

CHAPTER 4. DIGESTION

1. GENERAL ORGANIZATION OF THE DIGESTIVE SYSTEM

Main structures

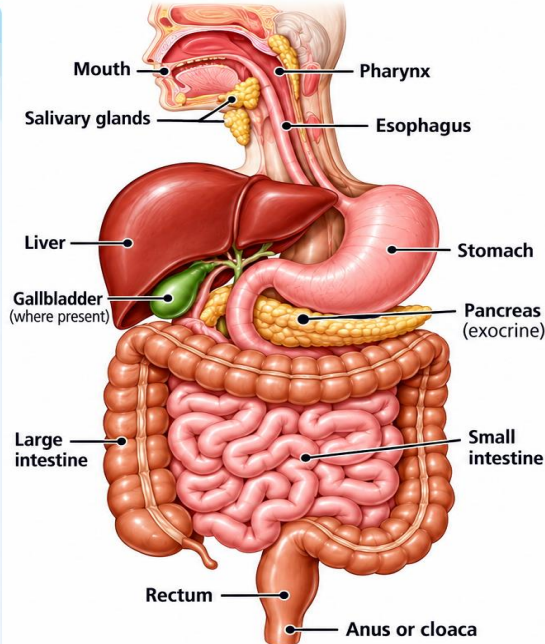
The digestive system consists of the alimentary canal plus accessory organs. The canal includes the mouth, pharynx, esophagus, stomach, small intestine, large intestine, rectum, and anus or cloaca; accessory structures include salivary glands, liver, gallbladder where present, and exocrine pancreas.

Alimentary canal (GI tract)

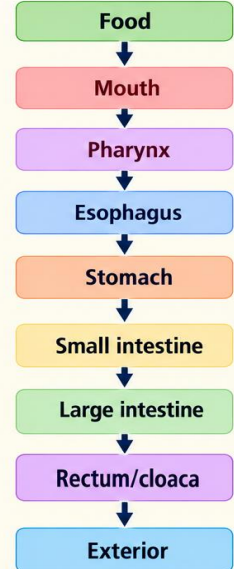
- Mouth
- Pharynx
- Esophagus
- Stomach
- Small intestine
- Large intestine
- Rectum
- Anus or cloaca

Accessory organs

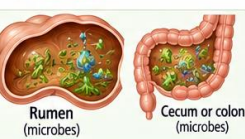
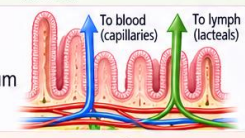
- Salivary glands
- Liver
- Gallbladder (where present)
- Exocrine pancreas



General pathway



2. CORE PROCESSES OF DIGESTION

Process	Meaning	Main example
Ingestion	Entry of food and water	Prehension and drinking 
Mechanical digestion	Physical reduction and mixing	Chewing, gastric mixing, gizzard grinding 
Chemical digestion	Enzymatic hydrolysis of nutrients	Pepsin and pancreatic enzymes 
Fermentation	Microbial conversion of feed	Rumen, cecum, or colon 
Absorption	Movement from lumen into blood or lymph	Uptake through intestinal epithelium 
Egestion	Removal of unabsorbed residue	Defecation through anus or cloaca 

Digestion of major nutrients

Digestion converts complex carbohydrates, proteins, and lipids into smaller molecules able to cross the intestinal epithelium; most enzymatic digestion takes place in the small intestine.

Carbohydrates



Proteins

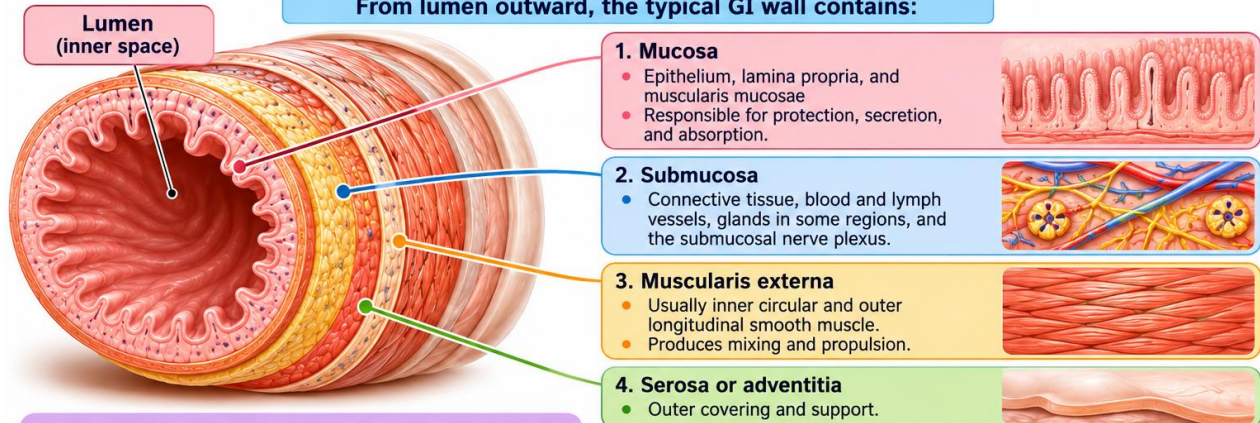


Lipids



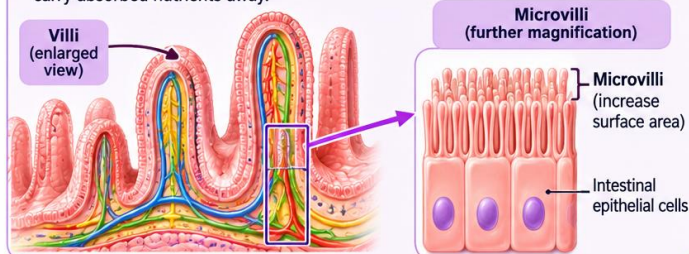
3. DIGESTIVE WALL

From lumen outward, the typical GI wall contains:

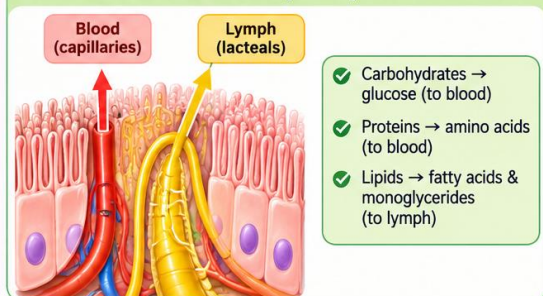


Small-Intestinal Mucosa: Villi and Microvilli

The small-intestinal mucosa contains villi and microvilli that enlarge the absorptive surface, while capillaries and lymphatic lacteals carry absorbed nutrients away.



Absorbed Nutrients: Pathways Away from the Lumen



1. MOTILITY OF THE GASTROINTESTINAL TRACT

Motility is the mechanical movement of food and digesta through the GI tract and includes several types of movement.

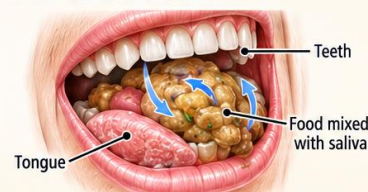
1. Prehension

Capture of food using lips, tongue, teeth, beak, or other structures.



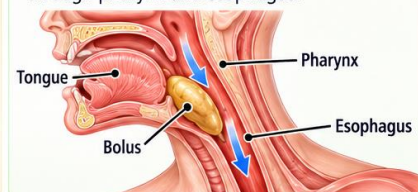
2. Mastication

Chewing reduces particle size and mixes feed with saliva.



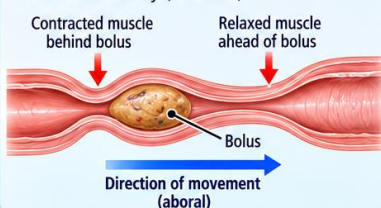
3. Deglutition

Swallowing transfers the bolus from mouth through pharynx and esophagus.



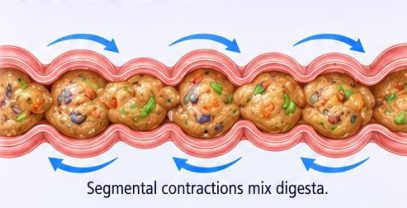
4. Peristalsis

A propagating contraction moves contents aborally (forward).



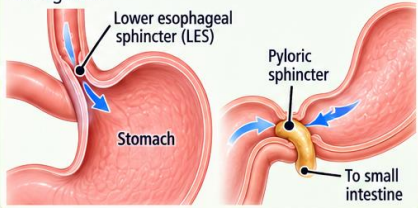
5. Segmentation

Local contractions mix contents and increase contact with the mucosa.



6. Sphincter tone

Controls movement between successive GI regions.



Integration of GI Motility

Peristalsis, segmentation, and sphincter resistance together regulate mixing, retention, and forward movement of digesta.

Peristalsis
propels contents forward

+

Segmentation
mixes contents and increases contact with the mucosa

+

Sphincter resistance
controls movement between successive GI regions

NEURAL CONTROL OF THE GASTROINTESTINAL TRACT

The gastrointestinal tract is regulated by the enteric nervous system, autonomic nervous system, and local sensory inputs.

1. Enteric nervous system (ENS)

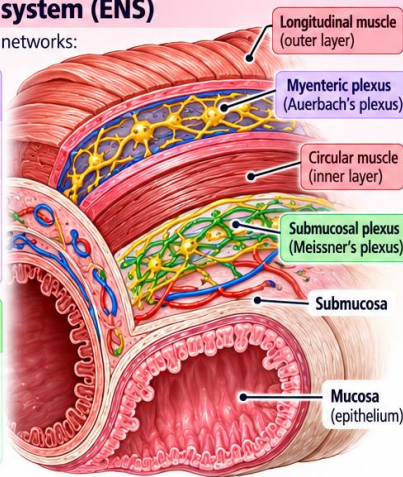
The ENS contains two main networks:

Myenteric plexus (Auerbach's plexus)

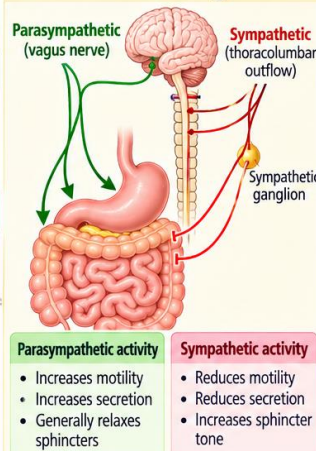
- Located between the circular and longitudinal muscle layers.
- Mainly coordinates smooth-muscle motility (e.g., peristalsis, segmentation).

Submucosal plexus (Meissner's plexus)

- Located in the submucosa.
- Primarily regulates mucosal secretion and local blood flow.



2. Autonomic regulation



3. Local sensory input

Local mechanoreceptors and chemoreceptors in the gut wall detect:

Mechanoreceptors

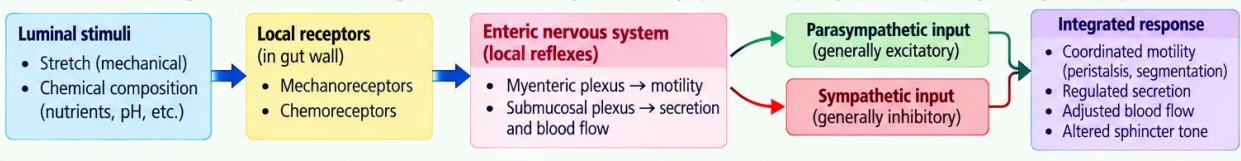
- Detect stretch (distension) and mechanical forces (e.g., from food).

Chemoreceptors

- Detect luminal composition (e.g., nutrients, pH, osmolarity, chemical signals).

4. Integrated neural control of GI function

The GI tract can generate local reflexes through the enteric nervous system, while sympathetic and parasympathetic pathways modify these responses.



SALIVA

Saliva lubricates food, assists swallowing, protects oral tissues, and supplies water and electrolytes.

Functions of saliva

- Lubricates food**
Moistens and lubricates feed, forming a bolus.
- Assists swallowing**
Helps form a cohesive bolus and facilitates deglutition.
- Protects oral tissues**
Keeps oral mucosa moist and provides protective factors (e.g., antimicrobial components).
- Supplies water and electrolytes**
Maintains moisture and electrolyte balance in the oral cavity and ingesta.



Composition of saliva

Water	~ 99%
Electrolytes	Na ⁺ , K ⁺ , Cl ⁻ , HCO ₃ ⁻ , phosphate (PO ₄ ³⁻)
Mucins (mucus)	Lubrication and protection
Enzymes	Varies by species (e.g., salivary amylase in many species)
Other components	Antimicrobial factors (e.g., lysozyme, IgA)

Species differences in salivary enzymes

Many species (e.g., humans, pigs, horses)

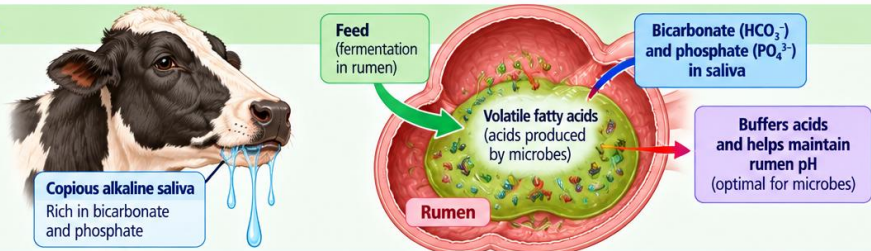
Salivary amylase begins starch (carbohydrate) digestion in the mouth.

Dogs and cats

Lack significant salivary amylase activity, so pancreatic amylase handles most starch digestion in the small intestine.

Special feature in ruminants

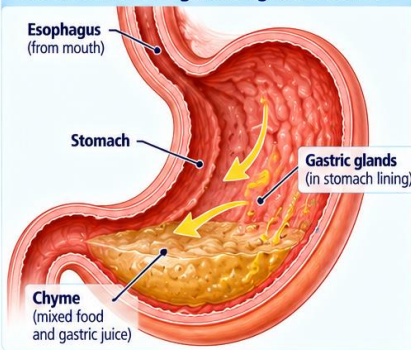
Ruminants produce copious, alkaline saliva that supplies bicarbonate (HCO₃⁻) and phosphate (PO₄³⁻). These buffers help maintain rumen pH by neutralizing acids formed during microbial fermentation of feed.



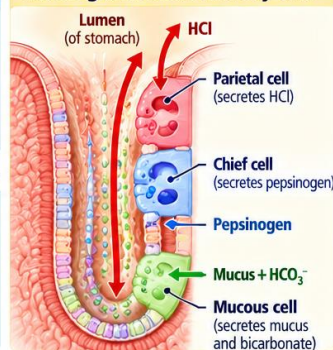
GASTRIC SECRETION

The stomach stores food, mixes it into chyme, and secretes gastric juice containing hydrochloric acid, pepsinogen, mucus, water and electrolytes.

The stomach: storage, mixing and secretion



Gastric glands and secretory cells



Main components of gastric secretion

Component	Source (cell type)	Functions
HCl Hydrochloric acid (HCl)	Parietal cells	• Lowers pH ($\approx 1-3$) • Denatures protein • Activates pepsinogen to pepsin
Pepsinogen	Chief cells	• Inactive precursor • Converted to pepsin for protein digestion
Mucus and bicarbonate (HCO_3^-)	Mucous cells	• Form a protective mucus layer on the gastric surface • Bicarbonate helps neutralize acid near the mucosa
Water and electrolytes	Various cells	• Contribute to gastric juice • Help dissolve and mix food

Functions of gastric secretion

Lowers pH

- Creates an acidic environment ($\approx 1-3$)
- Denatures dietary proteins
- Activates pepsinogen

Protein digestion

- Pepsin (active enzyme) begins protein breakdown in the stomach

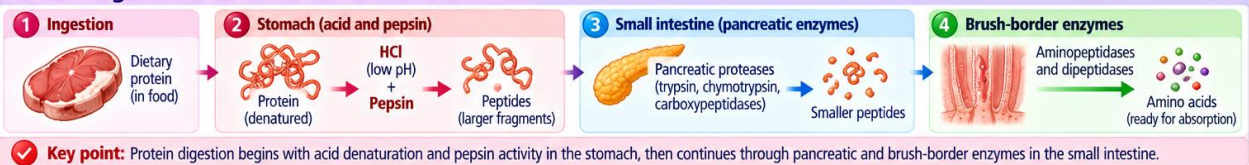
Protection

- Mucus and bicarbonate protect the gastric epithelium from acid and pepsin

Storage and mixing

- Stores food
- Mixes food with gastric juice to form chyme

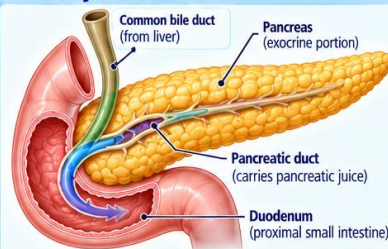
Protein digestion: from stomach to small intestine



PANCREATIC SECRETION

The exocrine pancreas releases bicarbonate-rich fluid and digestive enzymes into the proximal duodenum, where they neutralize gastric acid and digest carbohydrates, proteins, lipids, and nucleic acids.

Anatomy and secretion



Major components of pancreatic secretion

Component	Source (acinar/duct cell)	Main function
Bicarbonate (HCO_3^-)	Duct cells (secrete bicarbonate-rich fluid)	• Neutralizes gastric acid (raises pH to $\approx 6-7$ in duodenum) • Provides optimal pH for digestive enzymes
Digestive enzymes (amylase, lipase, nucleases, protease precursors)	Acinar cells (secrete enzymes)	• Digest major nutrient classes (carbohydrates, lipids, nucleic acids, and proteins)
Water and electrolytes (Na^+ , K^+ , Cl^-)	Duct and acinar cells	• Provide fluid for enzyme delivery • Help flush enzymes into the duodenum

How pancreatic secretion is released



Pancreatic enzymes and their roles in digestion

1 Carbohydrate digestion

Pancreatic amylase

Starch (complex carbohydrate) is broken down into smaller sugars (e.g., maltose, oligosaccharides).

- Amylase hydrolyzes starch into smaller carbohydrates.

2 Lipid digestion

Pancreatic lipase

Triglycerides (dietary fats) are broken down into fatty acids and monoglycerides.

- Lipase hydrolyzes dietary triglycerides into fatty acids and monoglycerides (then form micelles with bile salts).

3 Nucleic acid digestion

Pancreatic nucleases (RNase and DNase)

DNA and RNA (nucleic acids) are broken down into nucleotides.

- Nucleases hydrolyze nucleic acids into nucleotides.

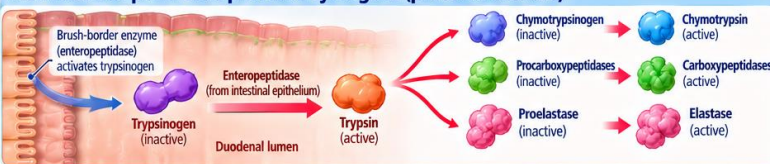
4 Protein digestion (protease precursors)

Proteases secreted as inactive zymogens

Proteins (dietary protein) are broken down into peptides (smaller fragments).

- Trypsinogen $\rightarrow$ trypsin
- Chymotrypsinogen $\rightarrow$ chymotrypsin
- Procarboxypeptidases $\rightarrow$ carboxypeptidases
- Proelastase $\rightarrow$ elastase
- Secreted as inactive zymogens to prevent pancreatic self-digestion.

Activation of pancreatic protease zymogens (protease cascade)

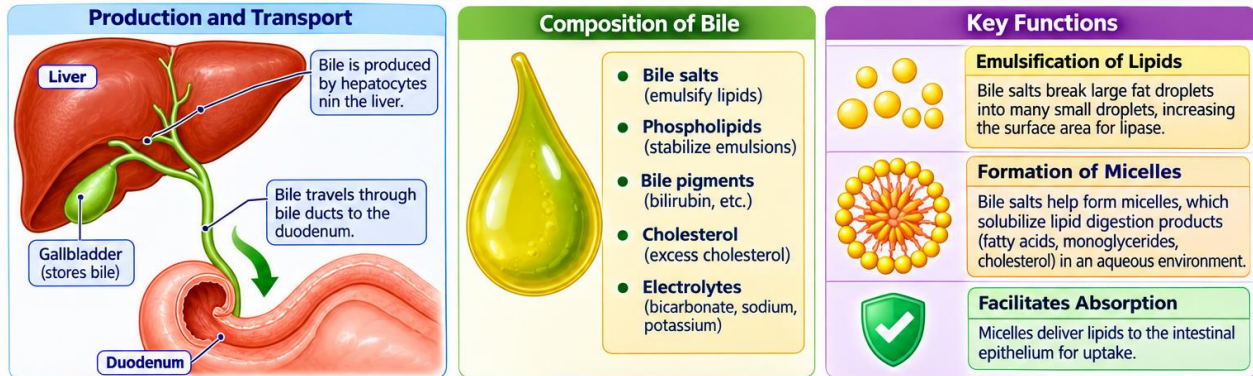


Key functions of pancreatic secretion

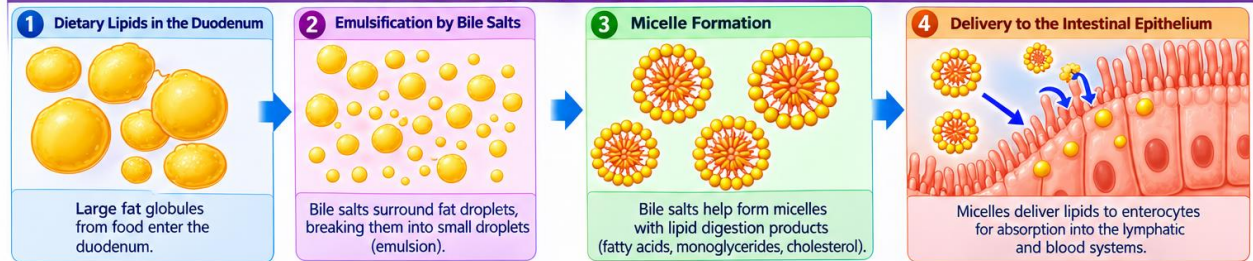
- ✓ Neutralizes gastric acid (bicarbonate raises pH to $\approx 6-7$).
- ✓ Provides digestive enzymes for carbohydrates, lipids, nucleic acids, and proteins.
- ✓ Enzymes are secreted as inactive zymogens, reducing the risk of pancreatic self-digestion.
- ✓ Intestinal activation of proteases initiates a protease cascade, amplifying protein digestion.
- ✓ Works together with bile and intestinal brush-border enzymes to complete digestion in the small intestine.

BILE

The liver produces bile. Bile salts emulsify dietary lipids and help form micelles, making water-insoluble products of lipid digestion accessible to the intestinal epithelium.



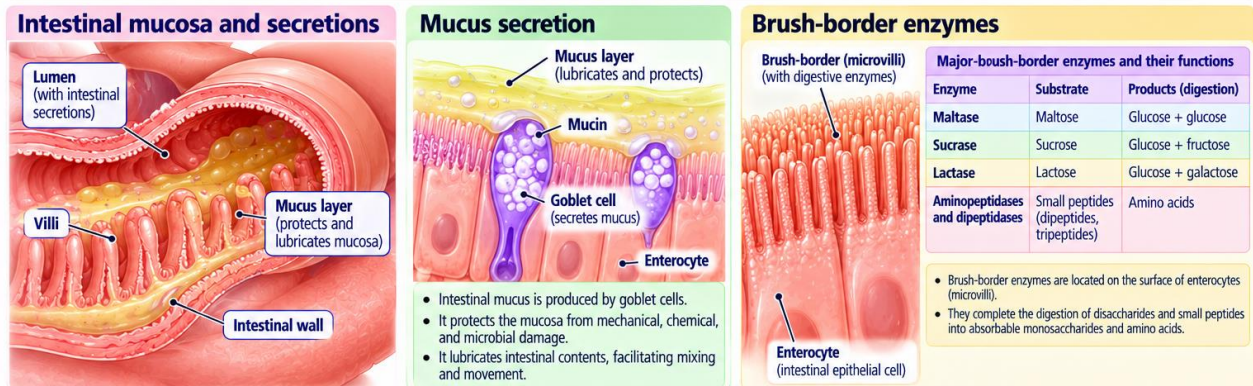
How Bile Helps Lipid Digestion and Absorption



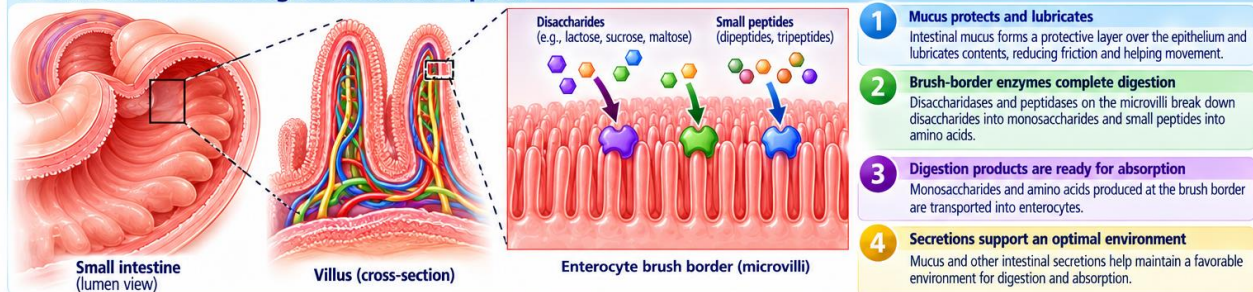
Bile is essential for lipid digestion because it emulsifies fats, forms micelles, and enables efficient absorption of dietary lipids.

INTESTINAL SECRETION

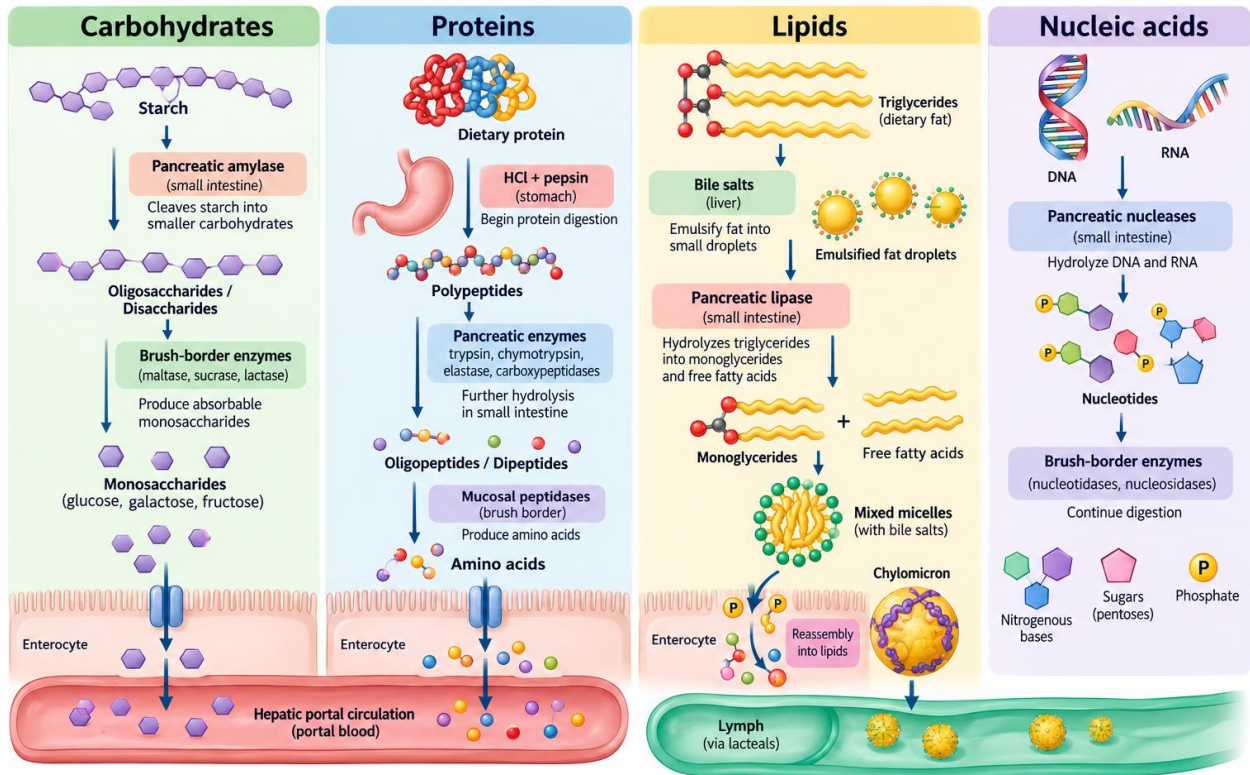
The intestine secretes mucus to protect and lubricate the mucosa, and brush-border enzymes complete the digestion of disaccharides and small peptides at the surface of enterocytes.



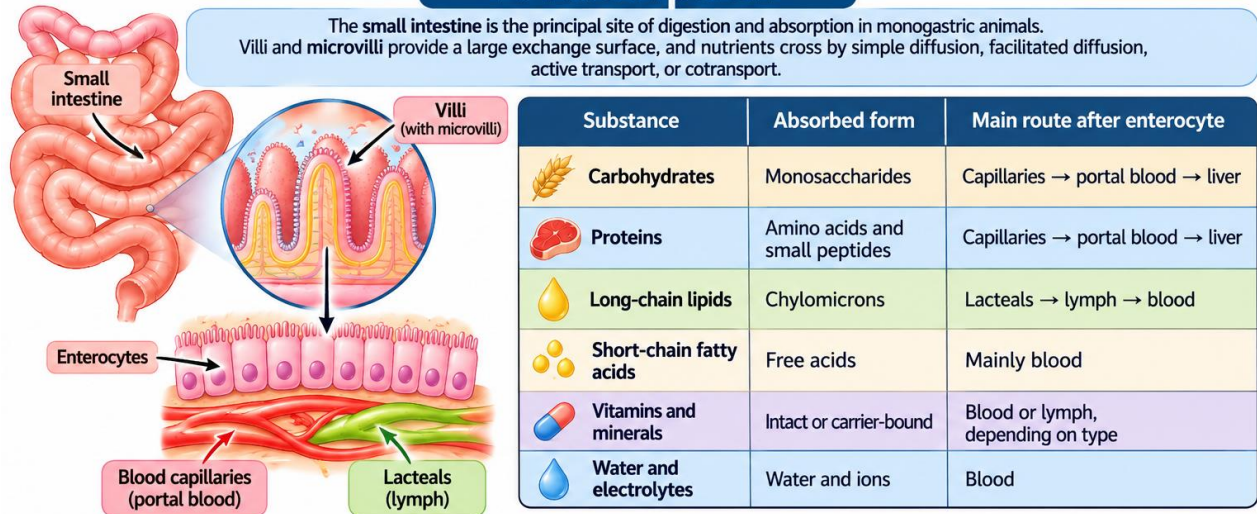
Location and roles in digestion and absorption



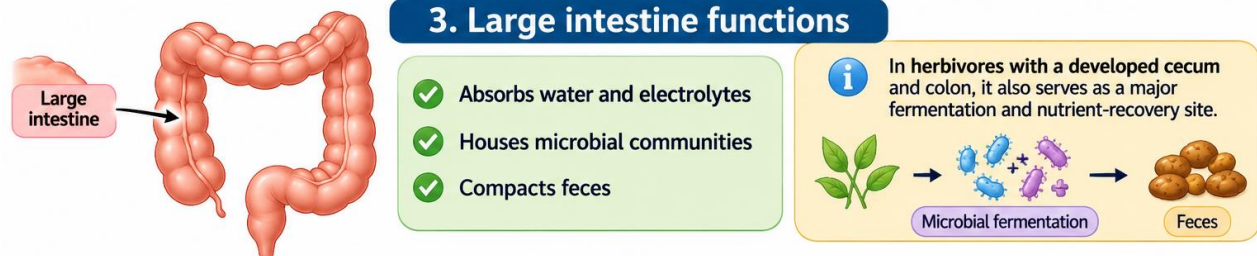
1. Chemical digestion of nutrients



2. Absorption

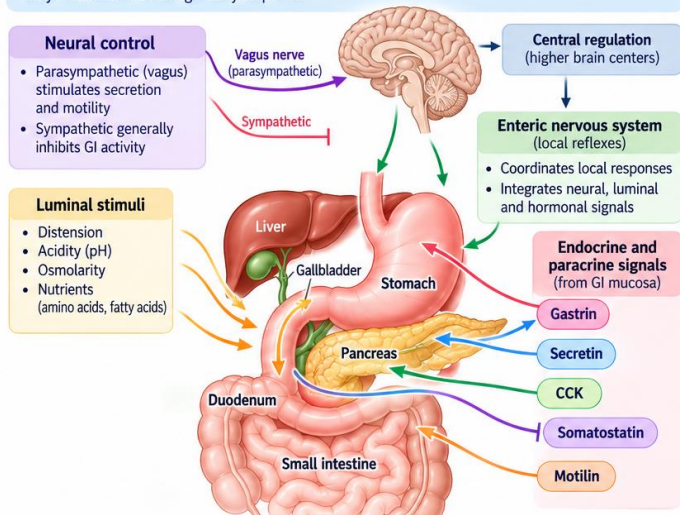


3. Large intestine functions



6. Regulation of digestion

Digestion is controlled by interactions among local enteric circuits, autonomic nerves, luminal stimuli, and endocrine or paracrine signals. Distension, acidity, osmolarity, amino acids, and fatty acids can initiate regulatory responses.



Regulator	Main stimulus	Major actions
Gastrin	Peptides and stomach distension	- Increases gastric acid secretion - Increases gastric activity (motility and mucosal growth)
Secretin	Acid entering duodenum	- Increases pancreatic and biliary bicarbonate secretion - Helps neutralize acid in the duodenum
Cholecystikinin (CCK)	Fatty acids and amino acids	- Stimulates pancreatic enzyme secretion - Stimulates gallbladder contraction (bile release) - Slows gastric emptying
Motilin	Interdigestive period	- Supports migrating motor activity (MMC) between meals - Promotes GI motility
Somatostatin	Acid and local signals	- Broadly inhibits GI secretion (gastric, pancreatic, intestinal) - Inhibits endocrine activity - Reduces GI motility

Major effects after a meal



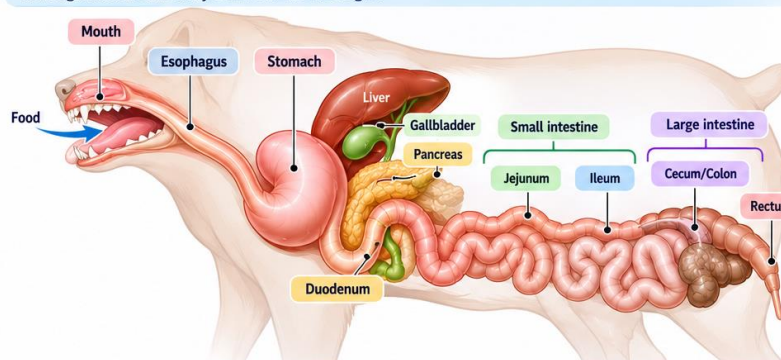
Interdigestive period



Secretin is a major mediator of pancreatic bicarbonate secretion after duodenal acidification, while CCK and vagal pathways promote post-meal pancreatic enzyme secretion. Species differences are important, particularly between mature ruminants and single-stomached animals.

7. Monogastric mammals

Monogastric animals have a single-chambered stomach. In common domestic examples such as pigs, dogs, and cats, digestion relies mainly on gastric, pancreatic, and intestinal enzymes, although microbial activity occurs in the distal gut.



Main functions along the digestive tract

Mouth	- Ingestion, chewing and mechanical breakdown - Mixing with saliva (lubrication, initial enzymatic action)
Esophagus	Transport of food to the stomach (peristalsis)
Stomach	- Stores and acidifies food (low pH) - Initiates protein digestion (pepsin)
Duodenum	- Receives pancreatic secretion (enzymes and bicarbonate) - Receives bile from the liver (emulsification of lipids)
Jejunum	- Continues digestion - Major site of nutrient absorption
Ileum	- Completes digestion - Absorbs remaining nutrients (e.g. bile salts, vitamin B12)
Cecum/Colon	- Recovers water and electrolytes - Houses microbial communities - Ferments residual substrates (especially in pigs) - Forms and compacts feces
Rectum	Stores and expels feces

Digestive flow in monogastric mammals



Key points

- The stomach stores and acidifies food and initiates protein digestion.
- The duodenum receives pancreatic secretion and bile.
- The jejunum and ileum complete digestion and absorb nutrients.
- The colon recovers water and electrolytes and forms feces.

Examples of monogastric mammals

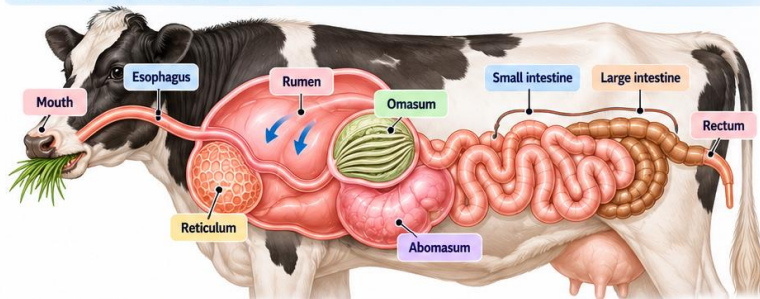
Pig (omnivore)	Dog (carnivore)	Cat (carnivore)
- More developed large intestine and cecum - Significant microbial fermentation - Suited to a mixed diet	- Relatively simple digestive tract - Shorter large intestine - Adapted to nutrient-dense, high-protein and high-fat diet	- Short and simple digestive tract - Small cecum and colon - Highly adapted to animal protein and fat

Species differences

Diet explains important species differences. Carnivores generally have comparatively simple tracts suited to nutrient-dense food, while omnivorous pigs have more substantial large-intestinal fermentation; digestive structure and enzyme expression broadly reflect dietary chemistry.

7. Ruminants

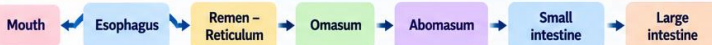
Cattle, sheep, goats, and buffalo possess three forestomach compartments—the rumen, reticulum, and omasum—followed by the glandular abomasum.



Forestomach compartments

Compartment	Principal role
Rumen	Large anaerobic fermentation chamber; mixing and VFA absorption.
Reticulum	Particle sorting; participates in rumination and eructation.
Omasum	Further particle reduction; absorption of water, electrolytes, and fermentation products.
Abomasum	"True stomach"; acid and enzymatic digestion.

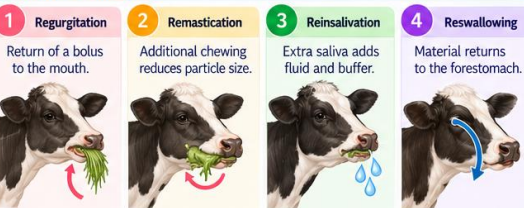
Digestive flow in ruminants



The rumen contains bacteria, protozoa, anaerobic fungi, methanogenic archaea, and viruses. Microbial communities degrade cellulose, starch, proteins, and some lipids, producing volatile fatty acids—mainly acetate, propionate, and butyrate—that the animal absorbs as major metabolic fuels.



Rumination cycle



Fermentation products

- Volatile fatty acids (VFA):**
 - Acetate
 - Propionate
 - Butyrate
- Carbon dioxide (CO_2)
- Methane (CH_4)

Eructation and bloat

- Fermentation produces CO_2 and methane.
- Eructation removes these gases.
- Failure of gas removal can cause ruminal tympany, or bloat.

Microbial protein

- Microbes convert nitrogen sources into microbial protein.
- After microbes pass to the abomasum and small intestine, their proteins can be digested and supply amino acids to the host.

Preruminant calves

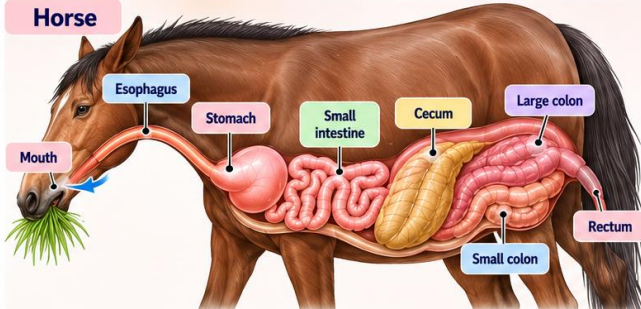


Young milk-fed calves are preruminants. Their digestive physiology initially resembles that of monogastric young, and the forestomach develops with solid-feed intake and microbial colonization.

9. Hindgut fermenters

Horses and rabbits have a simple stomach but an enlarged cecum and colon in which microbes ferment structural carbohydrates. Fermentation therefore occurs after the main enzymatic and absorptive region of the small intestine.

Horse



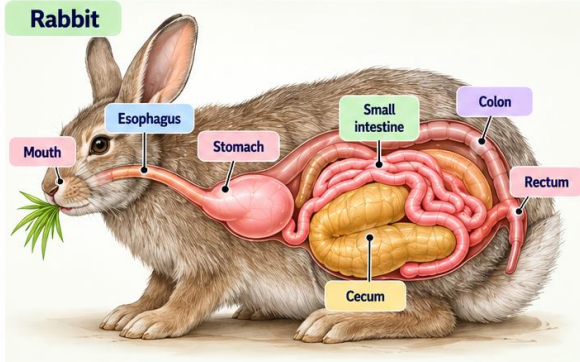
Digestive flow in the horse



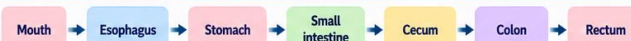
Key points in horses

- Horses absorb sugars, amino acids, and lipids in the small intestine.
- Cecal and colonic microbes convert fiber to volatile fatty acids, which the hindgut absorbs for energy.
- Microbial protein is less accessible than in ruminants because fermentation occurs after the small intestine.

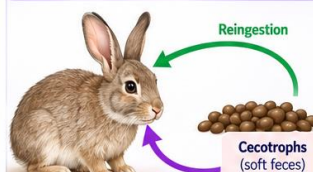
Rabbit



Digestive flow in the rabbit



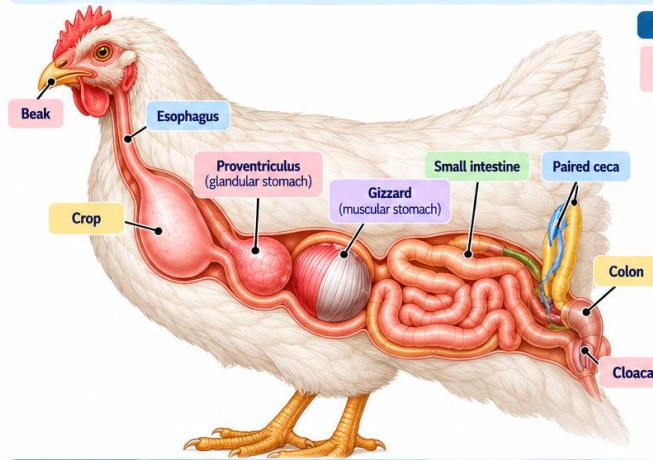
Cecotrophy in rabbits



- Rabbits produce nutrient-rich soft feces called cecotrophs.
- Cecotrophy returns microbial nutrients to the stomach and small intestine for further digestion and absorption.

10. Avian digestion

Birds lack teeth, so they combine storage, chemical digestion, and mechanical grinding in specialized organs. Food may be stored in the crop, enters the glandular proventriculus for gastric secretion, and then passes to the muscular gizzard for grinding.



Digestive flow in birds

Beak → Esophagus → Crop → Proventriculus → Gizzard → Small intestine → Paired ceca → Colon → Cloaca

Functions of each organ

- | | | |
|---|-----------------|--|
| 1 | Crop | <ul style="list-style-type: none"> Temporary storage and moistening of food. Development varies with diet and species. |
| 2 | Proventriculus | <ul style="list-style-type: none"> Secretes acid and enzymes. |
| 3 | Gizzard | <ul style="list-style-type: none"> Mechanically grinds food, often aided by swallowed grit. |
| 4 | Small intestine | <ul style="list-style-type: none"> Principal site of chemical digestion and absorption. |
| 5 | Ceca | <ul style="list-style-type: none"> Variable microbial fermentation. |
| 6 | Colon | |
| 7 | Cloaca | <ul style="list-style-type: none"> Shared terminal chamber of digestive, urinary, and reproductive systems. |

The two-part stomach

Proventriculus (glandular stomach)



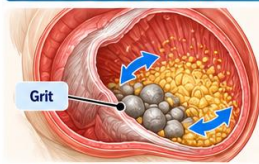
- Secretes hydrochloric acid and digestive enzymes.
- Performs chemical (glandular) digestion.

Gizzard (muscular stomach)



- Strong muscular walls.
- Mechanically grinds food, often with the help of swallowed grit.
- Performs mechanical reduction of particle size.

Role of grit in grinding



Swallowed grit helps the gizzard to mechanically grind food.

Key points



- Birds lack teeth, so they use a crop for storage, a proventriculus for gastric secretion, and a gizzard for mechanical grinding.
- The small intestine is the main site of digestion and absorption.
- The ceca provide variable microbial fermentation.
- The cloaca is a common chamber for digestive, urinary, and reproductive systems.