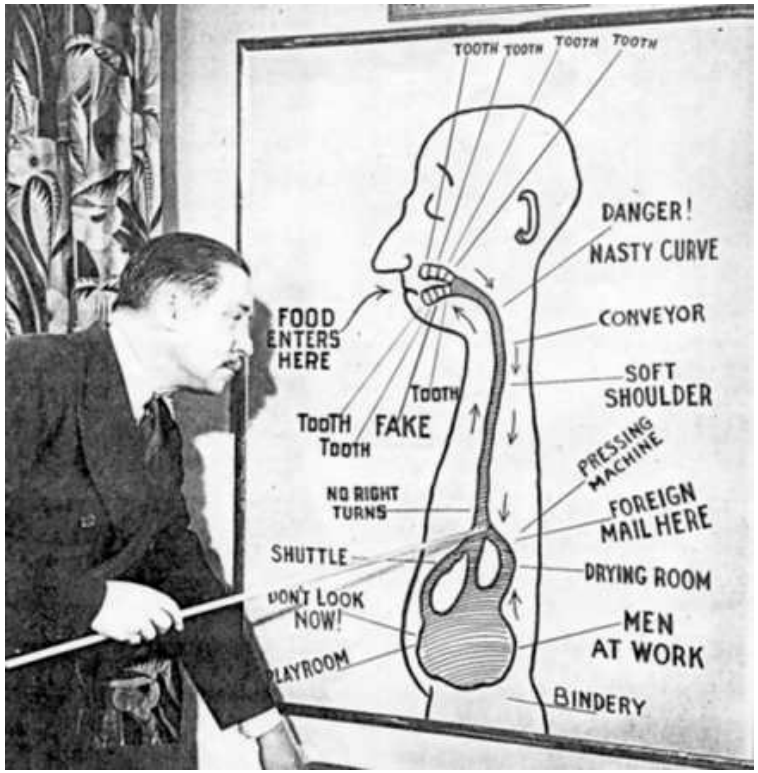

http://www.geocities.com/emruf4/chart.jpg

食品與營養化學(00070256)

Food and nutritional chemistry

保健營養學系三年級

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Digestion and Absorption

Learning Objectives

- **Structures of the GI tract (1 h)**
- **Regulation of the digestive and absorption processes (1.5 h)**
- **Macronutrient digestion and absorption (1.5 h)**

References

- **Gropper SS, Smith JL, Groff JL. Advanced Nutrition and Human Metabolism, 5th ed. Wadsworth: Belmont, 2009.**
- **Gropper SS, Smith JL, Groff JL. Advanced Nutrition and Human Metabolism, 4th ed. Wadsworth: Belmont, 2005.**
- **Groff JL, Gropper, SS. Advanced Nutrition and Human Metabolism, 3rd ed. Wadsworth Thompson Learning: Belmont, 2000.**
- **Linder MC. Nutritional Biochemistry and Metabolism: with Clinical Applications, 2nd ed. Elsevier: New York, 1991.**

Gastrointestinal tract

- **upper gastrointestinal tract**

  mouth

  pharynx

  esophagus

  stomach

- **lower gastrointestinal tract**

  small intestine (duodenum, jejunum, ileum)

  cecum

  colon

  rectum

  anal canal

  } **large intestine**

Gastrointestinal tract

- **colon**

  ascending colon

  transverse colon

  descending colon

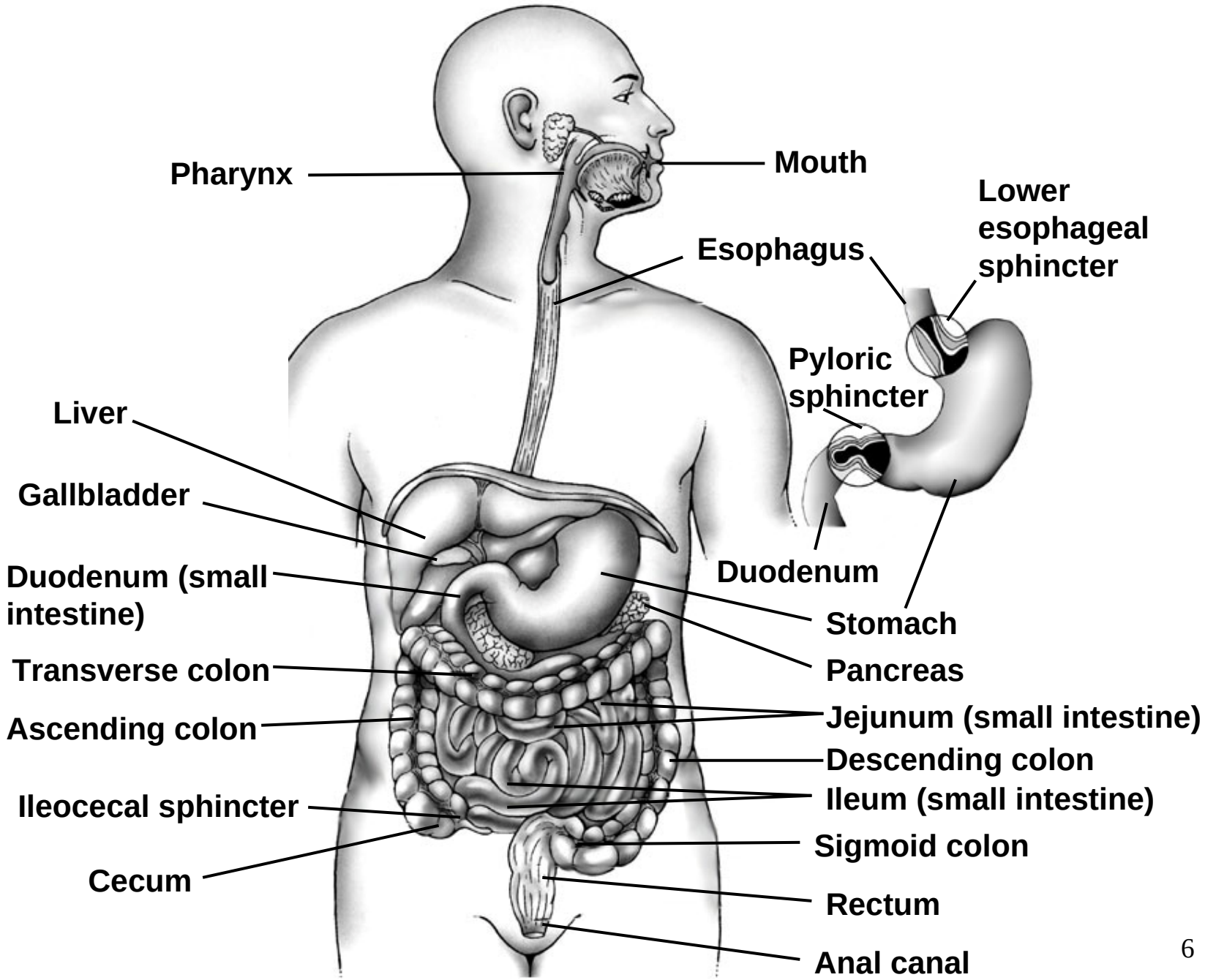
  sigmoid colon

- **accessory organs**

  liver

  gallbladder

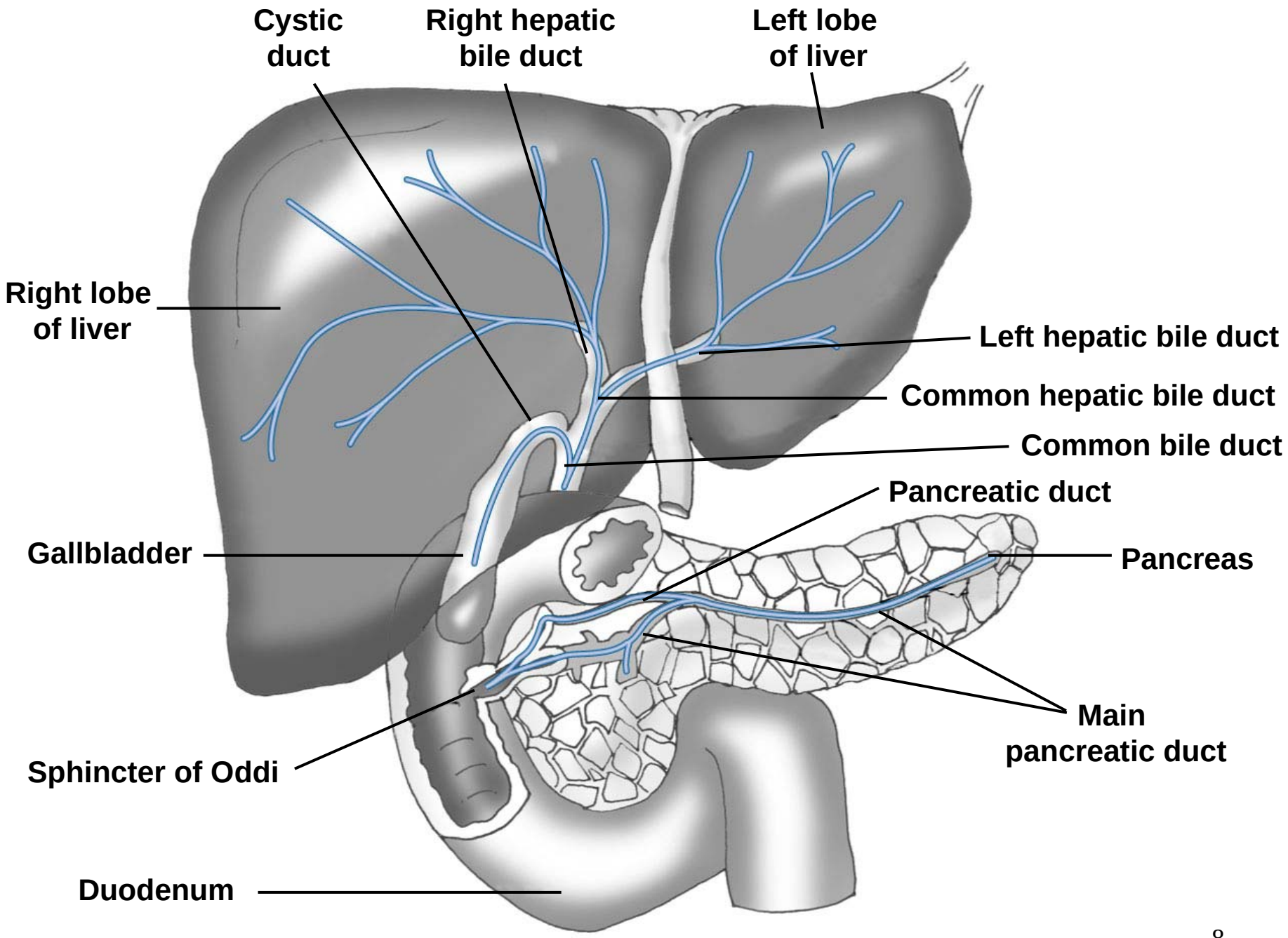
  pancreas



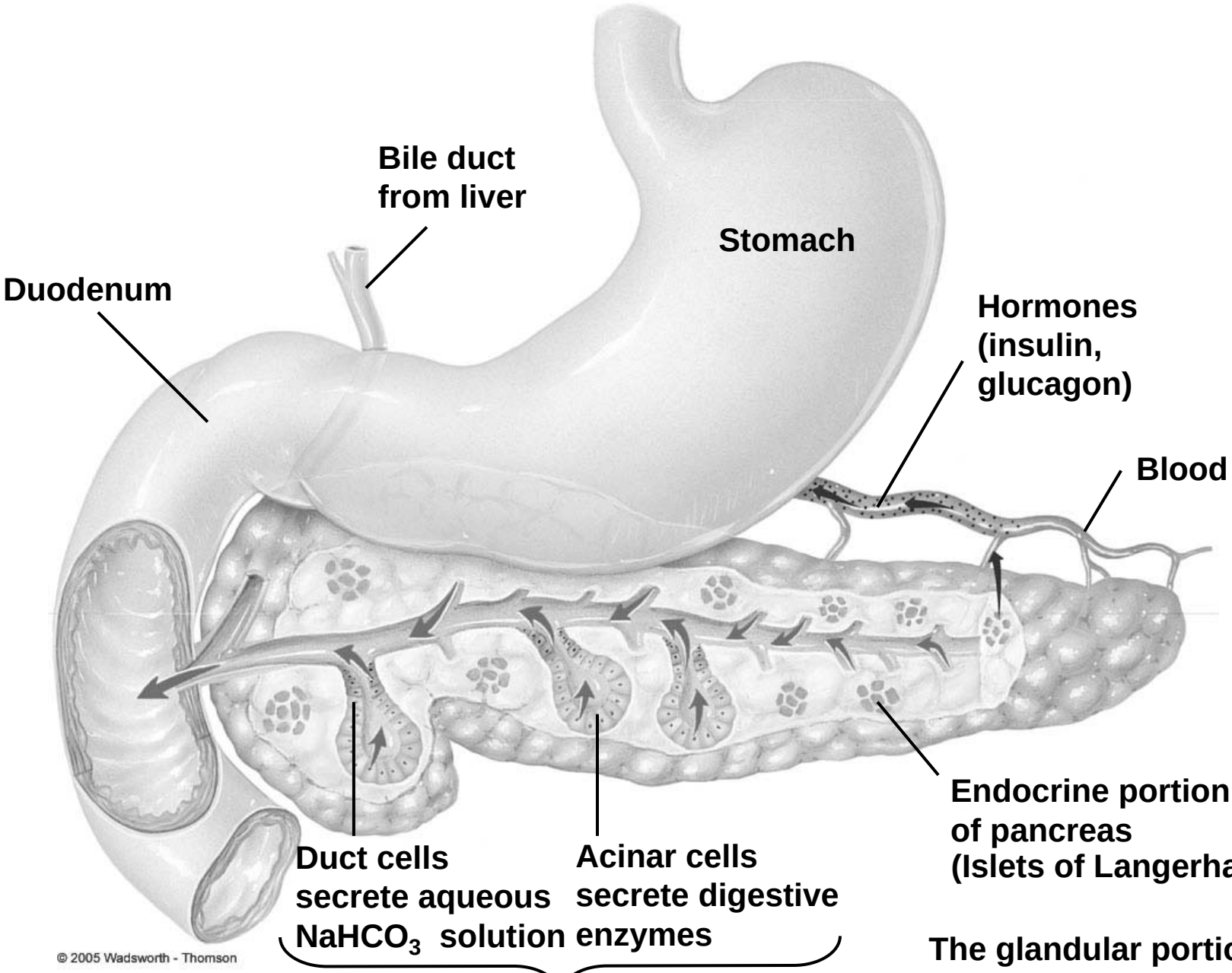
Gropper *et al.* 2005

Sphincter and valve

- **upper esophageal sphincter:**
  between pharynx and esophagus
- **lower esophageal sphincter:**
  between esophagus and stomach
- **pyloric sphincter:**
  between stomach and duodenum
- **Oddi's sphincter:**
  between bile pancreatic duct and duodenum
- **ileocecal valve:**
  between ileum and cecum

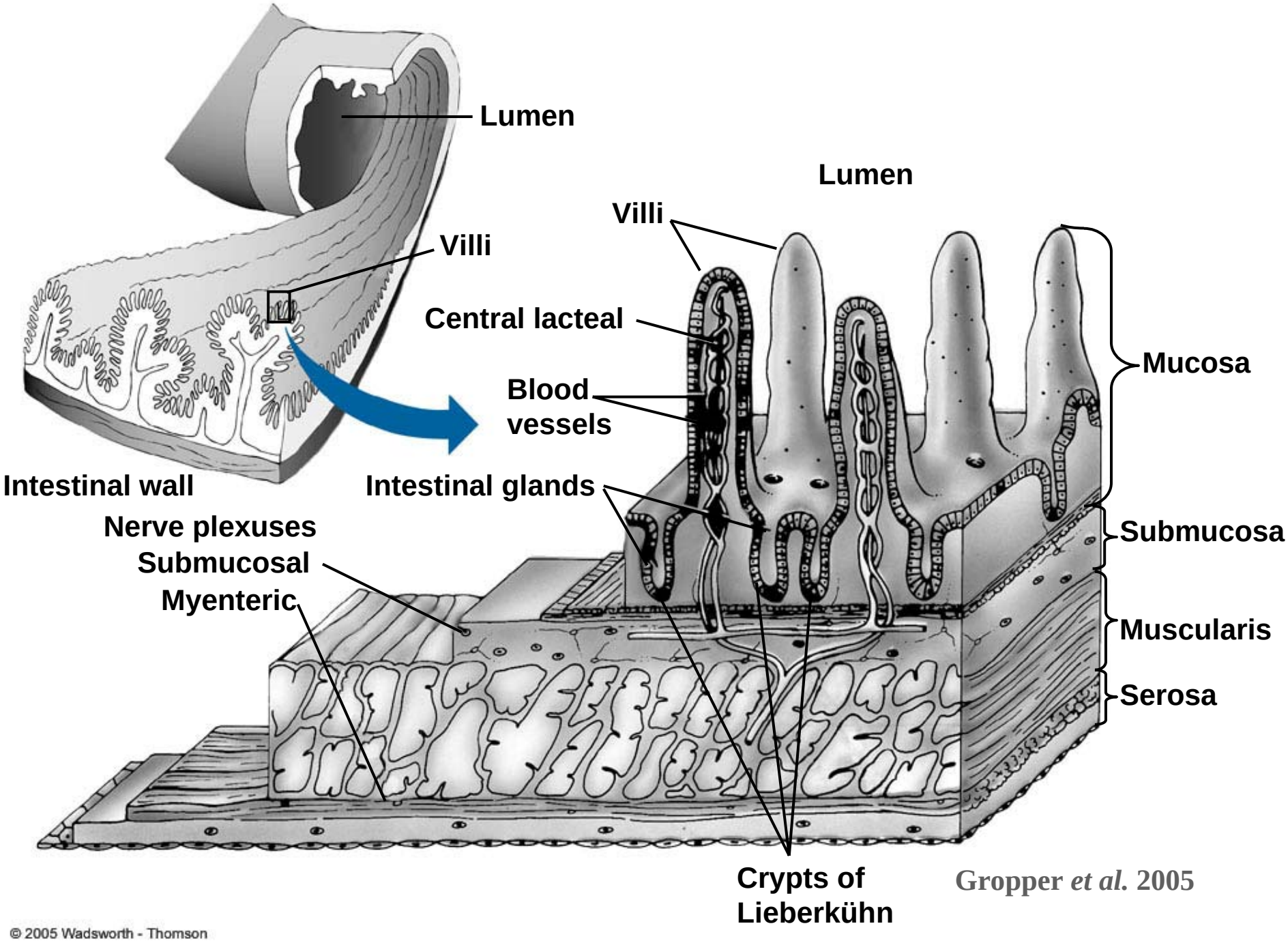


Gropper *et al.* 2005



Gropper *et al.* 2005

The glandular portions of the pancreas are grossly eggagerated.


Lumen
Villi
Intestinal wall
Lumen
Villi
Central lacteal
Blood vessels
Intestinal glands
Nerve plexuses
Submucosal
Myenteric
Mucosa
Submucosa
Muscularis
Serosa
Crypts of Lieberkühn
Gropper *et al.* 2005
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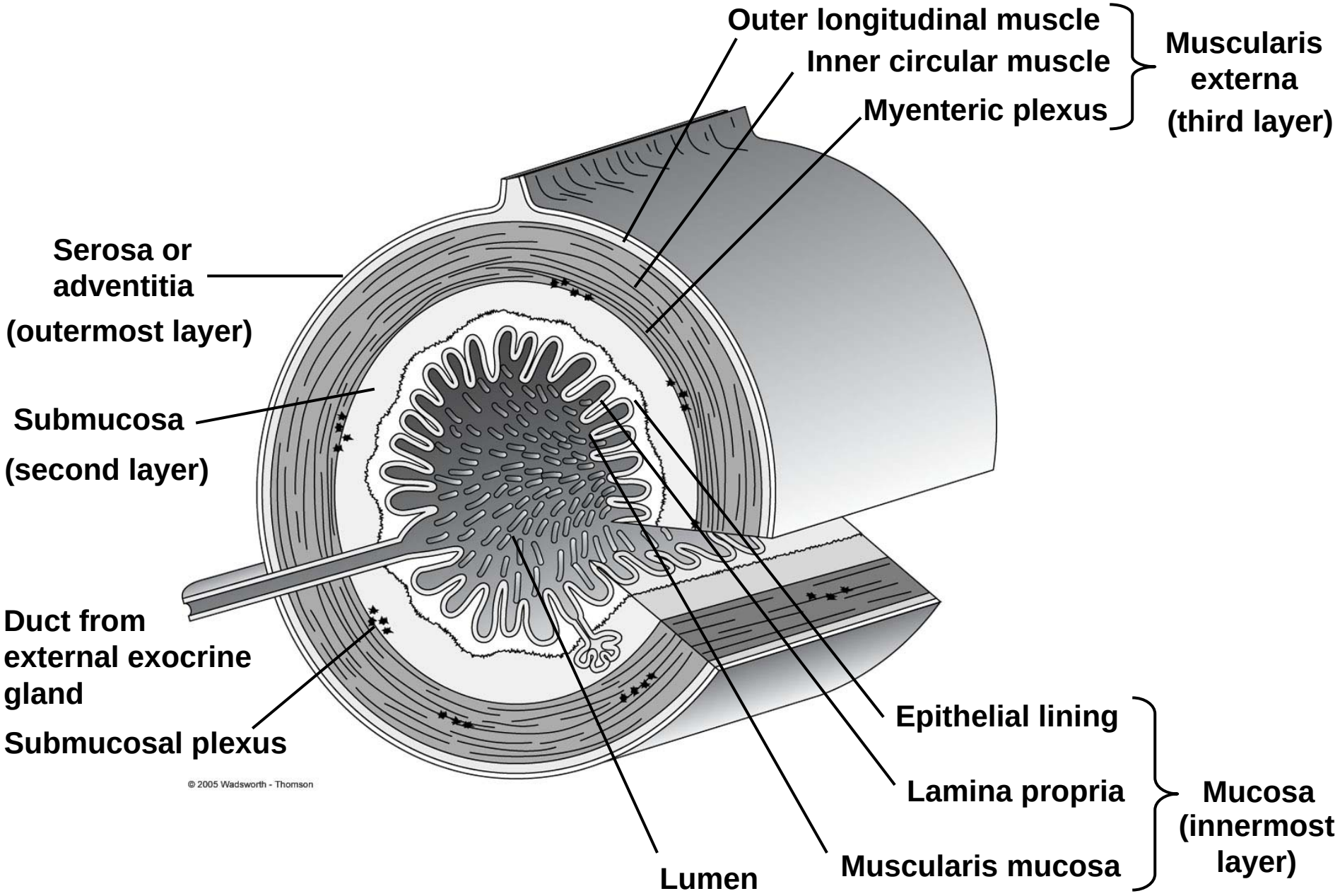
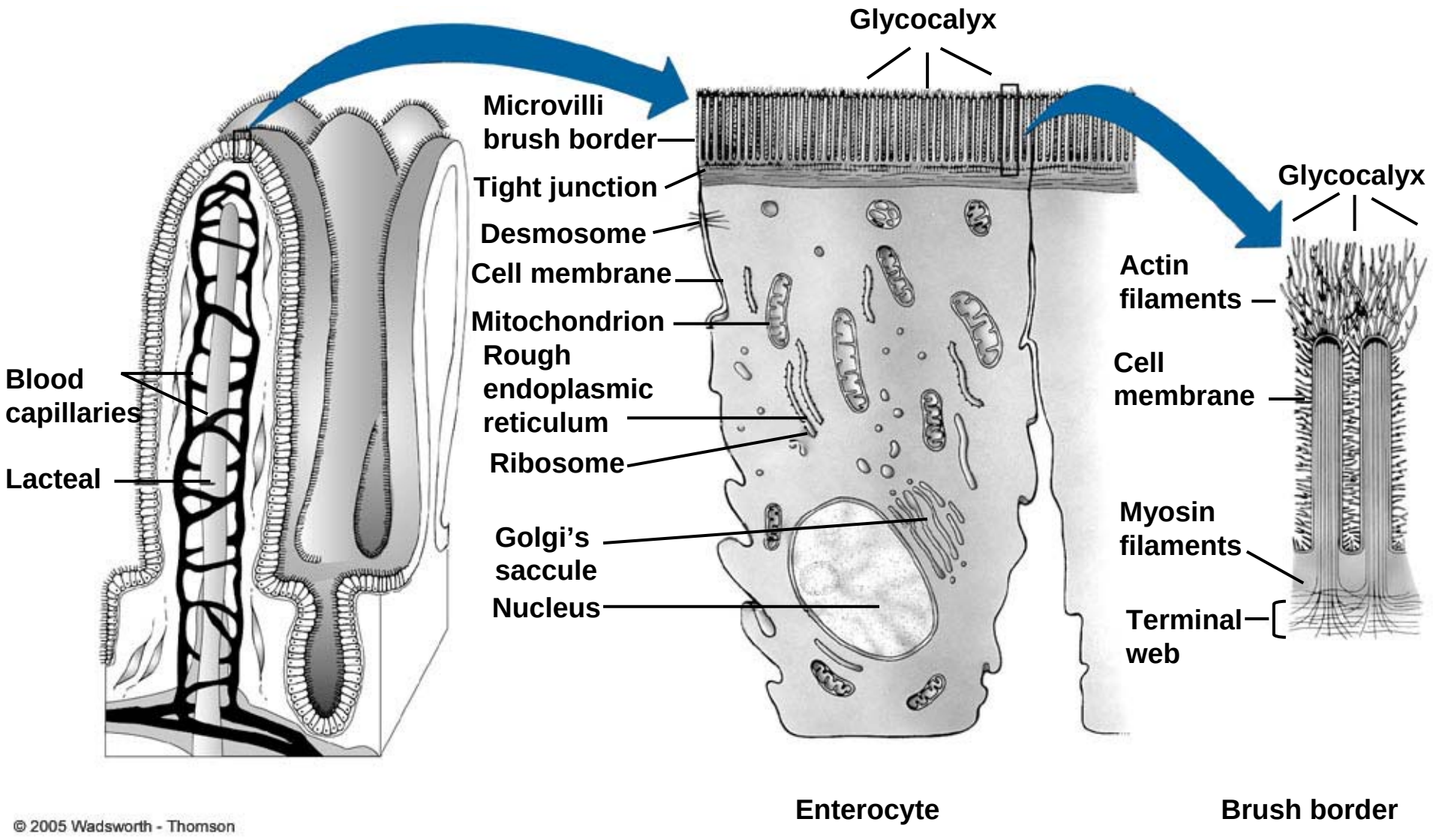


Gropper *et al.* 2005



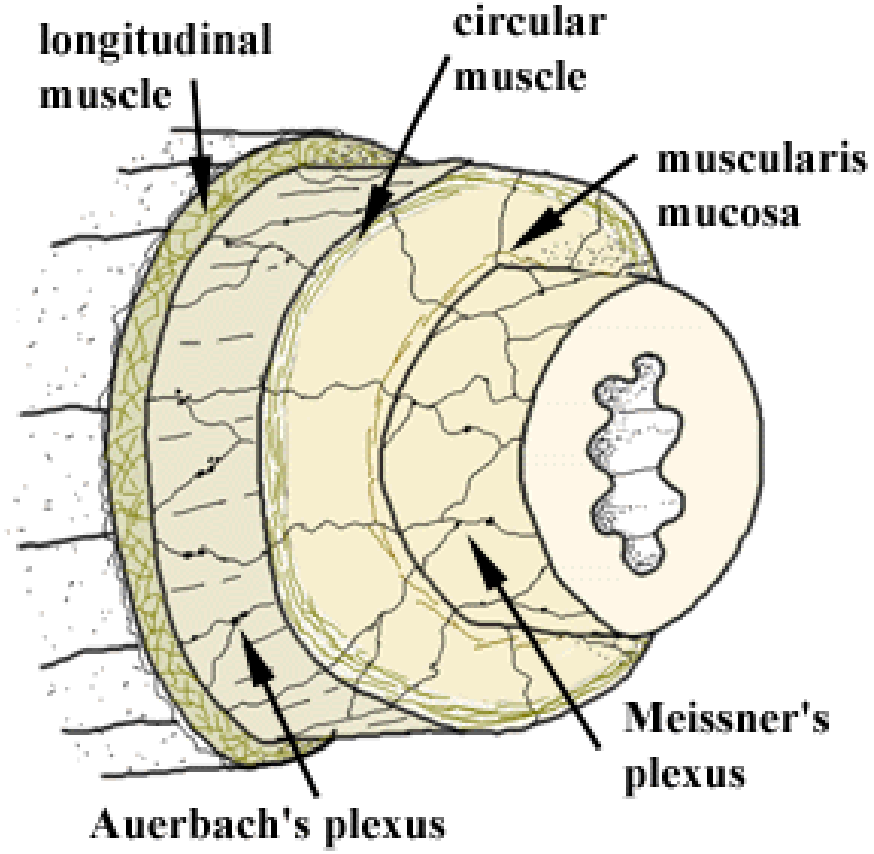
Gropper *et al.* 2005

Neural regulation

- **begins in esophagus and ends to anus**

  (1) neural plexuses

  (2) reflexes



http://www.med.mun.ca/anatomyts/digest/Auer.gif

Nerve plexus

- **submucosal nerve plexus:**
  in submucosa
- **myenteric nerve plexus:**
  between circular muscles and longitudinal muscles
  control peristaltic activity
- **sympathetic nerve**
  secrete norepinephrine, epinephrine (⊖ GI motility)
- **parasympathetic nerve (vagus nerve) :**
  secrete acetylcholine (⊕ GI motility)

Reflex

- **enterogastric reflex:**

  origin from intestine

  ⊖ **gastric motility and secretion**

- **colonoileal reflex:**

  origin from colon

  ⊖ **emptying of contents of ileum into colon**

Oral cavity and salivary gland

- **salivary glands:**

  parotid gland

  sublingual

  submaxillary or submandibular gland

- **functions:**

  secrete H_2O, electrolytes, enzymes, mucus, antibodies

  mucus: contains glycoproteins (i.e. mucin)

  lubricate food and protect oral mucosa

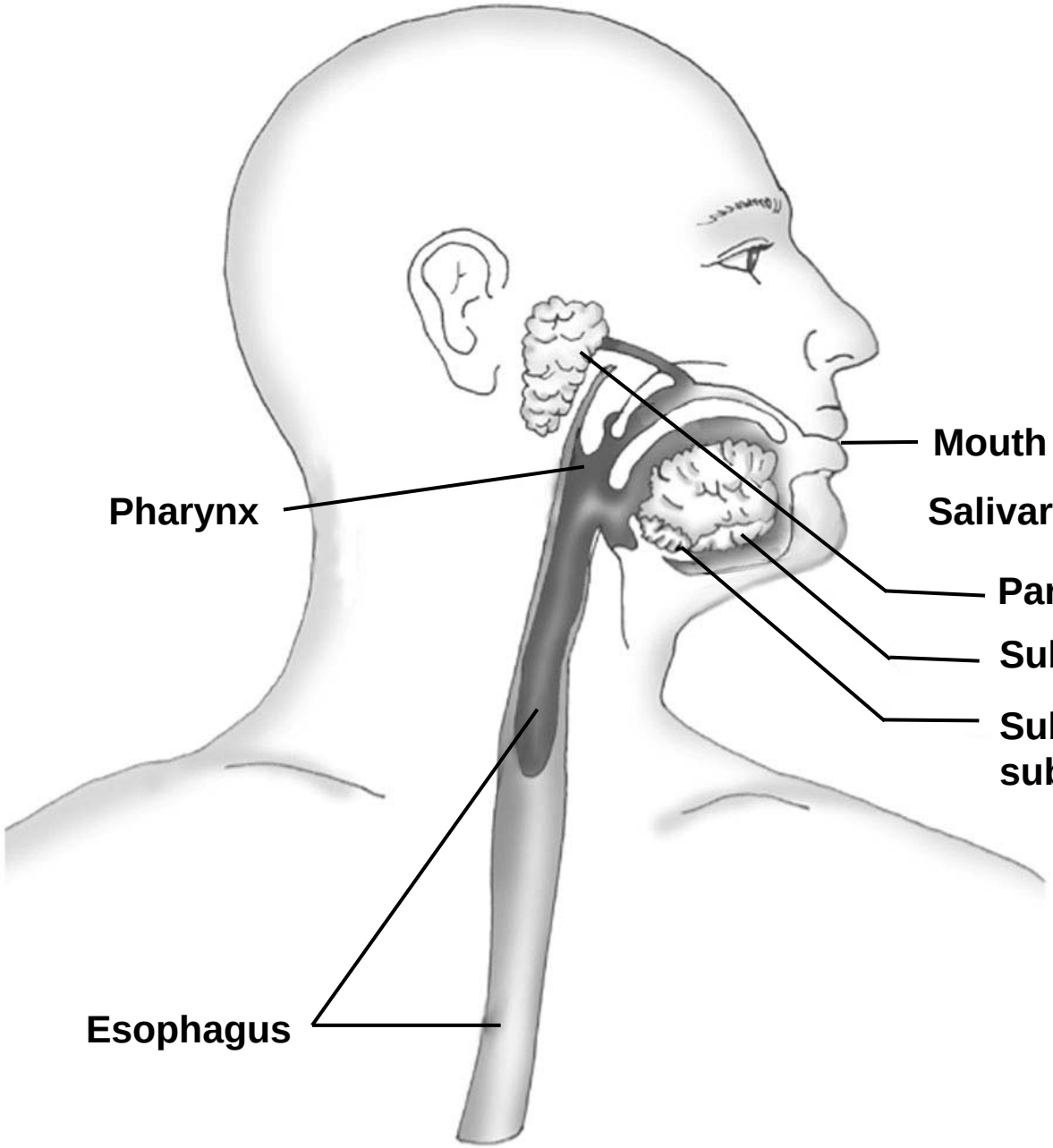
  antibodies: immunoglobulin A (IgA)

  α-amylase (ptyalin): cleaves α1-4 bonds within starch

  lingual lipase: produced by lingual serous gland

  hydrolyzes dietary TG in stomach and intestine

  important in infants



Saliva containing
- Water
- Electrolytes
- Mucus
- Enzymes*
- Antibacterial and antiviral compounds

*Main enzyme in saliva is salivary amylase, which hydrolyzes α 1-4 bonds in starch

Gropper *et al.* 2005

Esophagus

- striated muscles of upper portion (1/3)
- smooth muscles of distal portion (1/3)
- parasympathetic nerve stimulates peristalsis
- normally lower esophageal sphincter (LES) pressure > intragastric pressure
- swallowing → ↓ LES pressure → relax sphincter
- LES ↑ tonic pressure to prevent gastroesophageal reflux
- smoking, chocolate, high fat, alcohol, peppermint ↑ relaxation of LES (↓ LES pressure) → heartburn

Stomach

- **structure: fundus, body (3/4 stomach), antrum**
- **pH: 1.8~3.5, emptying volume: 50 mL, filled v.: 1~1.5 L**
- **gastric glands:**

cardiac gland (in fundus)

mucus (or neck) cells: secrete bicarbonate, mucus

endocrine cells: secrete hormones

oxyntic gland (in body)

mucus (or neck) cells

endocrine cells

parietal (oxyntic) cells: secrete HCl, intrinsic factor

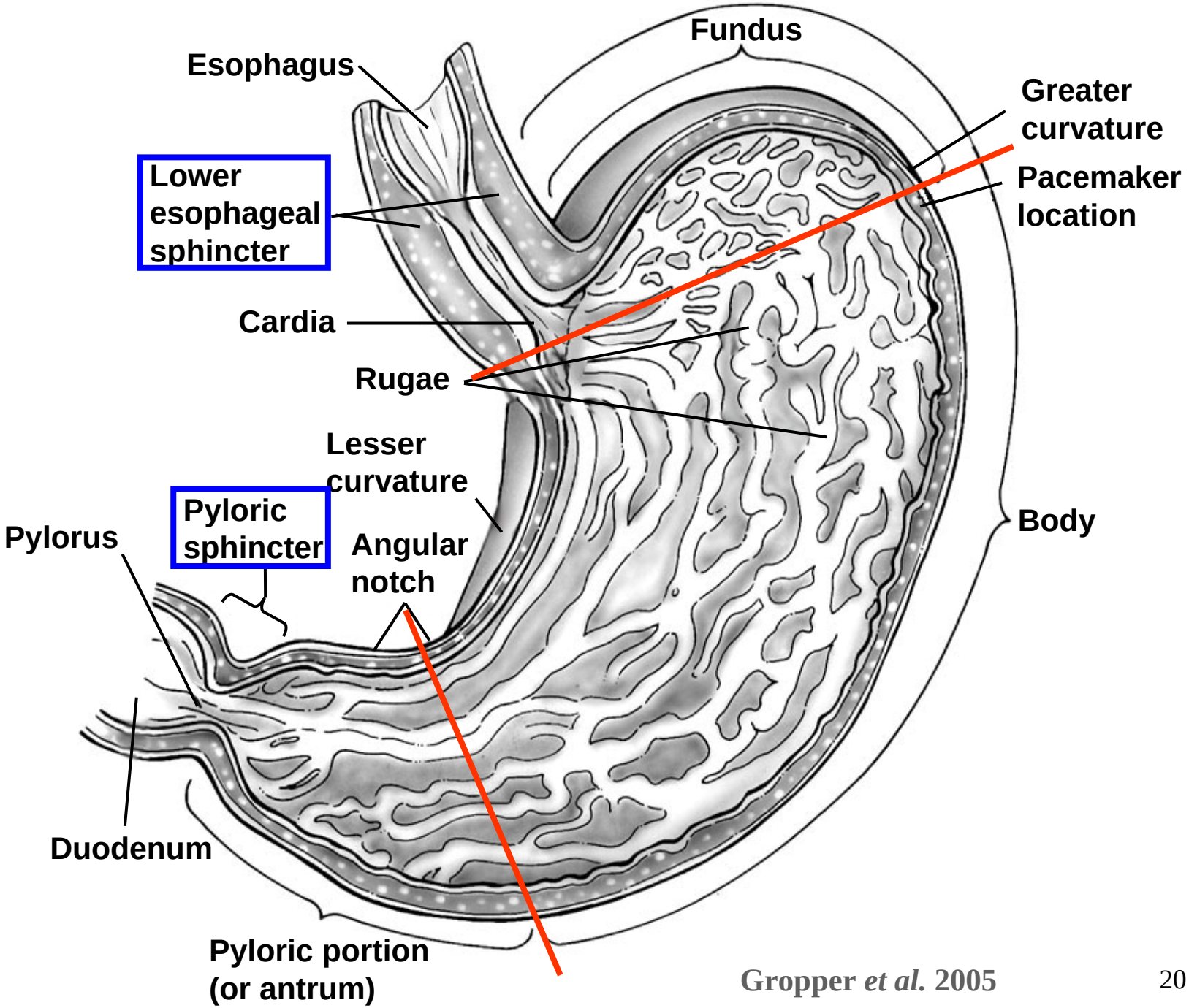
chief (peptic or zymogenic) cells: secrete pepsinogen

pyloric gland (in antrum)

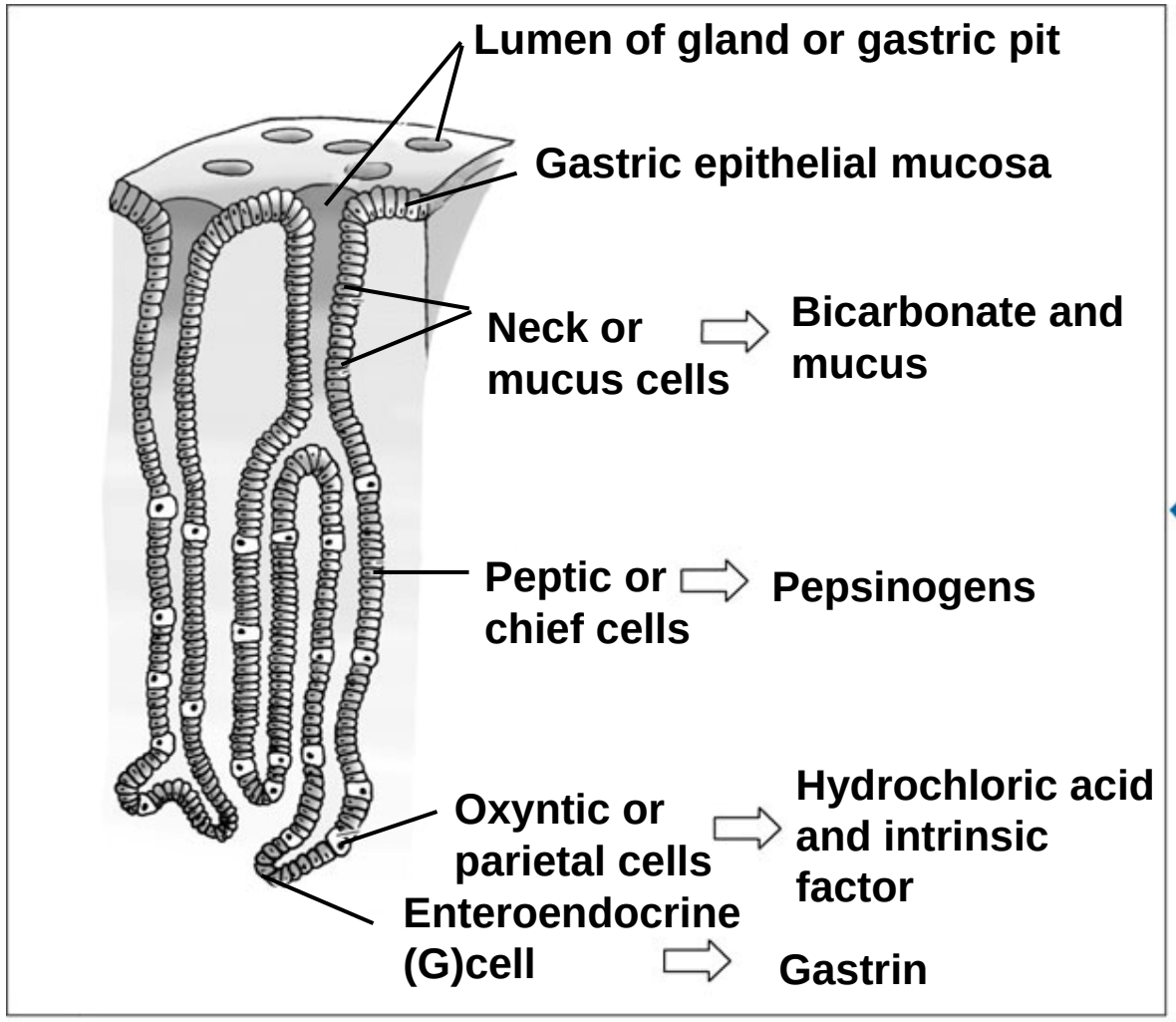
mucus cells

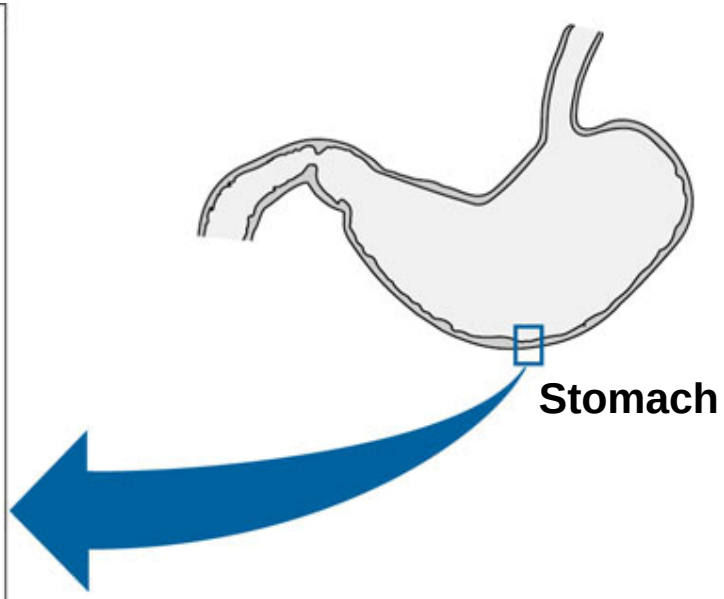
parietal cells

endocrine G cells: secrete gastrin



Gropper *et al.* 2005





Gropper *et al.* 2005

Stomach

- **gastric juice:**

  H_2O, electrolytes, hydrochloric acid (HCl), enzymes, mucus, intrinsic factor

- **HCl:**

  activate inactive proenzymes (zymogens) **pepsinogen** $\xrightarrow{\text{HCl}\ \oplus}$ **pepsin**

  denature proteins (destruction of secondary and tertiary structure)

  release nutrients from organic complexes

  bactericide

- **gastric lipase: hydrolizes 10~30% of dietary triacylglycerol**

- **absorption:**

  H_2O, a few fat-soluble drugs (ethyl alcohol, aspirin), a few minerals (Cu^{++}, iodide, F^-, molybdenum)

Stomach

- ⊕ **pepsinogen secreted by chief cells:**

  acetylcholine (from vagus nerve)

  acid

- ⊕ **HCl secreted by parietal cells: secretogogue**

  acetylcholine (from vagus nerve)

  gastrin ⟵ ⊕ **gastrin-releasing peptide (GRP; bombesin)**

  histamine ↑ **[epinephrine] in blood**

  alcohol ↑ **[amino acids or peptides] in gastric lumen**

  coffee

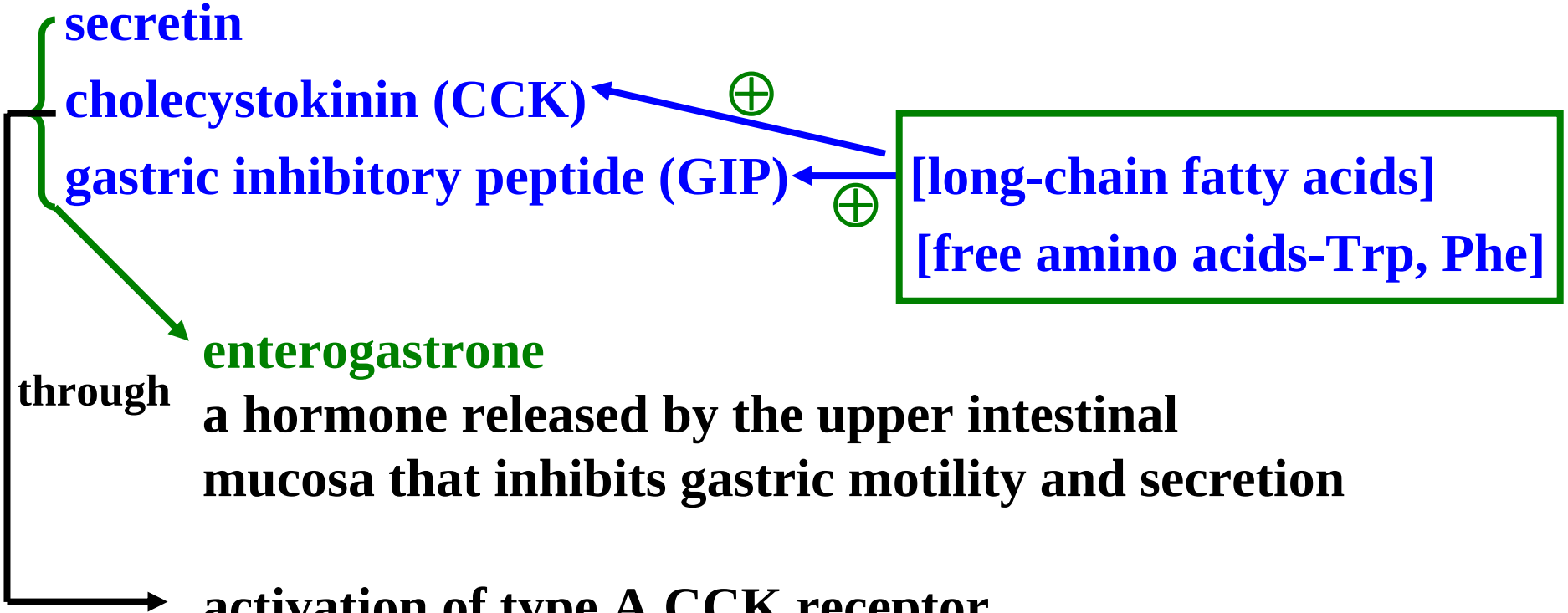
  calcium

Stomach

- ⊖ **HCl secreted by parietal cells:**

  acidification (pH < 2)

  somatostatin → ⊖ gastrin secretion → ⊖ HCl secretion



Stomach

- **gastric emptying:**

  response of antrum to signals

  osmolarity of chyme in duodenum

  volume of chyme in duodenum

- **emptying rate:**

  carbohydrate and protein: at the same rate

  fat slows gastric emptying (⊕GIP, CCK)

  salts, monosaccharides, free amino acids (Trp, Phe), soluble fiber ⊖ gastric emptying

Small intestine

- **duodenum (< 1 ft long), jejunum + ileum (9 ft long)**
- **small intestine surface: 300 m^2**
- **goblet cells: secrete mucus**
- **enterochromaffin cells: endocrine function**
- **crypts: continuously undergo mitosis, secrete fluid (reabsorbed by villi)**
- **duodenum is protected from gastric activity by pancreatic secretions with buffering capacity**

  mucus-containing secretion: pH 8.0~9.3

  bicarbonate release for neutralizing acid

after reaching the top, the cells will be sloughed off into intestinal lumen and excreted in feces every 3-5 d

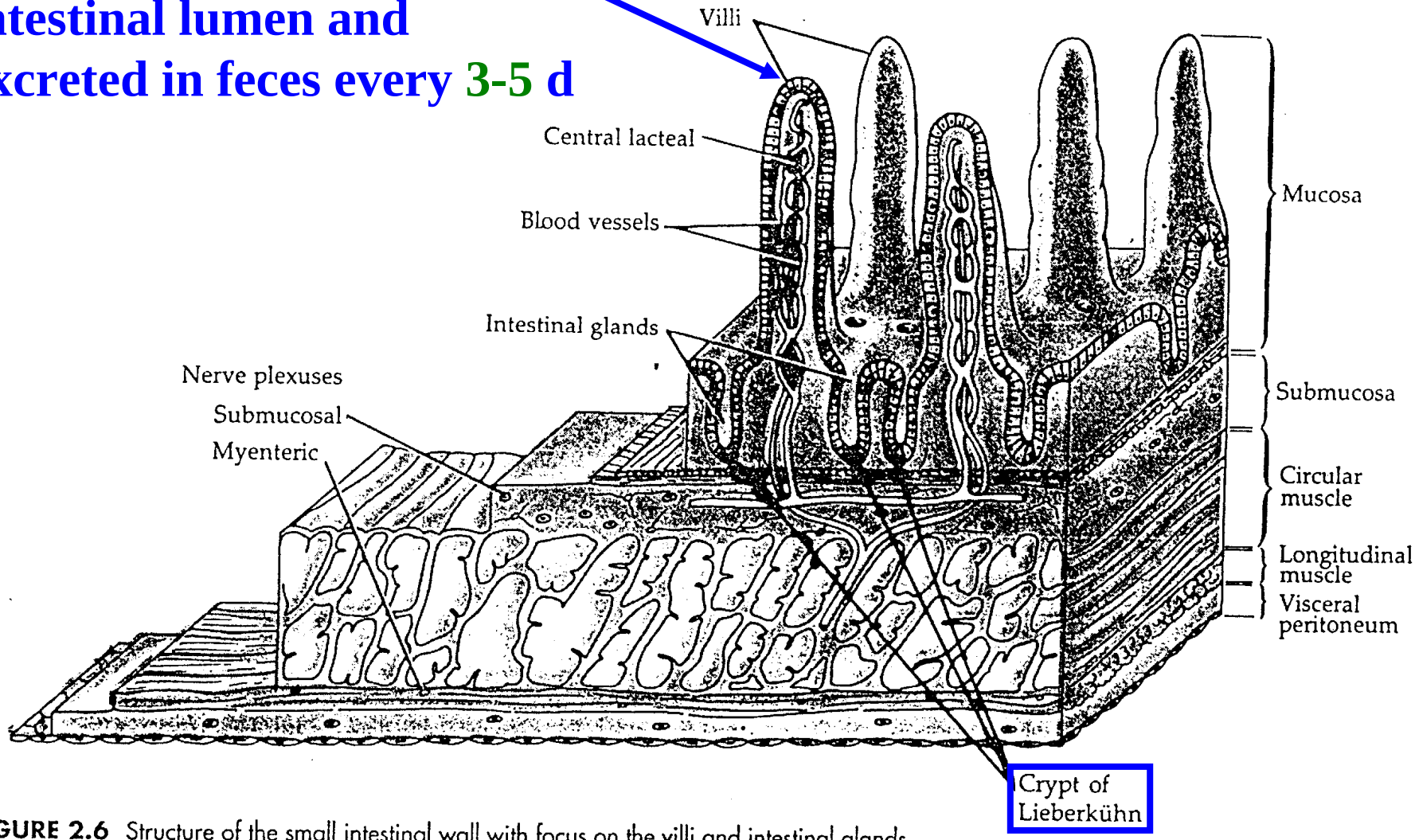


FIGURE 2.6 Structure of the small intestinal wall with focus on the villi and intestinal glands.

Groff and Gropper. 2000

Pancreas

- **acini (ducted exocrine) tissue**

  acinar cells: 82% by wt

  produces digestive enzymes (zymogens or enzymes)
- **ductless endocrine tissue**

  secretes hormones (insulin, glucagon)

  bicarbonate release for neutralizing acid
- **zymogens (proenzymes):**

  trypsinogen

  chymotrypsinogen

  procarboxypeptidase

  proelastase

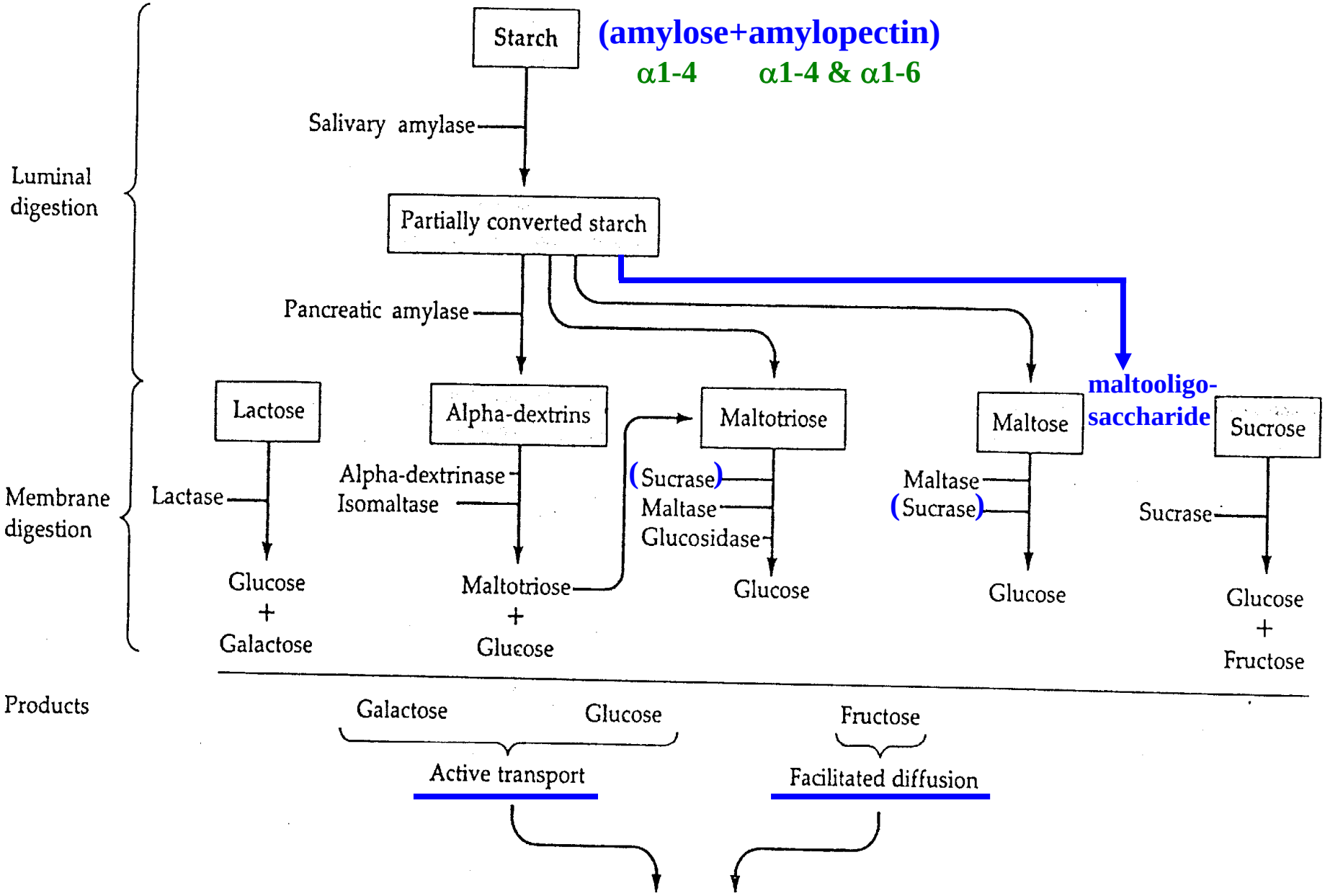
  collagenase

Pancreas

- trypsinogen —(enteropeptidase (enterokinase))→ trypsin
  - CCK ⊕
- chymotrypsinogen —(enteropeptidase, trypsin)→ chymotrypsin
- procarboxypeptidase —(trypsin)→ carboxypeptidase
- prophospholipase —(trypsin)→ phospholipase

Carbohydrate digestion

- **starch** —(pancreatic α-amylase)→ **maltooligosaccharide (4~9 gluc)**
  + branched-chain α-dextrin (5~9 gluc)
  + maltotriose (3 gluc)
  + maltose (2 gluc)
- **maltooligosaccharide** —(glucoamylase)→ **glucose**
- **branched-chain α-dextrin** —(α-dextrinase (isomaltase))→ **glucose + maltotriose**
- **maltotriose** —(glucosidase (sucrase))→ **maltose + glucose**
- **maltose** —(maltase (sucrase))→ **2 glucose**

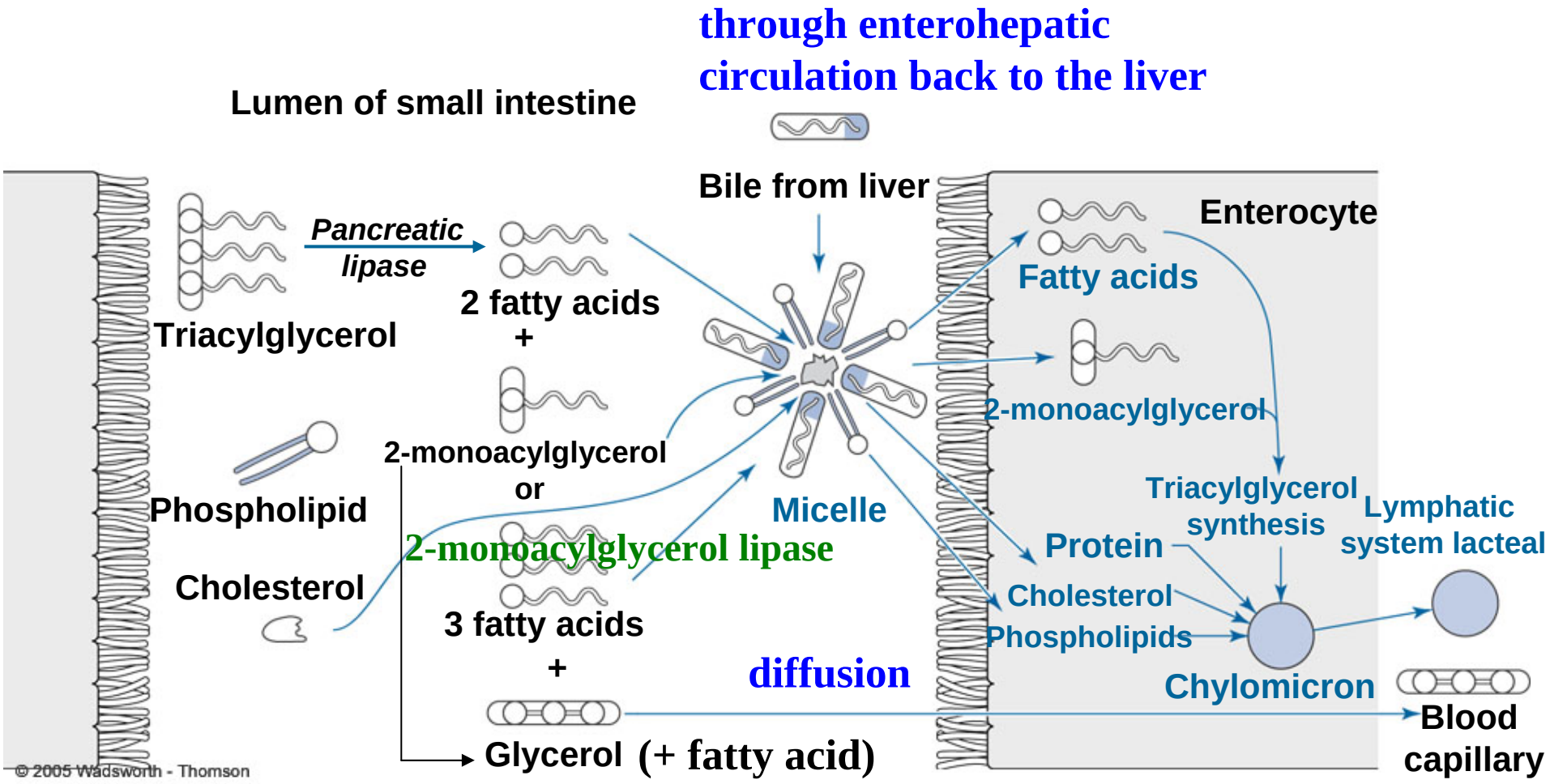


Groff and Gropper. 2000

through brush border to absorptive cells
via facilitated diffusion or diffusion to mucosal capillaries

Lipid digestion

- triacylglycerol —(pancreatic lipase; colipase ⊕)→ 2-monoacylglycerol + 2 free fatty acids
- 2-monoacylglycerol —(2-monoacylglycerol lipase)→ glycerol + free fatty acid
- cholesterol ester —(cholesterol esterase; bile is needed for its activity)→ cholesterol + free fatty acid



Gropper *et al.* 2005

Protein digestion

- pancreatic proteases hydrolyze peptide bond to form:

  oligopeptide (4~10 amino acids)

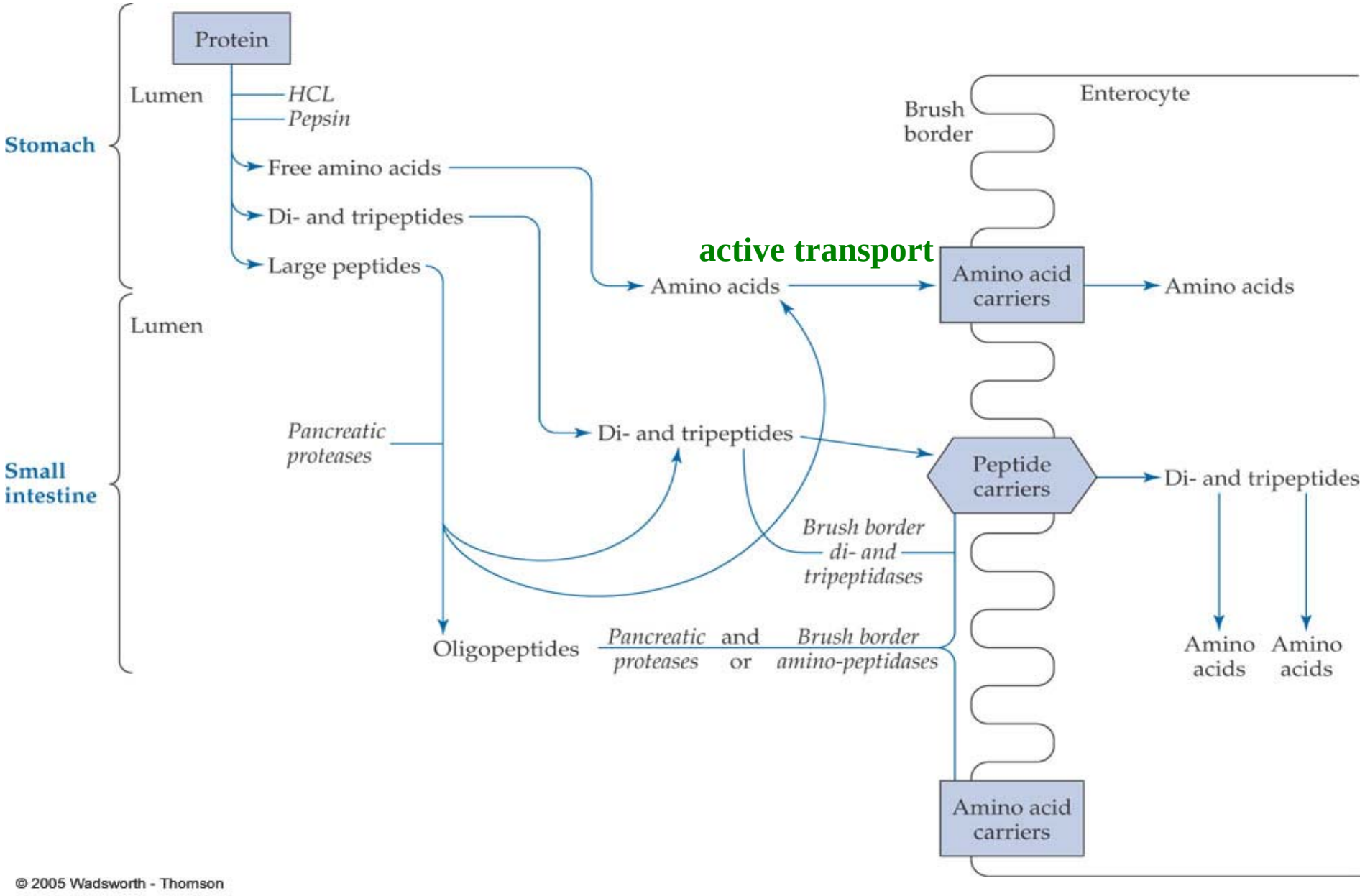
  tripeptide

  dipeptide

  free amino acid (aa)

- oligopeptide —(brush border: aminopeptidase)→ tripeptide + dipeptide + aa
- tripeptide —(brush border or intracellular: tripeptidase)→ dipeptide + aa
- dipeptide —(brush border or intracellular: dipeptidase)→ 2 aas
- 67% of aas are absorbed in the form of small peptides

  33% of aas are absorbed in the form of free amino acid



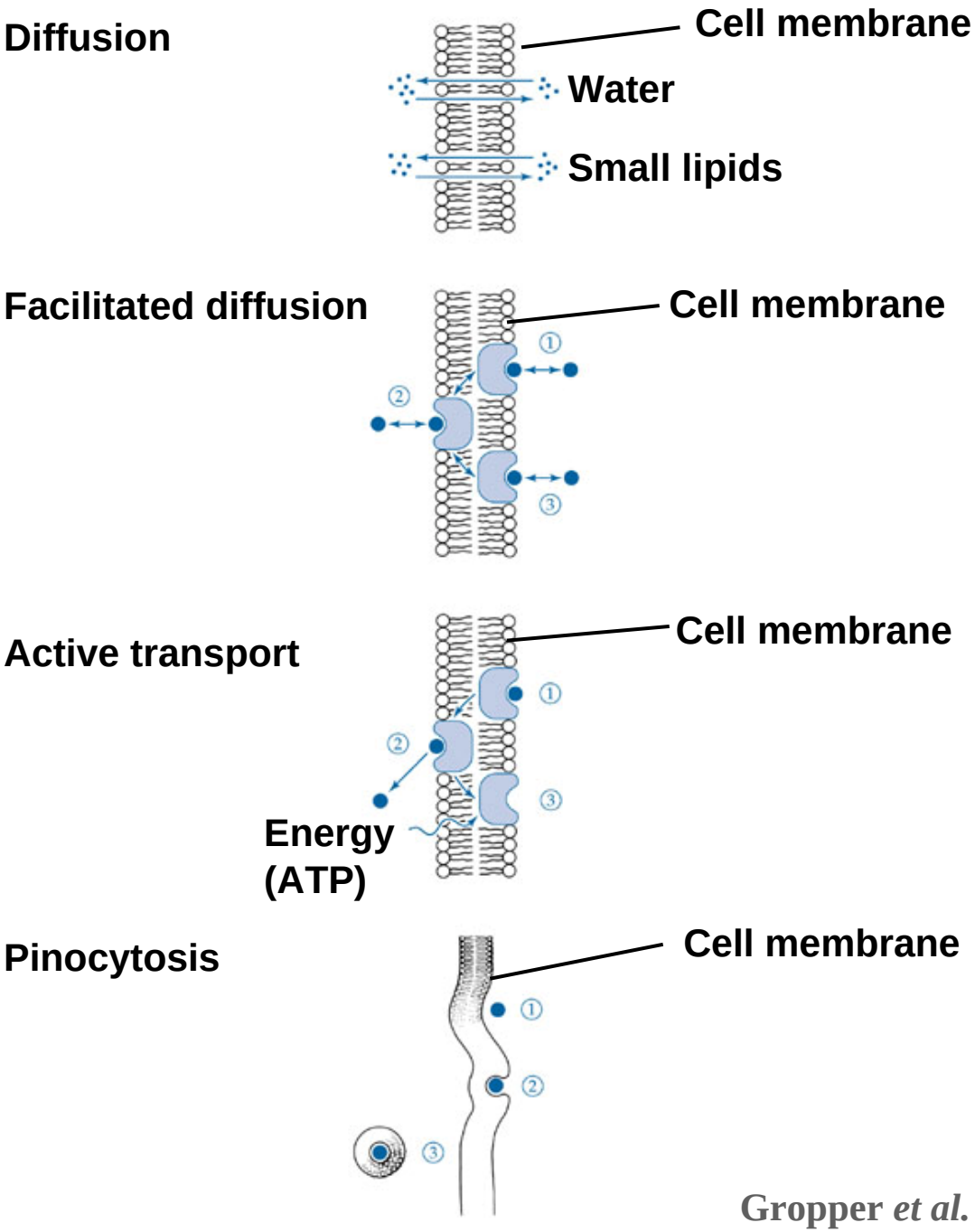
Gropper *et al.* 2005

Table 2.2 Digestive Enzymes and Their Actions

Enzyme or Zymogen/Enzyme	Site of Secretion	Preferred Substrate(s)	Primary Site of Action
Salivary α amylase	Mouth	α 1-4 bonds in starch, dextrins	Mouth
Lingual lipase	Mouth	Triacylglycerol	Stomach, small intestine
Pepsinogen/pepsin	Stomach	Carboxyl end of phe, tyr, trp, met, leu, glu, asp	Stomach
Trypsinogen/trypsin	Pancreas	Carboxyl end of lys, arg	Small intestine
Chymotrypsinogen/chymotrypsin	Pancreas	Carboxyl end of phe, tyr, trp, met, asn, his	Small intestine
Procarboxypeptidase/			
carboxypeptidase A	Pancreas	C-terminal neutral amino acids	Small intestine
carboxypeptidase B	Pancreas	C-terminal basic amino acids	Small intestine
Proelastase/elastase	Pancreas	Fibrous proteins	Small intestine
Collagenase	Pancreas	Collagen	Small intestine
Ribonuclease	Pancreas	Ribonucleic acids	Small intestine
Deoxyribonuclease	Pancreas	Deoxyribonucleic acids	Small intestine
Pancreatic α amylase	Pancreas	α 1-4 bonds, in starch, maltotriose	Small intestine
Pancreatic lipase and colipase	Pancreas	Triacylglycerol	Small intestine
Phospholipase	Pancreas	Lecithin and other phospholipids	Small intestine
Cholesterol esterase	Pancreas	Cholesterol esters	Small intestine
Retinyl ester hydrolase	Pancreas	Retinyl esters	Small intestine
Amino peptidases	Small intestine	N-terminal amino acids	Small intestine
Dipeptidases	Small intestine	Dipeptides	Small intestine
Nucleotidase	Small intestine	Nucleotides	Small intestine
Nucleosidase	Small intestine	Nucleosides	Small intestine
Alkaline phosphatase	Small intestine	Organic phosphates	Small intestine
Monoglyceride lipase	Small intestine	Monoglycerides	Small intestine
Alpha dextrinase or isomaltase	Small intestine	α 1-6 bonds in dextrins, oligosaccharides	Small intestine
Glucoamylase, glucosidase, and sucrase	Small intestine	α 1-4 bonds in maltose, maltotriose	Small intestine
Trehalase	Small intestine	Trehalose	Small intestine
Disaccharidases	Small intestine		Small intestine
Sucrase*		Sucrose	
Maltase		Maltose	
Lactase		Lactose	

*Part of an enzyme complex.

Gropper *et al.* 2005



Gropper *et al.* 2005

Bile acid

- **synthesis from cholesterol**

  cholesterol $\xrightarrow{\text{7α-hydroxylase}}$ **7α-hydroxycholesterol**

- **primary bile acids (80%): synthesized in liver**

  cholic acid (-OH on 3, 7, 12) (40%)

  chenodeoxycholic acid (-OH on 3, 7) (40%)

  conjugated with glycine, taurine: improve ability to form micelles

  glycocholic acid, taurocholic acid (75%:25%)

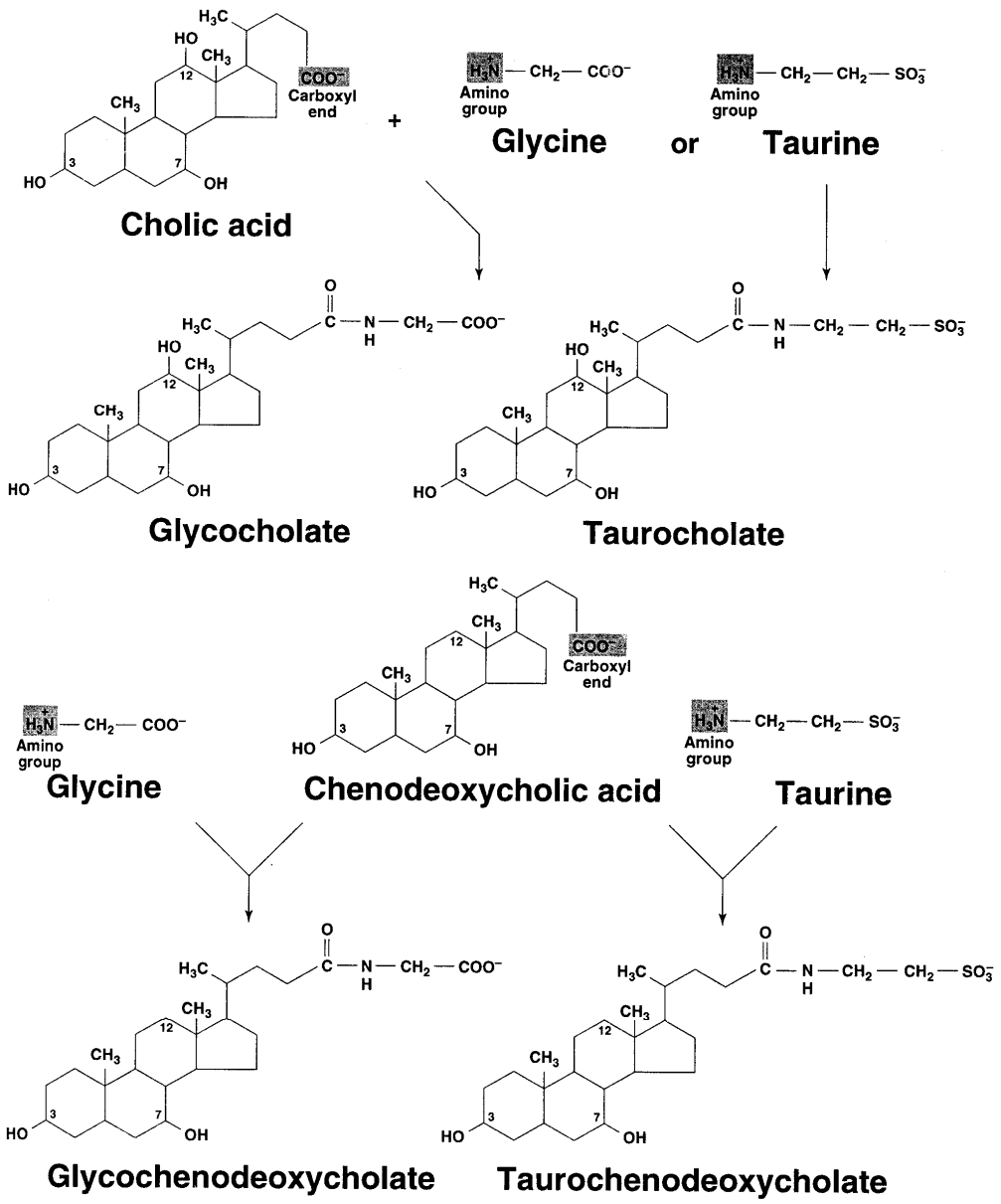
  glycochenodeoxycholic acid, taurochenodeoxycholic acid (75%:25%)

Bile acid

- **secondary bile acids (20%): synthesized through bacterial deconjugation and dehydroxylation by 7-dehydroxylase in colon**

  cholic acid → deoxycholic acid (-OH on 3, 12) can be reabsorbed

  chenodeoxycholic acid → lithocholic acid (-OH on 3) excreted in feces → 0.5 g bile salt/d in feces



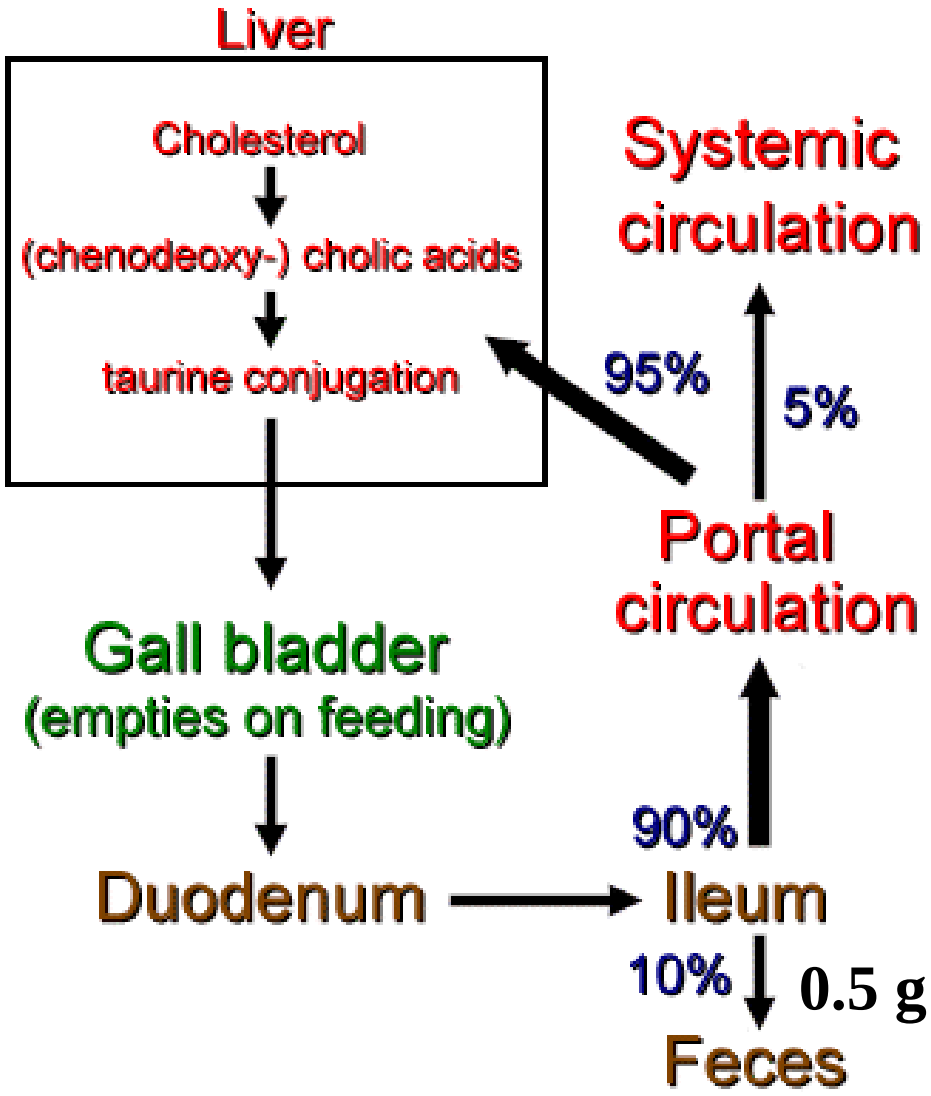
The Formation of Glycoholate, Taurocholate, Glycochenodeoxycholate, and Taurochenodeoxycholate Conjugated Bile Acids

Groff and Gropper. 2000

Enterohepatic circulation

- **90% bile acids are reabsorbed by active transport**
- **⟶ ileum ⟶ portal vein ⟶ attach to albumin ⟶ liver ⟶ cystic duct ⟶ gallbladder for storage**
- **recycle twice per meal**
- **10 times/day**
- **20-30 g bile acids entering and leaving SI/day**

Circulation of Bile Acids



http://diaglab.vet.cornell.edu/clinpath/modules/chem/images/ba.gif

Table 2.1 Actions of Selected Regulatory Peptides

Action	Hormones			
	Gastrin	CCK	Secretin	GIP
Acid secretion	S*	~~S~~ I	I*	I*
Gastric emptying	~~I~~ S	I	I*	I
Pancreatic HCO_3^- secretion	S	S*	S*	O
Pancreatic enzyme secretion	S	S*	S	O
Gallbladder contraction	S	S*	S	?
Gastric motility	S	I	I	I
Intestinal motility	S	~~S~~ I	I	?
Insulin release	S	S	S	S*
Mucosal growth	S*	S	I	?
Pancreatic growth	S	S*	S*	?

Gropper *et al.* 2005

Cholecystokinin (CCK)

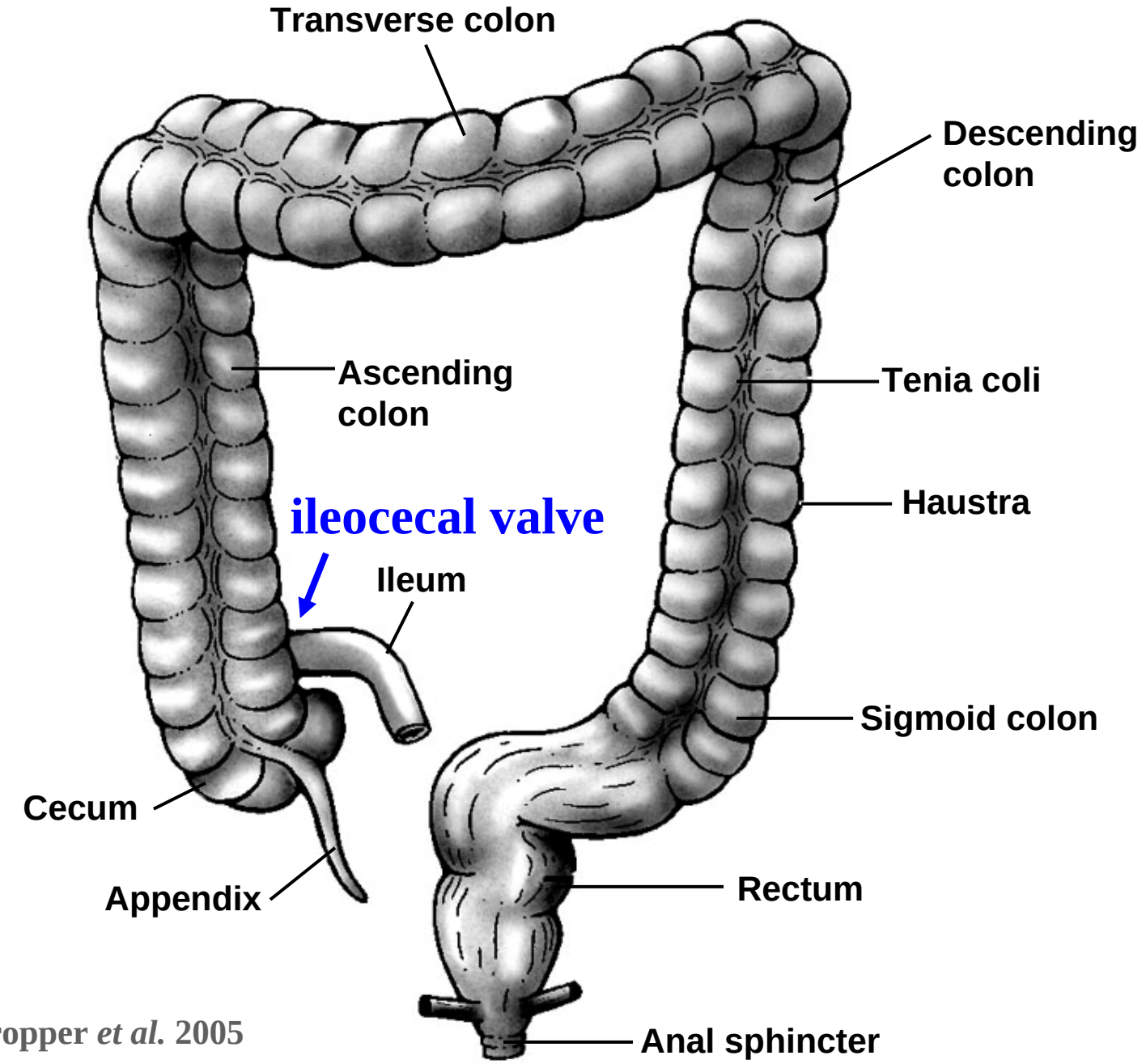
- + gallbladder contraction and bile HCO_3^- secretion
- + the contraction of pyloric sphincter
- + satiety
- + mucosal and pancreatic growth
- + the secretion of pancreatic juice (H_2O + HCO_3^-) and enzymes into duodenum
- + pancreatic insulin release
- – intestinal motility
- – gastric motility
- – gastric emptying
- – the secretion of gastric acid

Secretin

- + gallbladder contraction and bile HCO_3^- secretion
- + pancreatic growth
- + the secretion of pancreatic juice (H_2O + HCO_3^-) and enzymes into duodenum
- + pancreatic insulin release
- – mucosal growth
- – intestinal motility
- – gastric motility
- – gastric emptying
- – the secretion of gastric acid

Gastric inhibitory peptide (GIP)

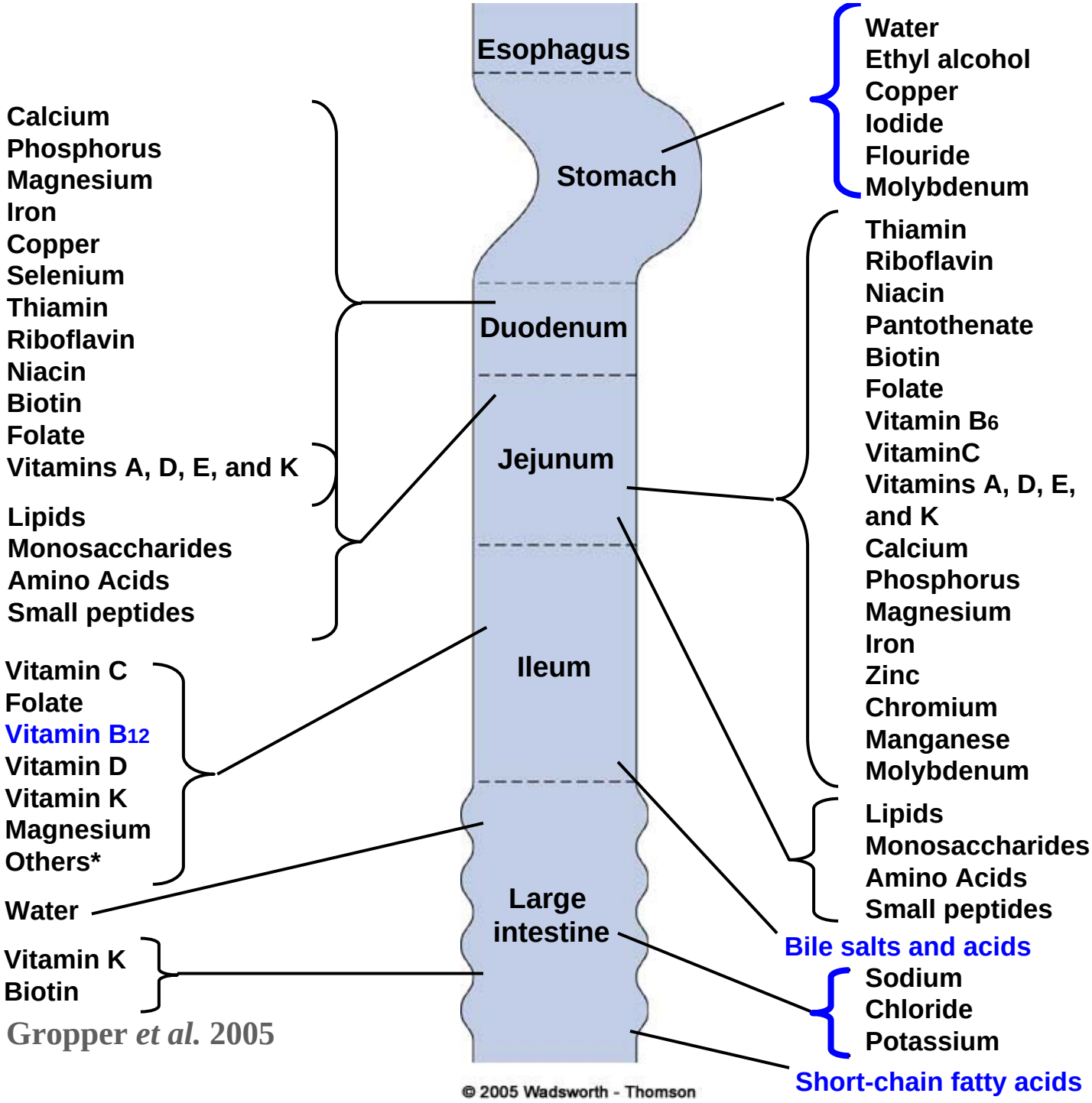
- + intestinal secretion
- + pancreatic insulin release
- – gastric motility
- – gastric emptying
- – the secretion of gastric acid
- – gastrin release
- – the response of parietal cells to gastrin



Gropper *et al.* 2005

Fermentation

- **colonic bacterial action on unabsorbed carbohydrate**
- **production of lactate**
- **production of short-chain (volatile) fatty acids**
- **acetate (2C), propionate (3C), butyrate (4C)**
- **production of gases**
- **methane (CH_4), hydrogen (H_2), H_2S, CO_2**



Gropper *et al.* 2005

Summary

- **Various mechanisms in the GI tract that allow food to be ingested, digested, and absorbed and its residue to be excreted reveals the complexity of the digestion and absorption processes.**
- **Many factors, including nervous, endocrine, and circulatory systems, affect and regulate digestion and absorption.**
- **The integrity and regulatory mechanisms must be coordinated to maintain normal functions of the GI tract.**