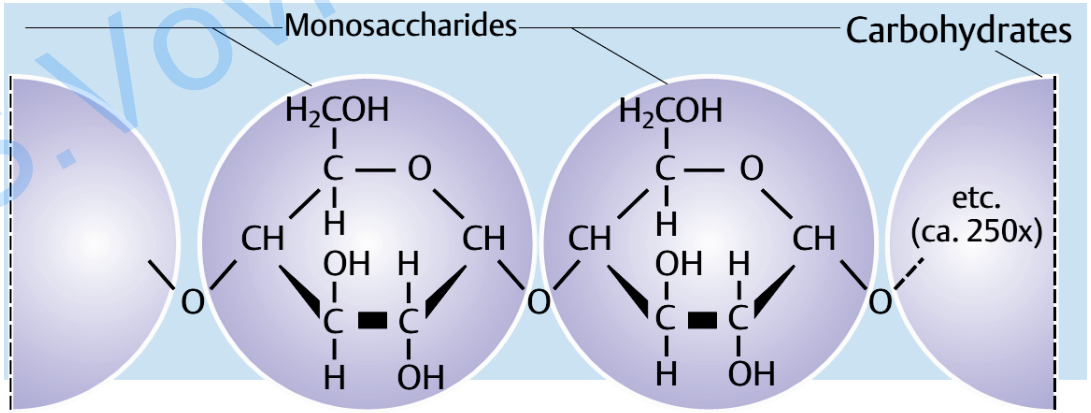
Regulation of Secretion of Small Intestine

- **Local reflexes**, stimulated by **chyme**, entering the small intestine, stimulates which play an important role in increasing the secretion of intestinal juice
- Chyme also stimulates the **secretion of secretin** and **cholecystokinin**, which promote the secretion of intestinal juice

Chemical Structure of Food Components



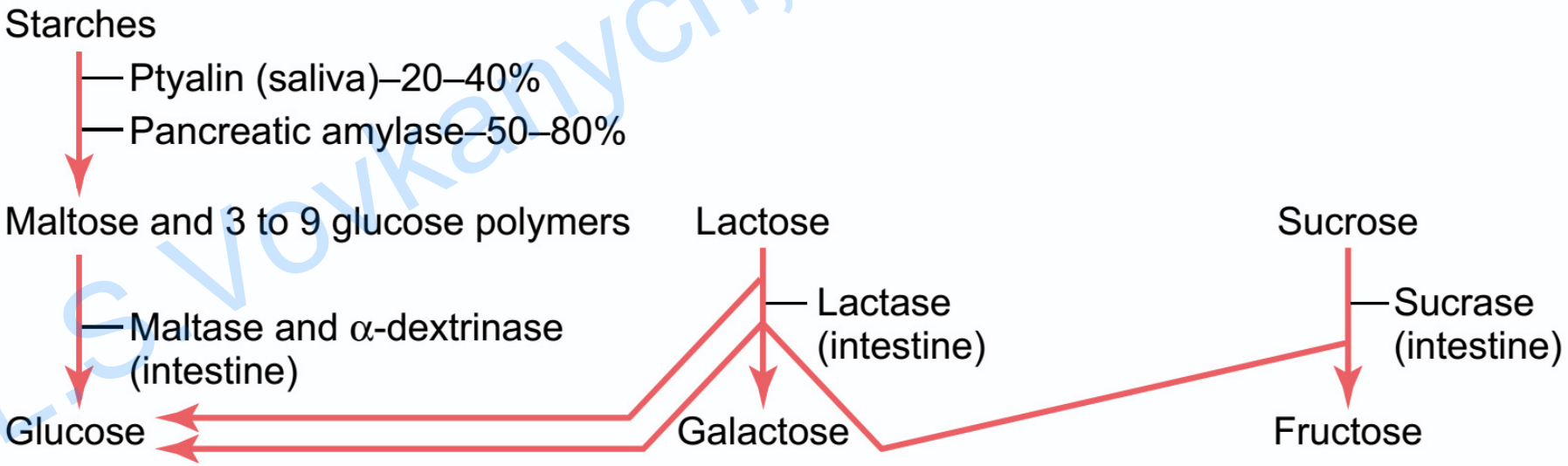




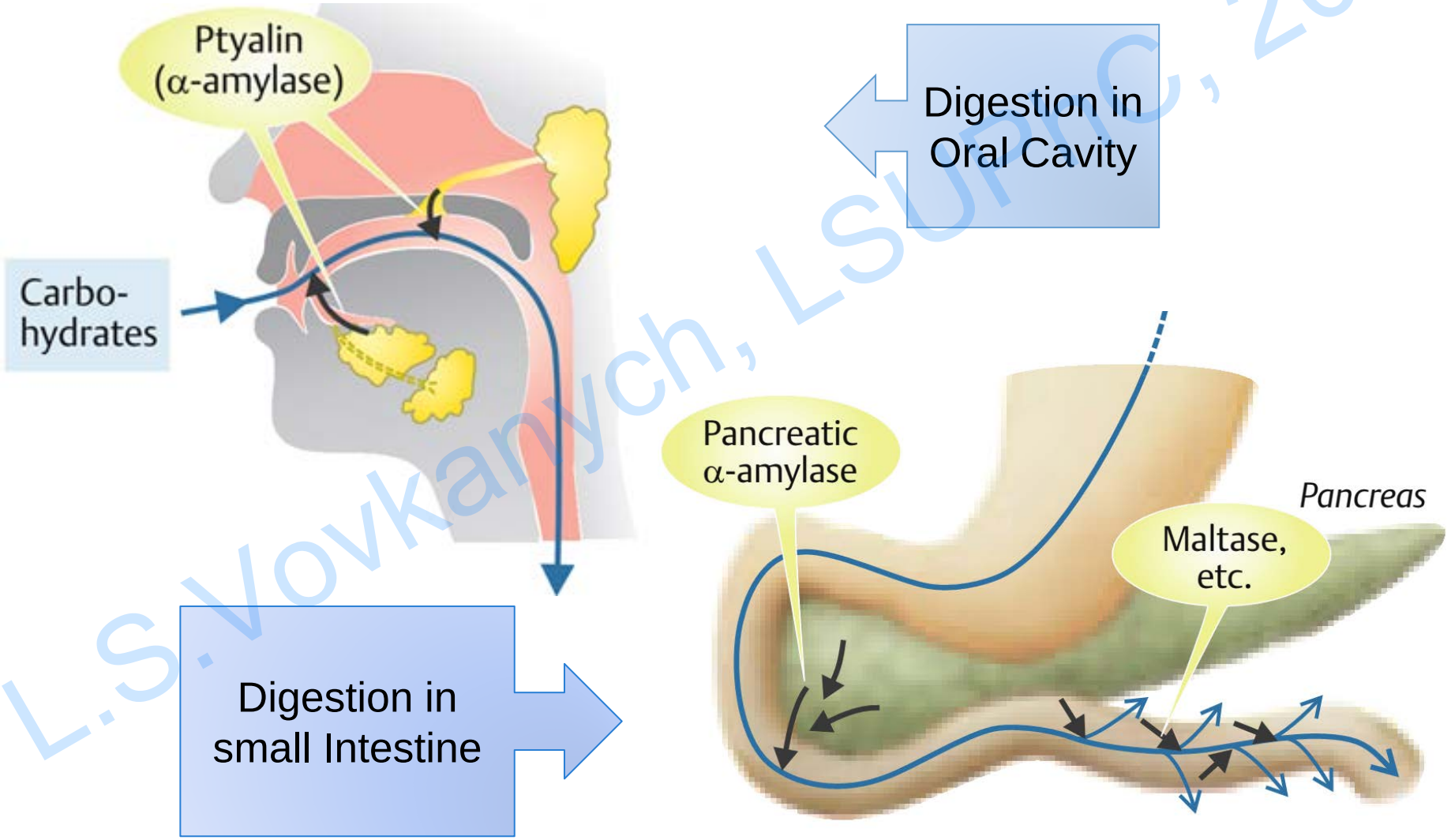
Digestion of Carbohydrates

Human diet contains three types of carbohydrates:

- **polysaccharides** - glycogen, amylose and amylopectin, which are in the form of starch
- **disaccharides** - sucrose (glucose + fructose), lactose (glucose + galactose)
- **monosaccharides** – mostly glucose and fructose



Digestion of Carbohydrates



Digestion of carbohydrates

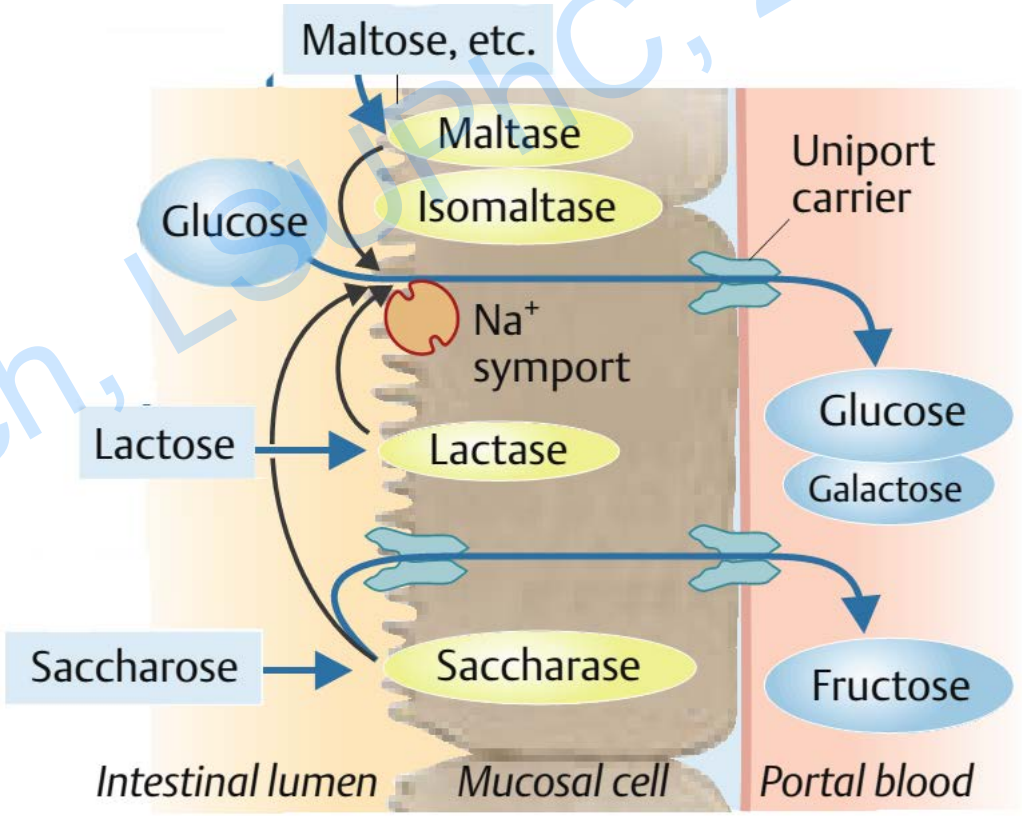
Area	Juice	Enzyme	Substrate	End product
Mouth	Saliva	Salivary amylase	Polysaccharides	Disaccharides – dextrin and maltose
Stomach	Gastric juice	Gastric amylase	*Weak amylase*	*The action is negligible*
Small intestine	Pancreatic juice	Pancreatic amylase	Polysaccharides	Disaccharides
	Intesinal juice	Sucrase Maltase Lactase Dextrinase	Sucrose Maltose Lactose Dextrin, maltose and maltriose	Glucose and fructose Glucose Glucose and galactose Glucose

Absorption of Carbohydrates

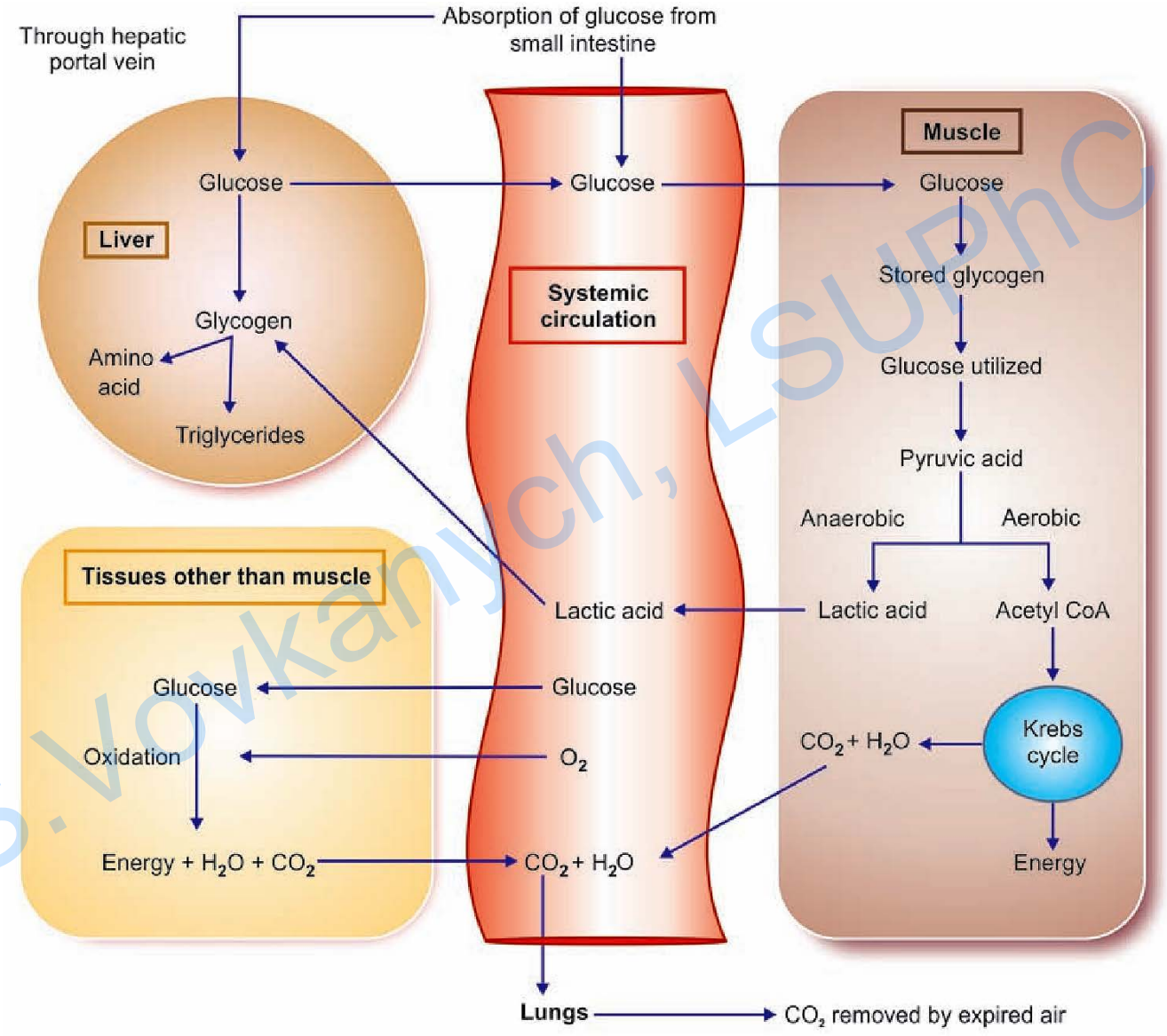
Into epithelial cells the **glucose** and **galactose** are transported by means of sodium cotransport

From the epithelial cell, **glucose** is absorbed into the portal vein by facilitated diffusion

Fructose is absorbed into blood by means of facilitated diffusion



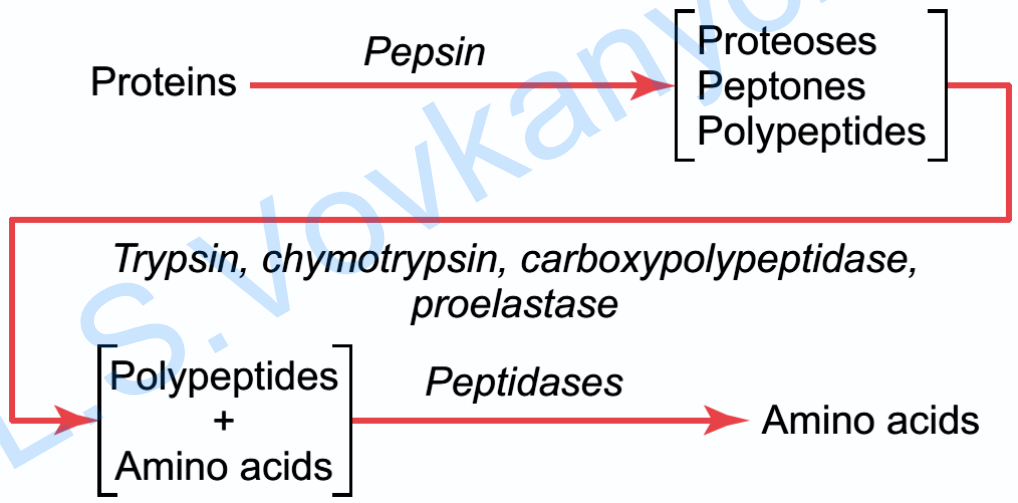
Metabolism of Carbohydrates

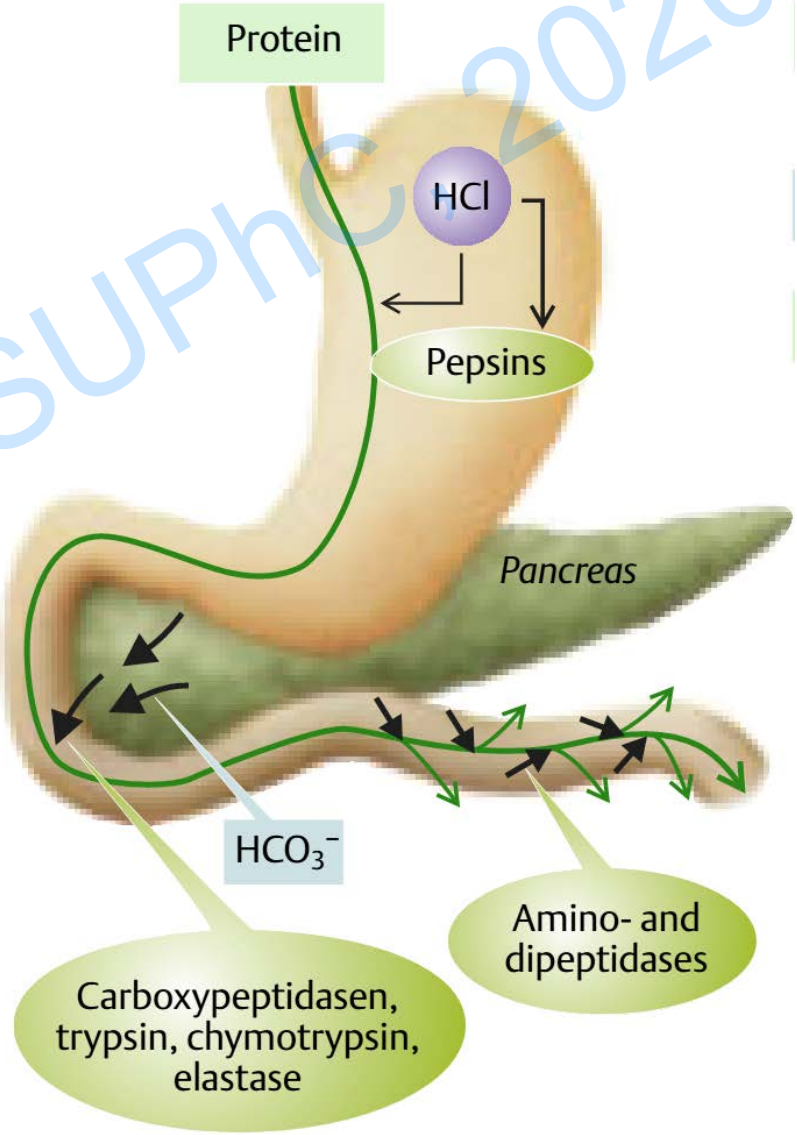


Digestion of Proteins

Proteins present in food are:

- gluten (glutenin and gliadin)
- casein, lactalbumin, albumin and myosin
- albumin and vitellin
- collagen, albumin and myosin



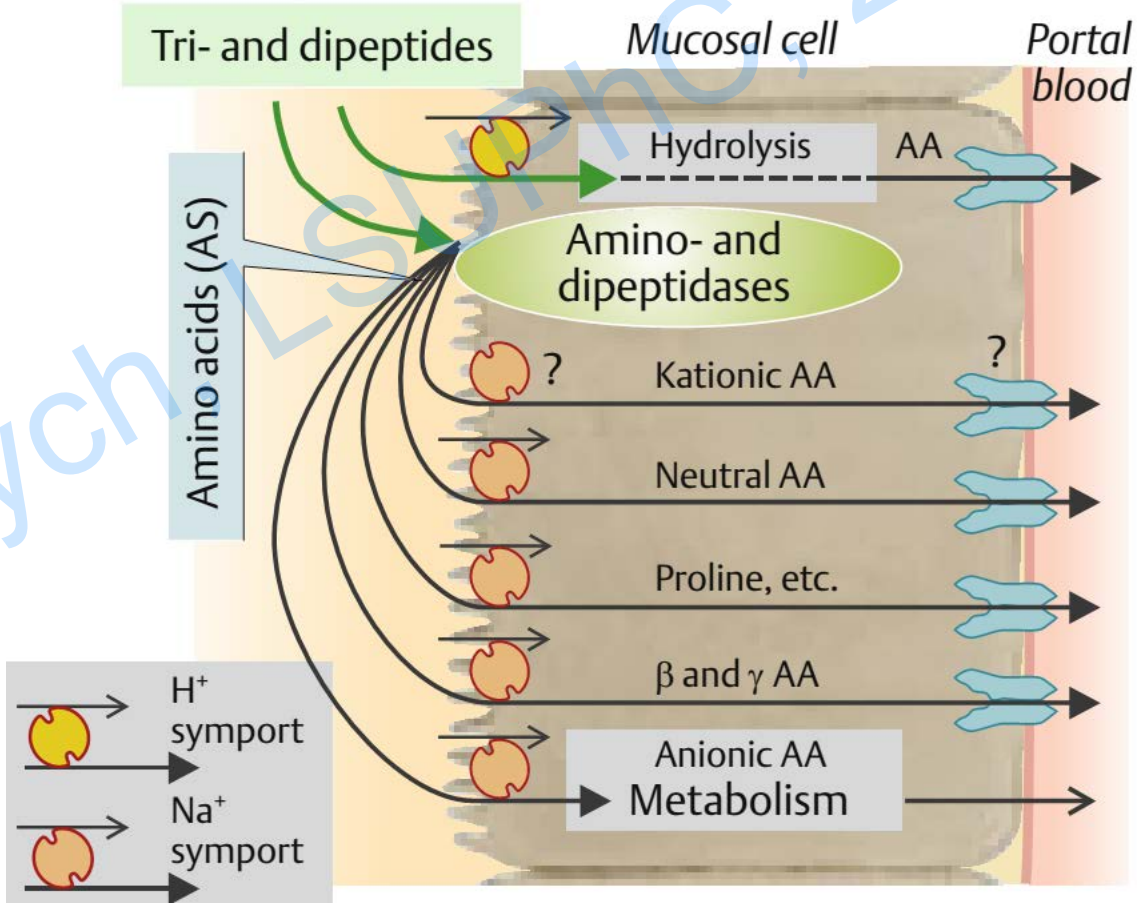


Digestion of Proteins

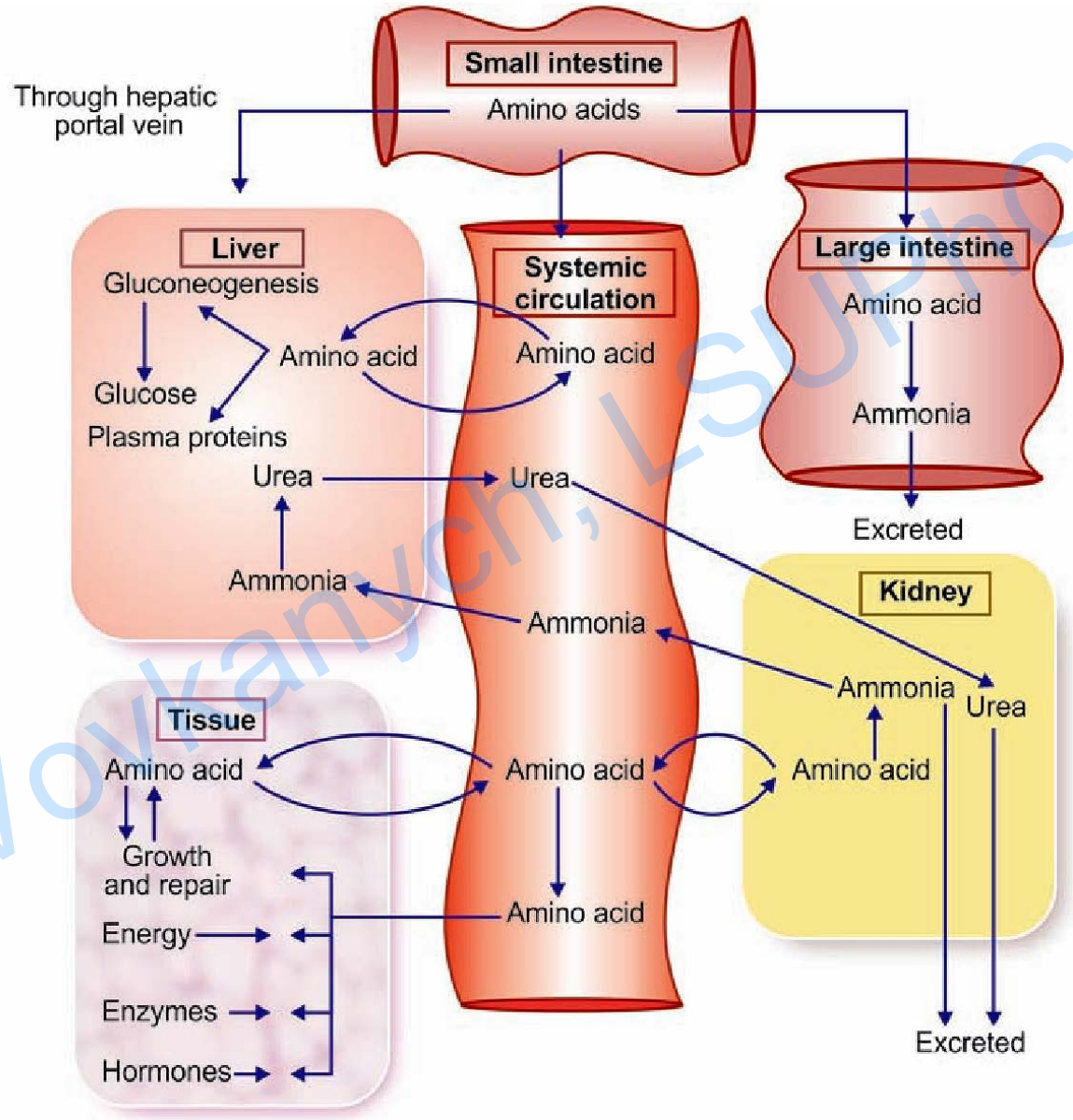
Area	Juice	Enzyme	Substrate	End product
Mouth	Saliva	No proteolytic enzymes		
Stomach	Gastric juice	Gastric amylase	Proteins	Proteoses, peptones, large polypeptides
Small intestine	Pancreatic juice	Trypsin, Chymotrypsin	Proteoses Peptones	Dipeptides Tripeptides Polypeptides
		Carboxypeptidases	Dipeptides Tripeptides Polypeptides	Amino acids
	Intesinal juice	Dipeptides Tripeptides Amyno peptides	Dipeptides Tripeptides Polypeptides	Amino acids

Absorption of Amino Acids

- Amino acids are absorb from **small intestine**
- Amino acids (AA) are transported by a number of specific carriers by **symport** with Na^+ or H^+
- **Dipeptides and tripeptides** can be absorbed as intact molecules by a symport carrier
- Absorption of amino acids **is faster in duodenum** and **jejunum** and slower in ileum

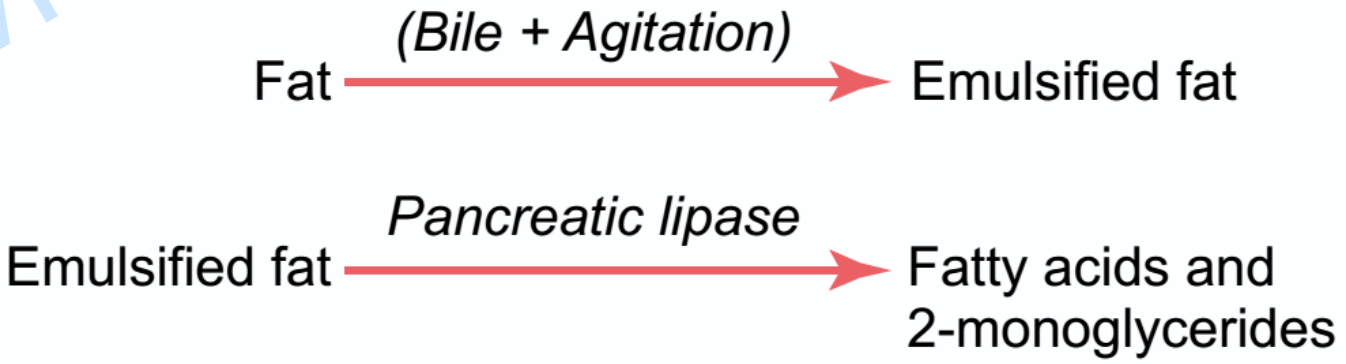


Metabolism of Proteins



Digestion of Lipids

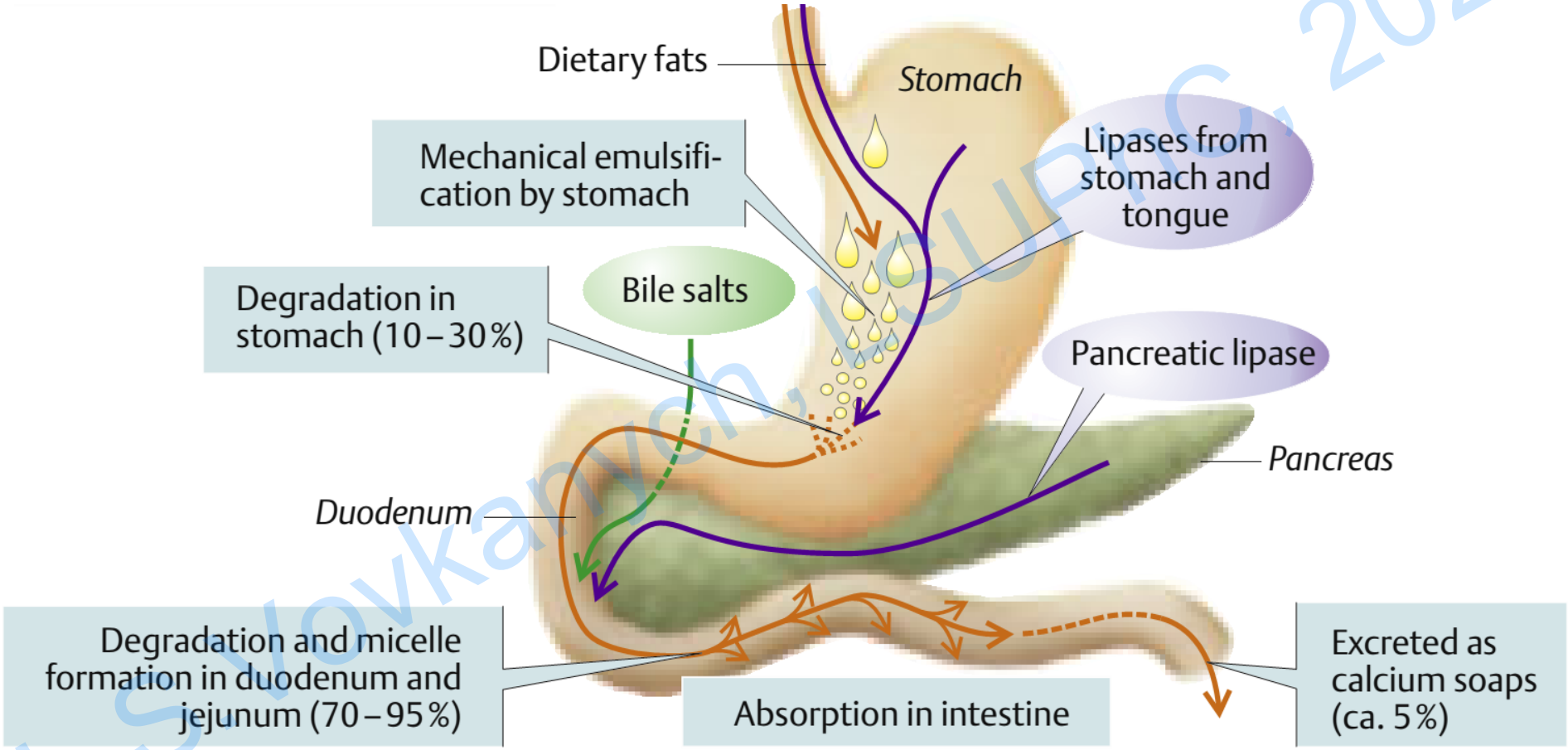
- Lipids are mostly consumed in the form of **neutral fats** (**triglycerides**) and small quantities of **cholesterol** and **cholesterol esters**
- **Dietary fats** are classified into two types:
  - **Saturated** fats (triglycerides formed from only saturated fatty acids.)
  - **Unsaturated** fats (unsaturated fatty acids)
  - **Polyunsaturated** fats belong to the family of essential fatty acids
  - **Omega-3**
  - **Omega-6**



Digestion of Lipids

Area	Juice	Enzyme	Substrate	End product
Mouth	Saliva	Lingual lipase	Triglycerides	Fatty acid 1, 2-diacylglycerol
Stomach	Gastric juice	Gastric lipase (weak lipase)	Triglycerides	Fatty acids Glycerol
Small intestine	Pancreatic juice	Pancreatic lipase	Triglycerides	Monoglycerides Fatty acid
		Phospholipases	Phospholipids Lysophospholipids	Lysophospholipids Phosphoryl choline Free fatty acids
	Intesinal juice	Intestinal lipase	Triglycerides	Fatty acids Glycerol (weak action)

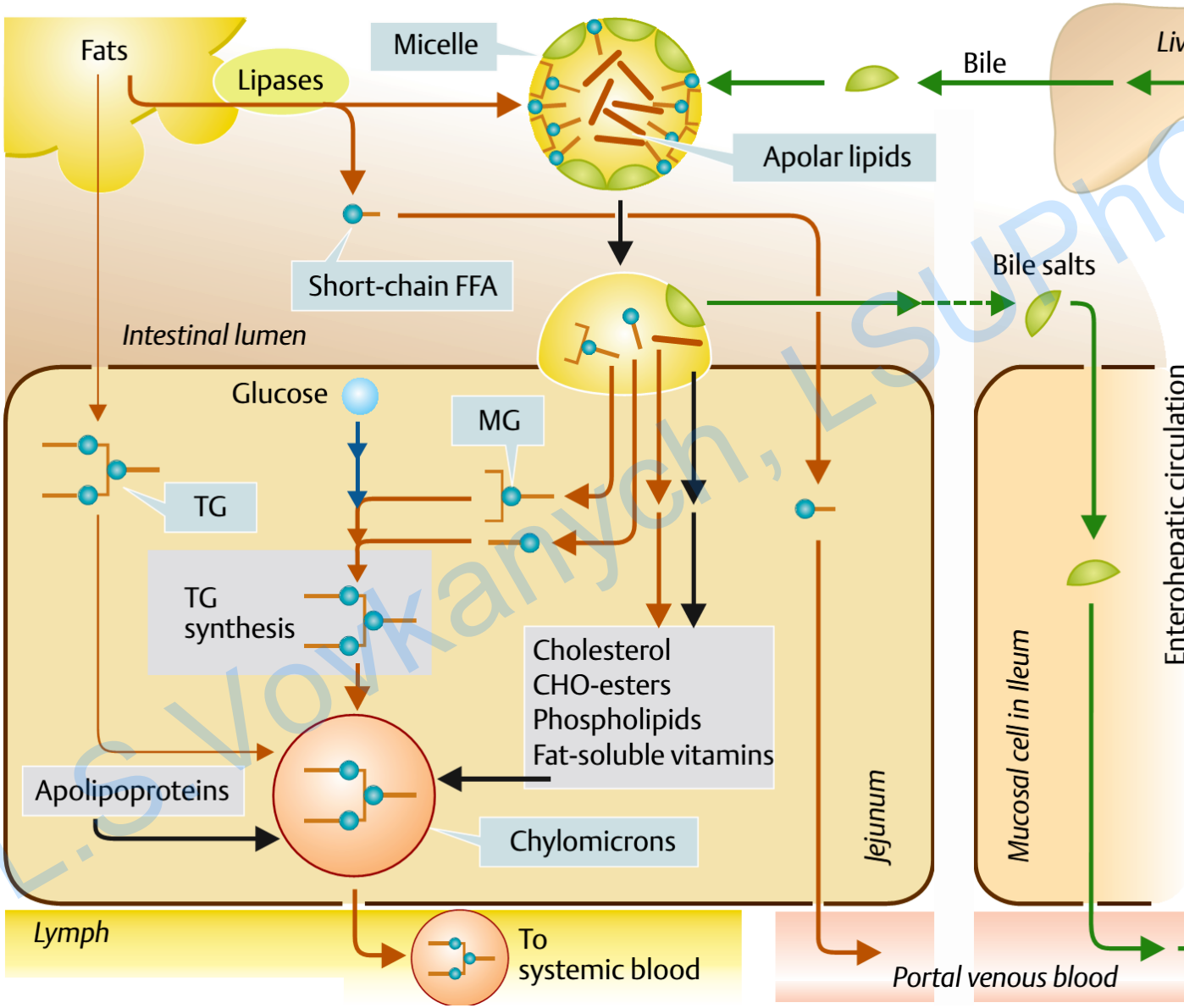
Digestion of Lipids



Absorption of Lipids

- In the **small intestine** 2-monoacylglycerols, long-chain free fatty acids and other lipids aggregate with bile salts to spontaneously form **micelles**
- **Micelles** enter the cells of intestinal mucosa by **simple diffusion**
- In the mucosal cells, most of the monoglycerides are converted into **triglycerides**
- Triglycerides and cholesterol esters are **coated** with a layer of protein, cholesterol and phospholipids to form the particles called **chylomicrons**
- **Chylomicrons** enter the **lymph vessels** (because of the large size) and then are transferred into blood from lymph
- **Fatty acids** containing less than 10 to 12 carbon atoms enter the portal blood from mucosal cells
- Most of the fats are absorbed in the **upper part of small intestine**

Absorption of Lipids



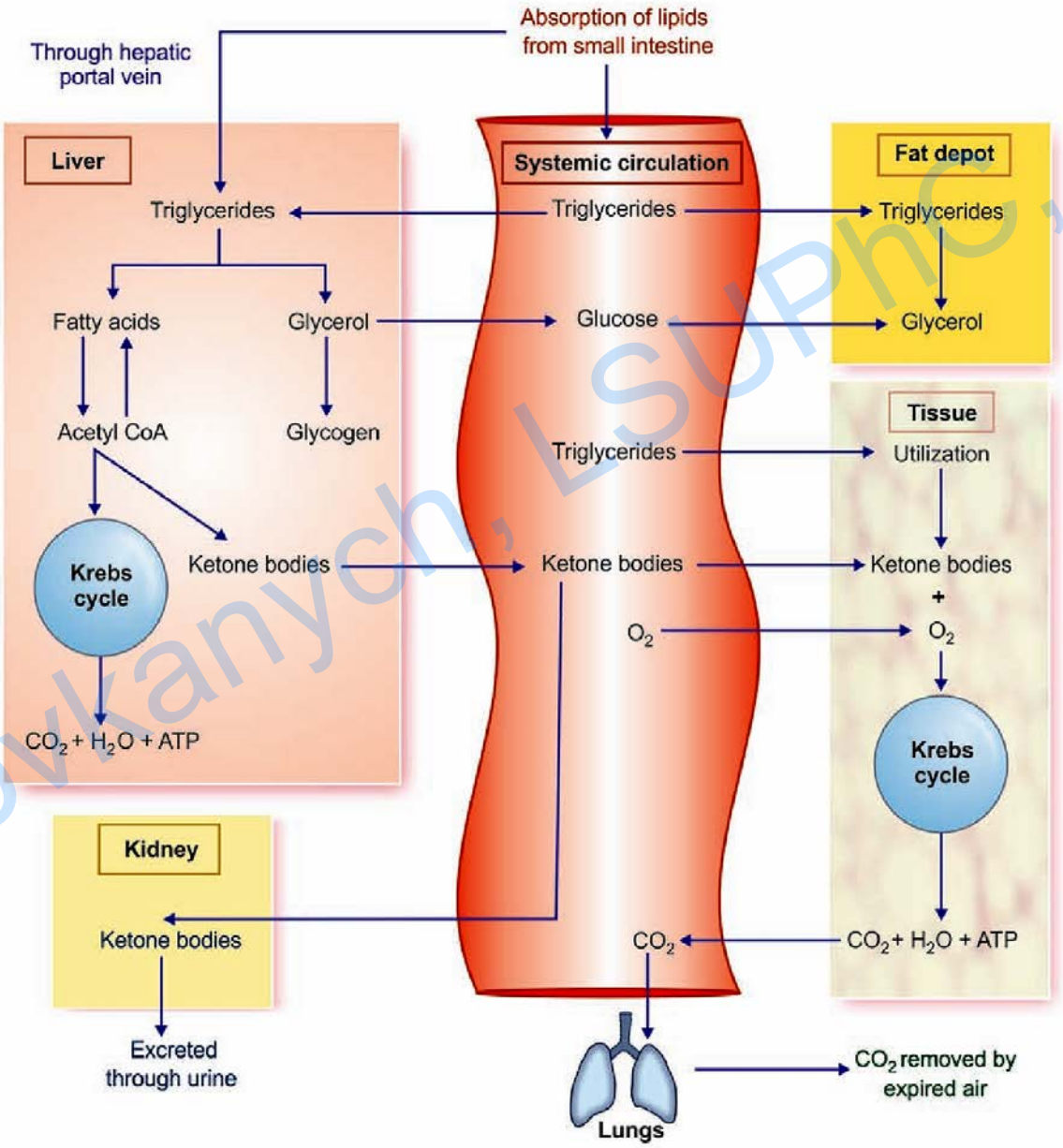
FFAs - free fatty acids

TG – triacylglycerol

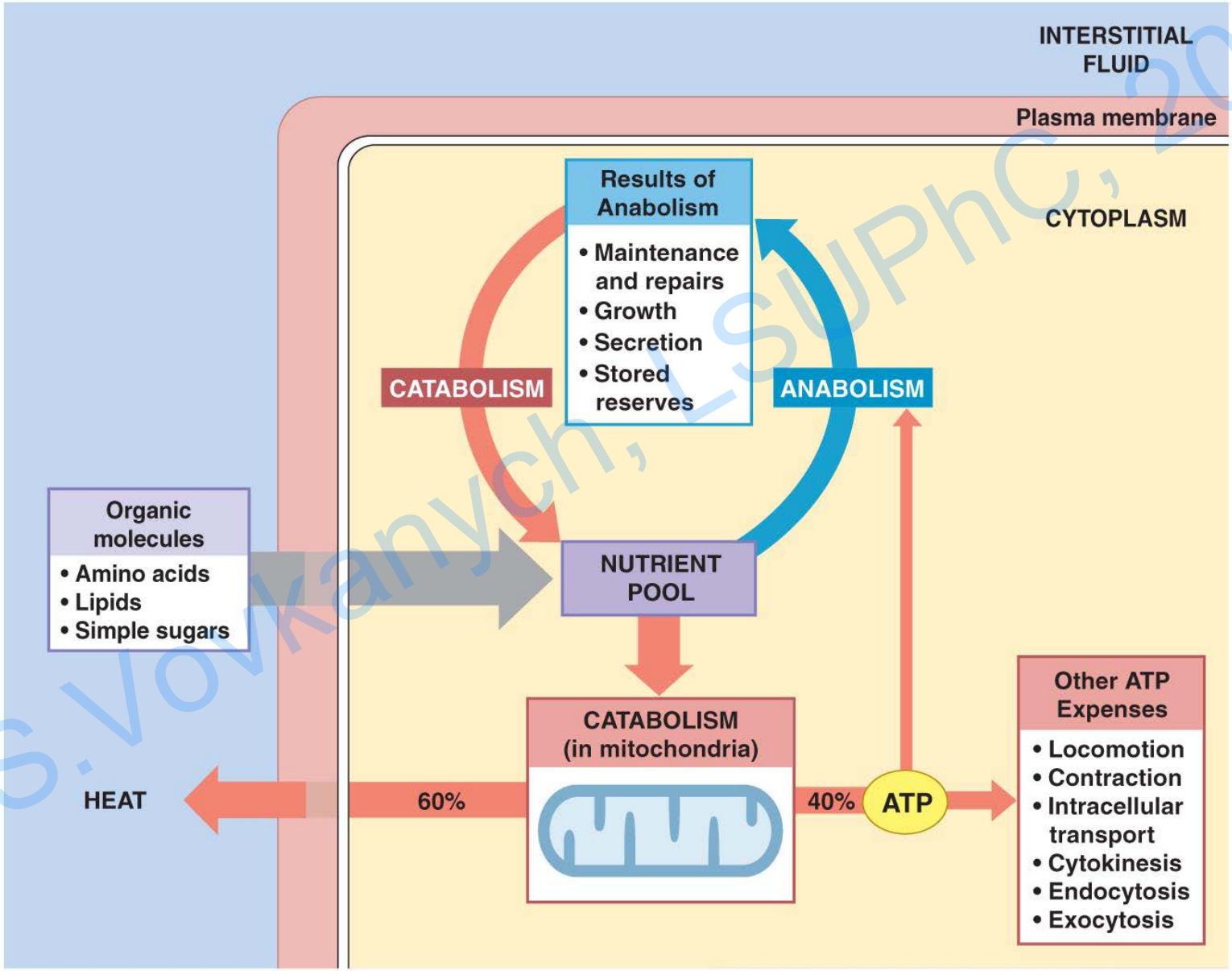
MG – monoacylglycerol

CHO-esters - cholesterol esters

Metabolism of Lipids



Metabolism



Metabolism

The **Nutrient Pool**

- Contains all **organic building blocks** cell needs
- To **provide energy**
- To **create new cellular components**
- Is **source of substrates** for catabolism and anabolism

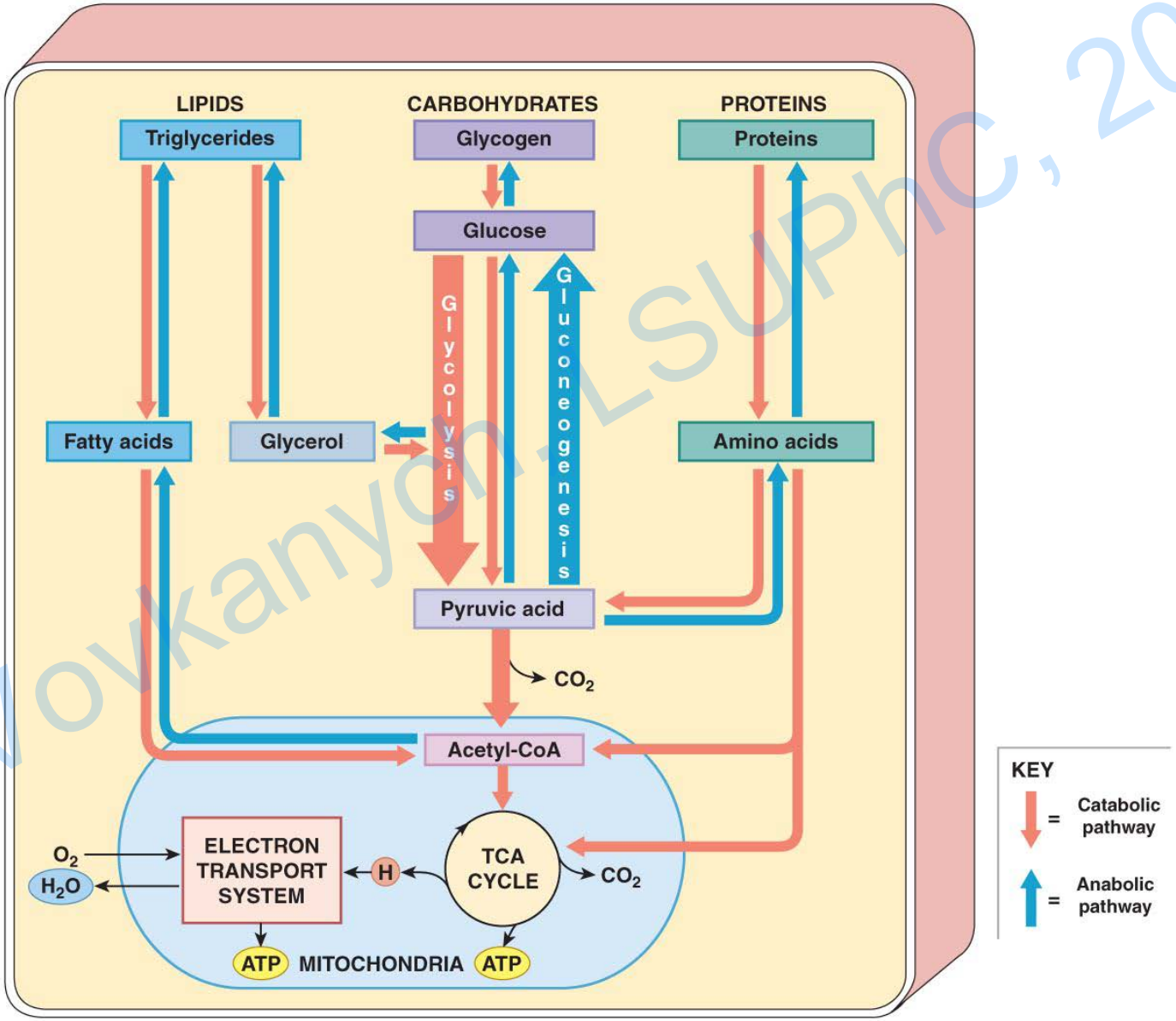
Catabolism

- Is the **breakdown** of organic substrates
- **Releases energy** used to synthesize high-energy compounds (e.g., ATP)

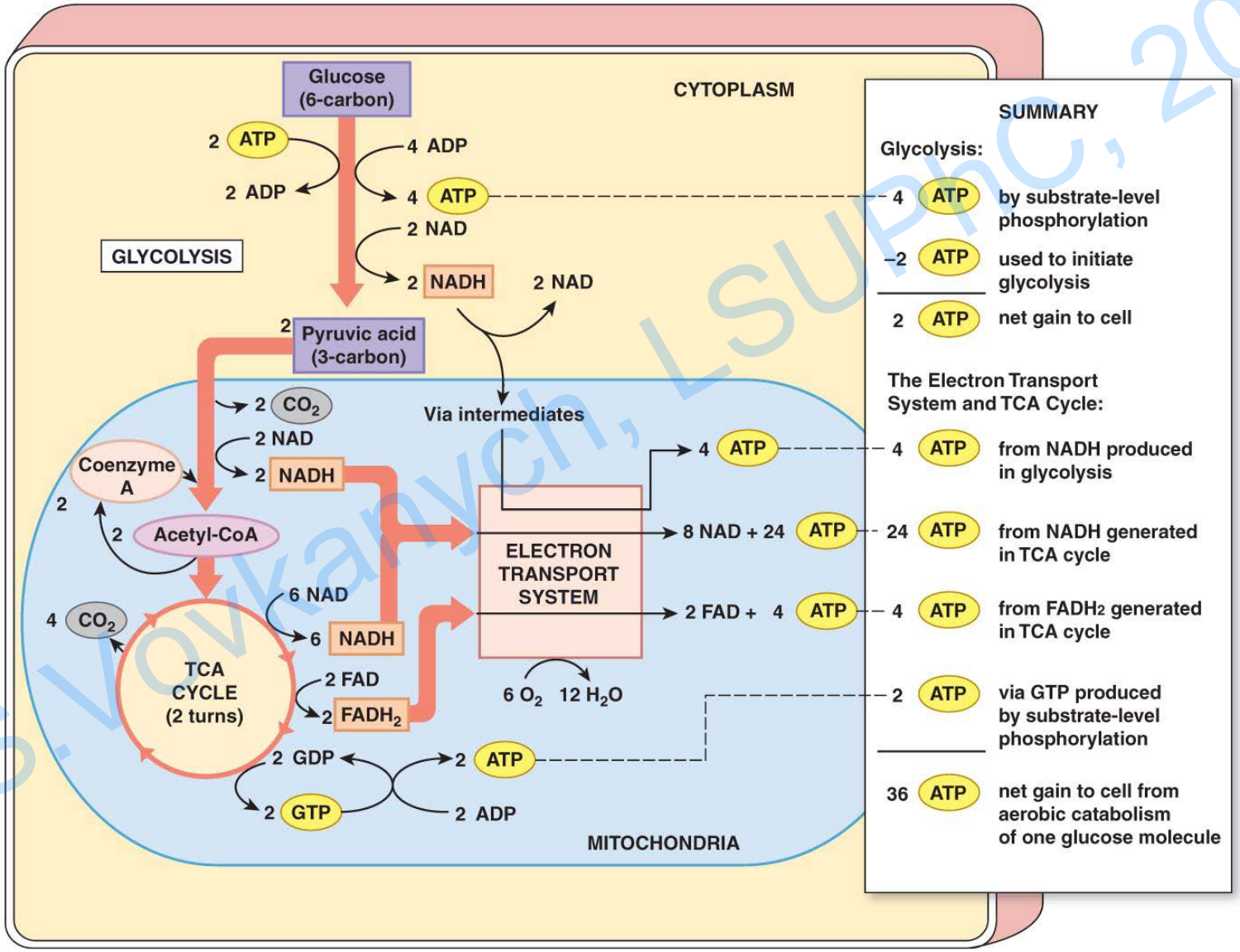
Anabolism

- Is the **synthesis** of new organic molecules
- Needs the energy (e.g., ATP) and substrates

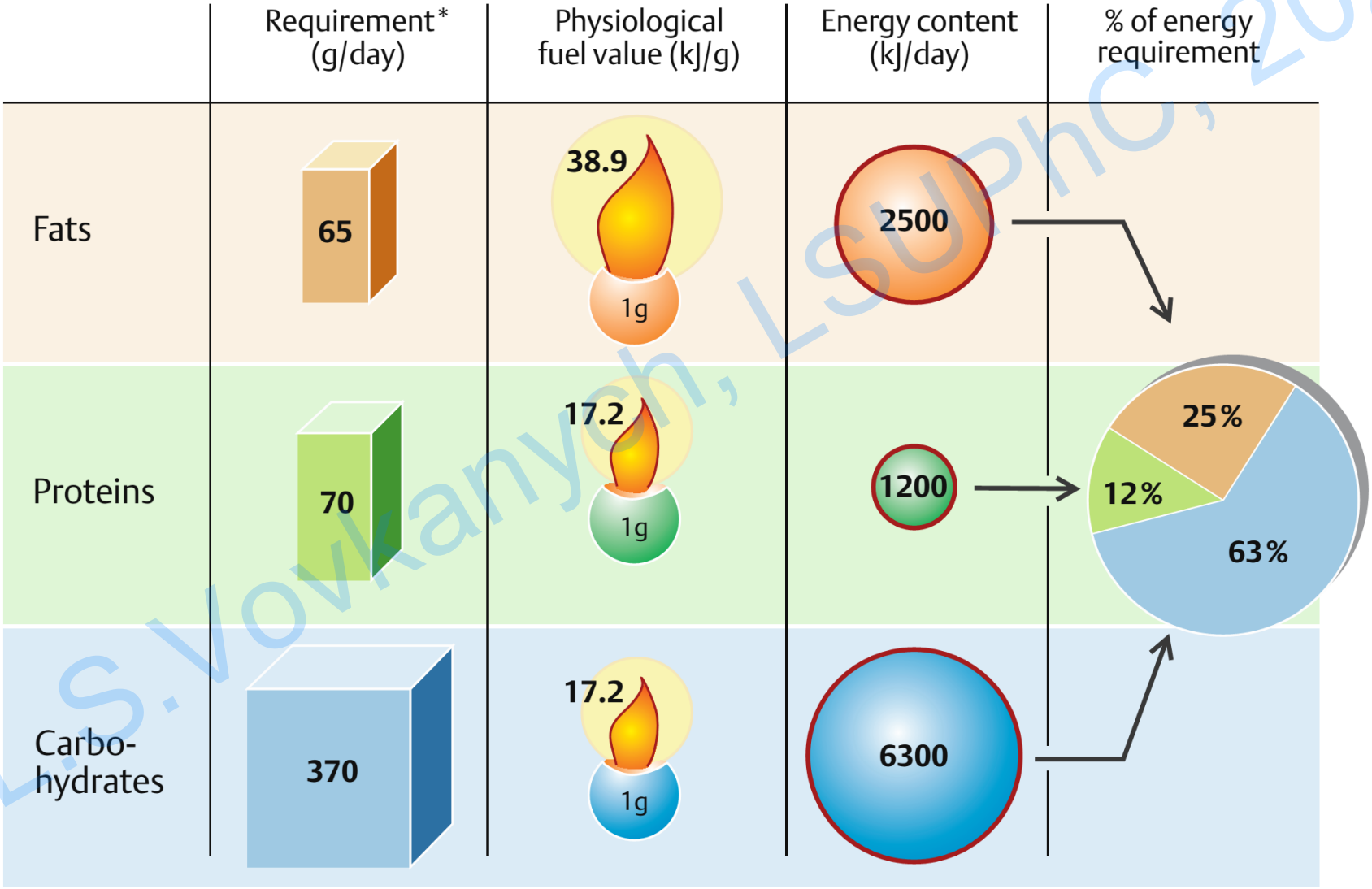
Pathways of Catabolism and Anabolism



Summary of the Energy Yield



Main Components of Food as Energy Sources



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