Physiology of the Small Intestine: Motility, Secretion and Absorption

Objectives:

- Motility in the small intestine.
- Control of intestinal motility.
- Secretions of the small intestine.
- Digestion of carbohydrates, proteins and fats.
- Basic principles of gastrointestinal absorption.
- Absorption and secretion of electrolytes and water.

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Colour index:
- Important
- Numbers
- Extra

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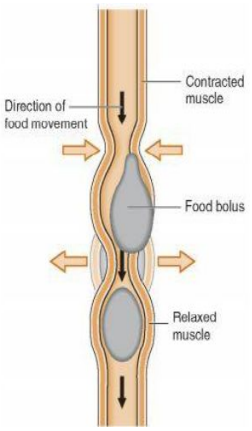
Motility in the Small Intestine

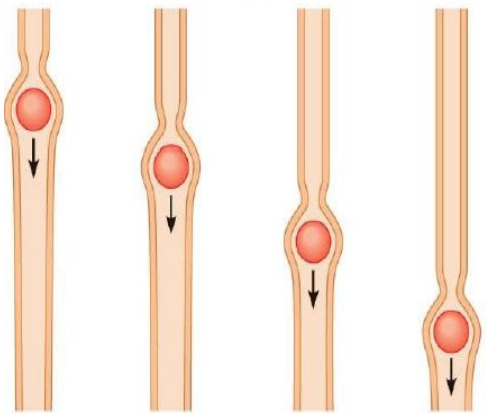
➢ The movements of the small intestine can be divided into:

1) Propulsive Peristaltic Movement
2) Segmentation (Mixing) Contractions
3) Migrating Motor Complex
4) Anti-Perist alsis
5) Peristaltic Rush

1. Propulsive Movement (Peristalsis) Law of gut



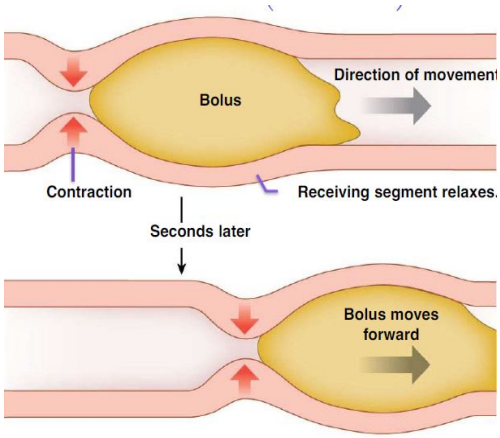
- Usual stimulus is distention.
- A contraction ring appears around gut, then moves forward.
- It organizes propulsion of material over variable distances.
- It is faster in the proximal intestine and slower in the terminal intestine (velocity 0.5 to 2.0 cm/sec), (3 to 5 hours are required for passage of chyme from the pylorus to the ileocecal valve).
- The net movement along the small intestine normally averages only 1 cm/min
- Myenteric plexus is important.
- They can be blocked by atropine.



The law of gut
When there is distention (food) in proximal part (propulsive segment) it will stimulate the peristalsis movement

❖ **Propulsive** segment
  ➢ Contraction (**Circular** Muscle)
  ➢ Relaxation (**Longitudinal** Muscle)

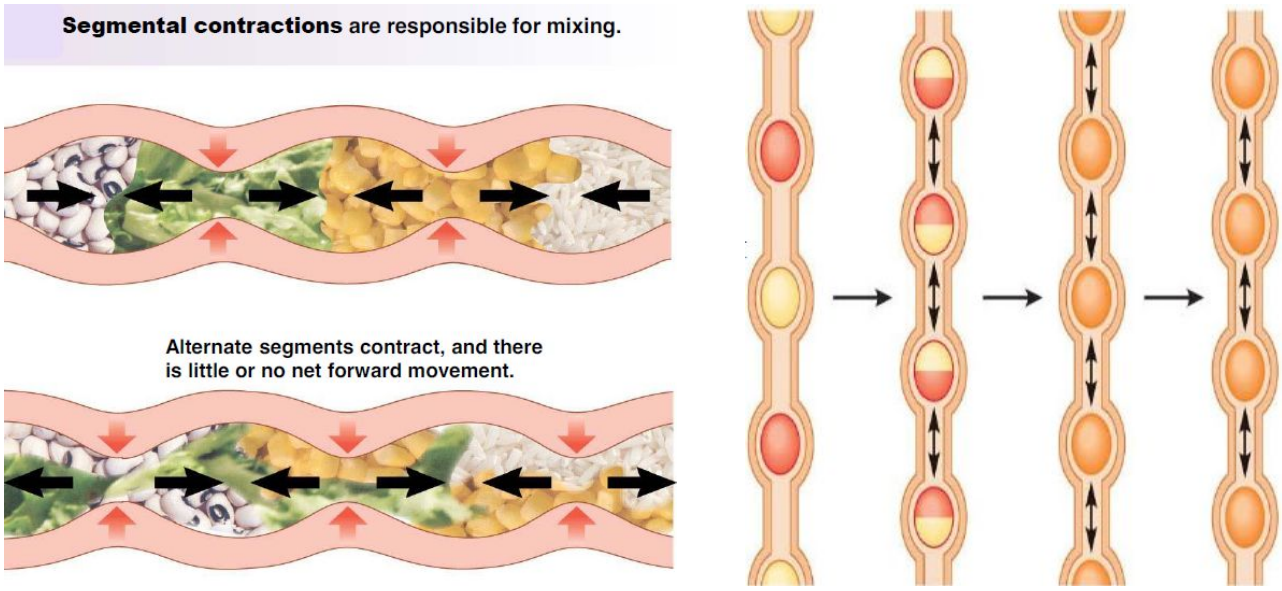
❖ **Receiving** segment
  ➢ Contraction (**Longitudinal** Muscle)
  ➢ Relaxation (**Circular** Muscle)



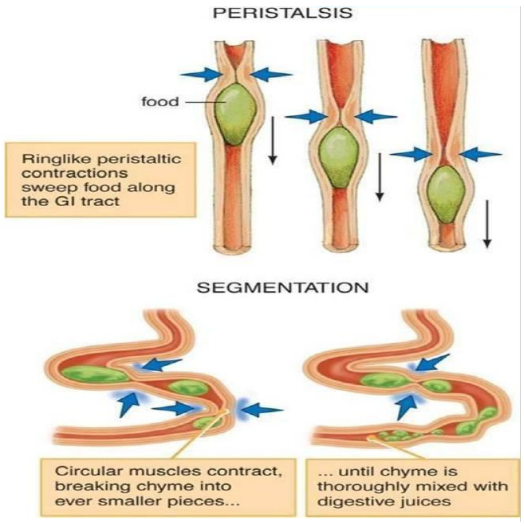
2. Mixing (Segmentation) Contractions

Segmenting is the type of movement and mixing is the function

- A localized contraction of circular smooth muscles that constricts the intestine into spaced segments, and have the appearance of a chain of sausages.
- It last for fraction of min. As one set of segmentation contractions relaxes, a new set begins at points between the previous ones.
- Usual stimulus is distention.
- It is activated by enteric nervous system. The myenteric plexus
- They can be blocked by atropine.
- The **significance**:
  - Blend different juices with the chyme
  - Bring products of digestion in contact with absorptive surfaces

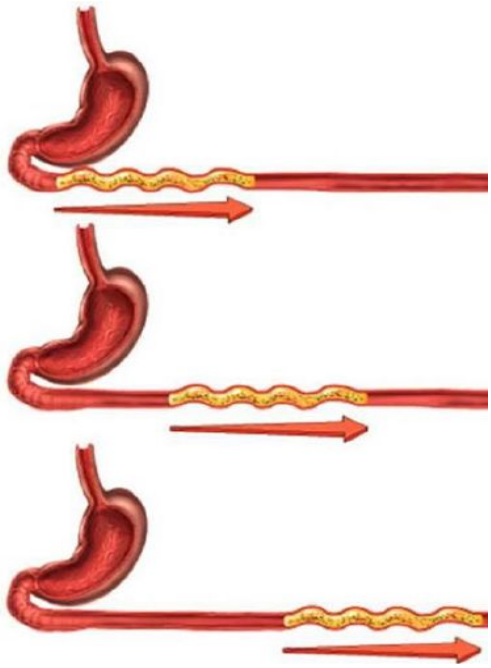


Peristalsis versus segmentation



3- Migrating Motor Complex (MMC)

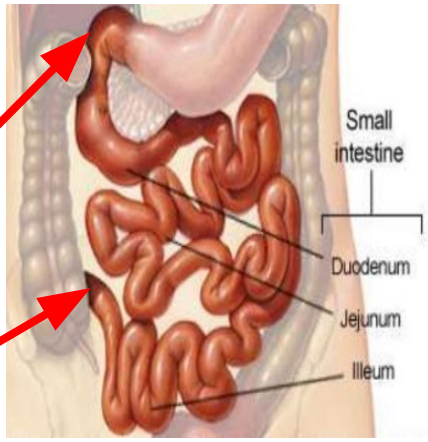
- Bursts of depolarization accompanied by peristaltic contraction that begins in empty stomach during interdigestive period (after absorption occurs)
- Travels along whole length of small intestine to reach ileocaecal valve after 1.5-2 h. When it disappears, a new wave of MMC starts.
- Activity of MMC terminates as soon as food is ingested.
- Function of MMC is to sweep material (undigested food residues, dead mucosal cells and bacteria) into colon, keeping the small intestine clean.
- No MMC in the colon



4- Antiperistalsis

Can happen pathologically while vomiting

- ➢ A wave of contraction in the alimentary canal that passes in an oral (i.e. upward or backwards) direction and propel the chyme in the opposite direction.
- ➢ Occurs between:-
  - Stomach and duodenum to allow more time for neutralization of chyme.
  - Ileum and caecum to allow time for absorption



5- Peristaltic rush

Initiated due to irritation of intestinal mucosa by presence of infectious substance or toxic substance

- Powerful rapid peristalsis due to intense irritation of intestinal mucosa (as in infectious diarrhea).
- Initiated mainly by extrinsic nervous reflexes to brain stem and back to gut.
- Sweeps the contents of intestine into the colon without much absorption leading to diarrhea and thereby relieving the small intestine of irritative chyme or excessive distension.

Movements of the Villi

- Initiated by local nervous reflexes in response to chyme in small intestine.
- Consists of fast shortening and slow lengthening as well as side to side movements.
- Stimulated by **villikinin hormone** released by intestinal mucosa when it comes in contact with digestive products.
- Facilitate absorption and lymph flow from central lacteals into lymphatic system.

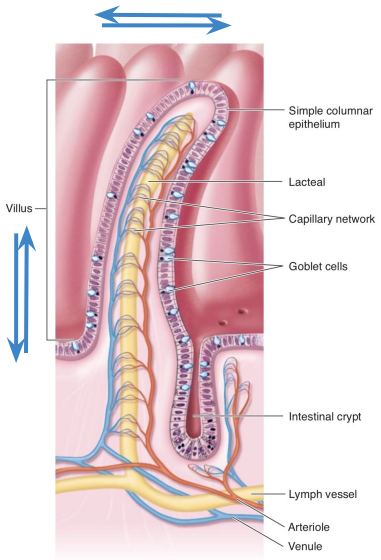


FIGURE 26–2 The structure of intestinal villi and crypts.
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Control of Intestinal Motility

Neural Factors

- Vagal excitation increases intestinal and villous movements.
- Sympathetic excitation decreases intestinal and villous movements.

Gastroileal reflex:

- Initiated by gastric distension.
- Mediated by vagus nerve.
- Impulses are conducted through myenteric plexus to initiate a fast peristaltic wave passing to the ileum.
- The ileocaecal valve relaxes allowing chyme to pass into cecum

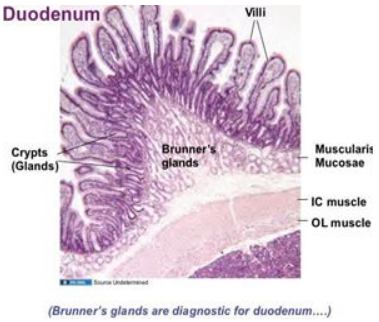
Hormonal Factors

- Gastrin, CCK, insulin and serotonin stimulate intestinal motility.
- Motilin secreted from duodenum stimulates intestinal motility and regulate MMC.
- Gastrin and CCK relax ileocaecal sphincter.
- Secretin and glucagon inhibits intestinal motility and contract ileocaecal sphincter.
- Villikinin stimulates movement of the villi.

Secretions of the small intestine:

1) Secretion of Mucus by Brunner's Glands in the Duodenum:

Brunner's glands: secrete large amounts of alkaline mucus, which contains a large amount of bicarbonate ions (Mucus protects the mucosa)



(Brunner's glands are diagnostic for duodenum....)

2) Intestinal Juices (Succus Entericus)

- ➔ Secreted from intestinal crypts (crypts of Lieberkühn) (small pits which lie between intestinal villi).
- ➔ pH: 7.5-8. It participates in the neutralization of acid chyme delivered from stomach.
- ➔ The surfaces of both the crypts and the villi are covered by an epithelium composed of 2 types of cells:
  - ◆ **(1) goblet cells,** secrete mucus
  - ◆ **(2) enterocytes**, secrete large quantities of H_2O and electrolytes and over the surfaces of adjacent villi, reabsorb H_2O, electrolytes & end products of digestion.

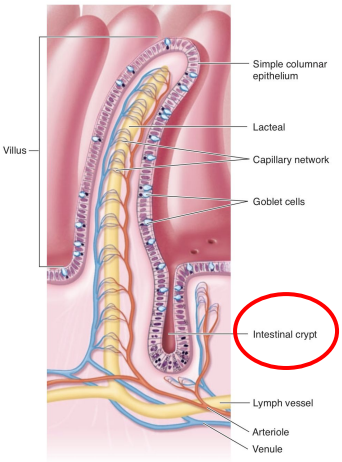


FIGURE 26–2 The structure of intestinal villi and crypts. (Reproduced with permission, from Fox SI: *Human Physiology*, 10th ed. McGraw-Hill, 2008.)

Brunner gland secretion

Stimulated by:

- Secretin
- Irritating stimuli on the duodenal mucosa
- Vagal stimulation

Inhibited by:
Sympathetic stimulation

Intestinal juice secretion

Stimulated by:

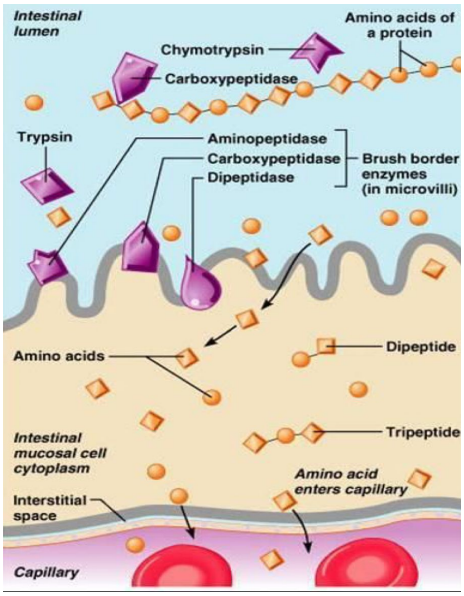
- Distension, tactile and vagal stimulation.
- Hormones as: gastrin, secretin, CCK, glucagons, enterocrinin.

Inhibited by:
Sympathetic stimulation

1- Digestion of carbohydrates

★ The enterocytes contain four enzymes (maltase, sucrase, lactase and a-dextrinase), which are capable of splitting the disaccharides lactose, sucrose, and maltose, plus other small glucose polymers, into their constituent monosaccharides.

★ These enzymes are located in the enterocytes covering the intestinal microvilli brush border, so that the disaccharides are digested as they come in contact with these enterocytes.



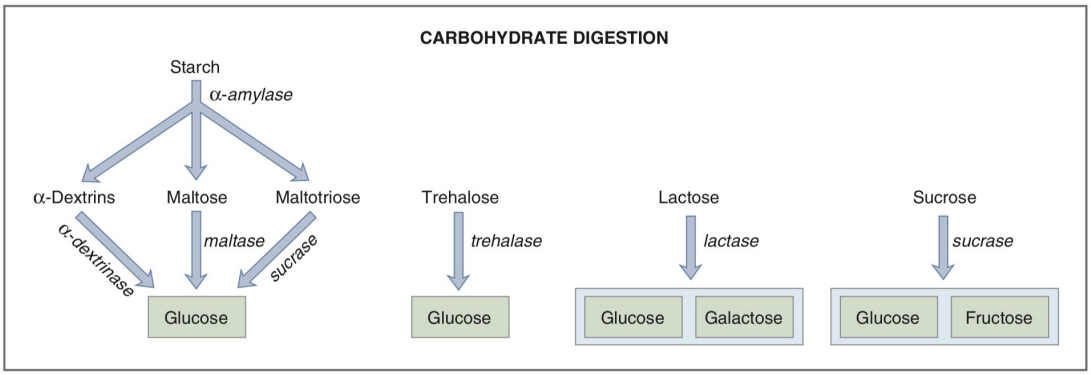


Fig. 8.26 Carbohydrate digestion in the small intestine.

2- Digestion of Proteins

- A small percentage of proteins are digested to **AA** by the <u>pancreatic enzymes</u>.
- Most proteins remain as **di**peptides and **tri**peptides.
- Most protein digestion occurs in the duodenum and jejunum by **<u>aminopeptidases</u>**, oligopeptides, **intracellular** di- and tripeptides for splitting small peptides into amino acids.

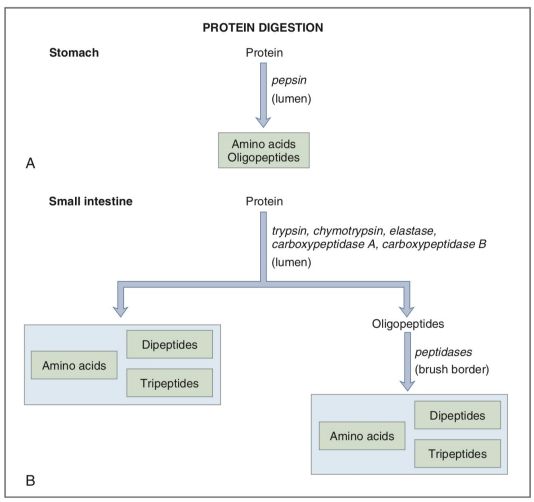
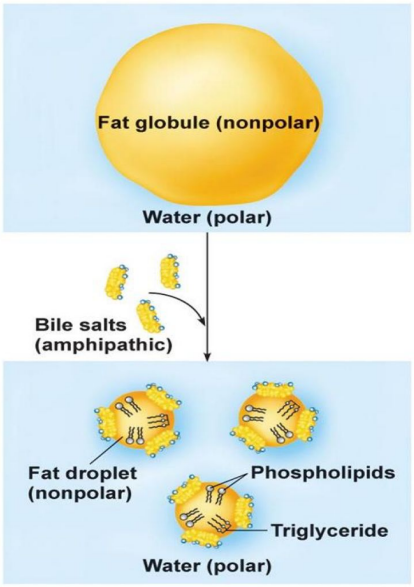


Fig. 8.29 Digestion of proteins in the stomach (A) and small intestine (B).

3- Digestion of Fats

- Less than 10 % of triglycerides is digested in the stomach by lipase.
- All fat digestion occurs in the small Intestine.
- Bile salts and lecithin in the bile help fat digestion by making the fat globules readily fragmentable with the water in the small intestine (emulsification of fat).
- Bile salts break the fat globules into very small sizes, so that the water-soluble digestive enzymes can act on the globule surfaces.



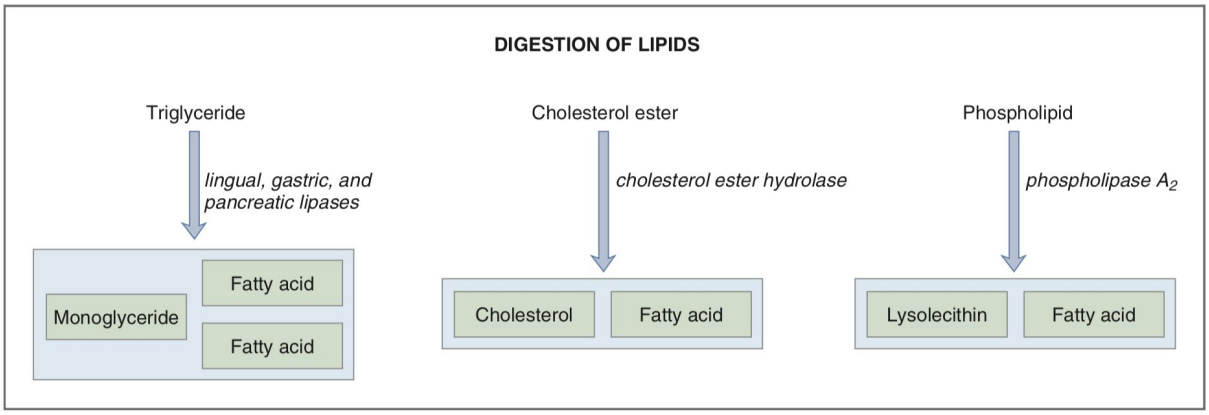
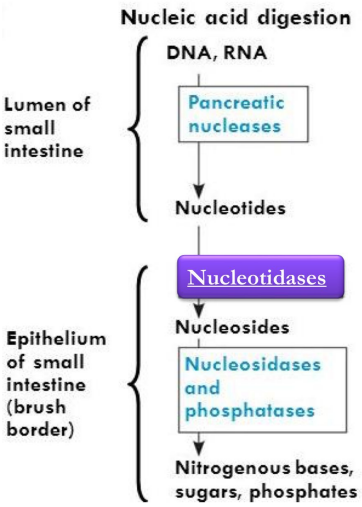


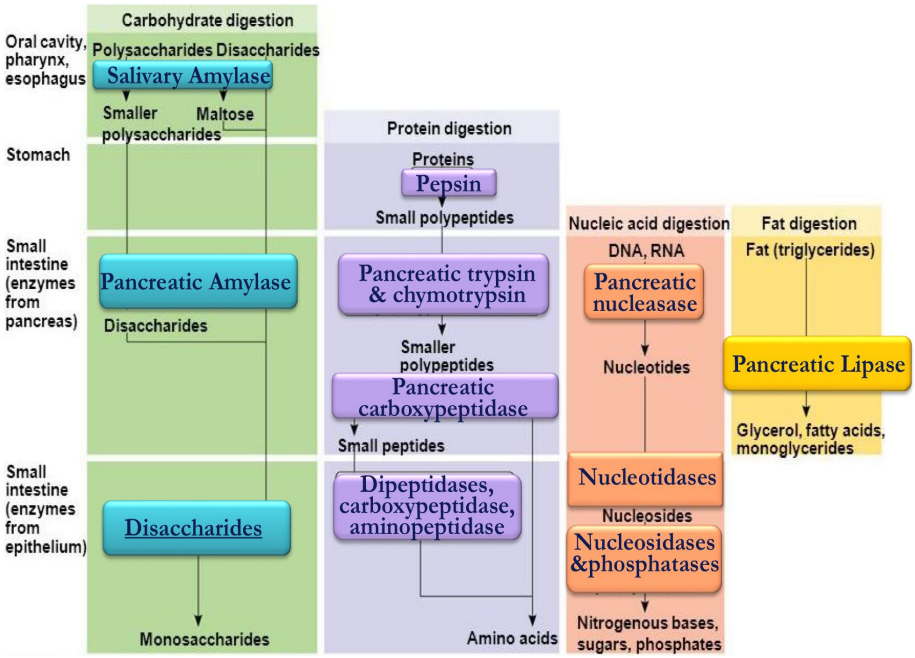
Fig. 8.31 Digestion of lipids in the small intestine.

4- Digestion of Nucleotides

Intestinal juice also contains **<u>nucleotidases</u>** for splitting nucleotides into nitrogenous bases (purine and pyrimidine), pentose sugar and phosphates.



Digestive Enzymes:
Could You Now Describe How a Happy Meal is Broken Down?



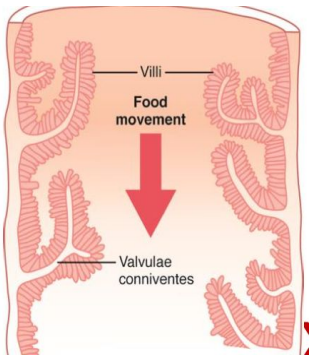
Basic Principles of Gastrointestinal Absorption

Absorptive surface of the small intestinal mucosa:

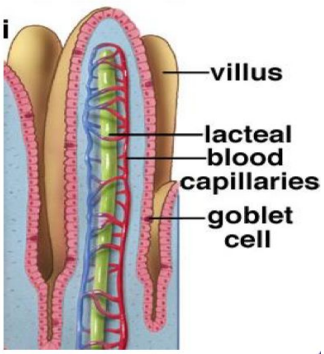
- There are three factors increases absorptive surface area of the small intestinal mucosa :

1. **3-fold:** mucosal folds (valvulae conniventes), well developed in the duodenum and jejunum.
2. **10-fold:** the villi on the mucosal surface
3. **20-fold:** about 1000 microvilli on the epithelial cells of each villus (the brush border)
4. So 3x10x20= 600
5. All of these factors increase the intestinal surface area to **600 fold** (equivalent to tennis court)

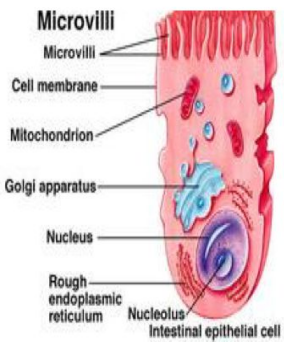
بعضكم الحين يسأل كيف مساحة السطح صارت ٦٠٠؟ تضربون ٣ في ١٠ في ٢٠
الي هم العوامل التي تؤثر على السطح بشكل فردي وناتج ضربهم ٦٠٠ التي تؤثر على السطح بشكل عام



3 folds



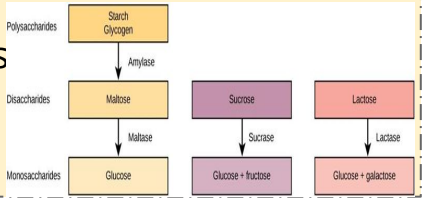
10 folds



20 folds

Absorption of Carbohydrates

- All the carbohydrates in the food are absorbed the form of monosaccharides; only a small fraction are absorbed as disaccharides.
- Glucose and galactose absorption occurs in a cotransport mode with active transport of Na^+ (2^{nd} active transport).
- **F**ructose is independent on Na+ but it transports in luminal membrane via **f**acilitated diffusion.
- **P**entose is transported by **p**assive diffusion



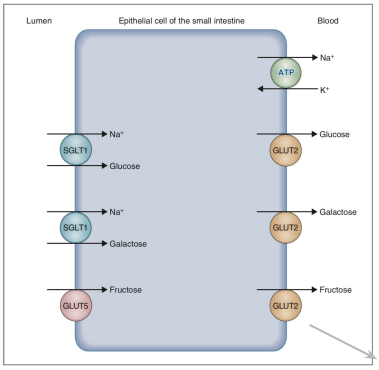
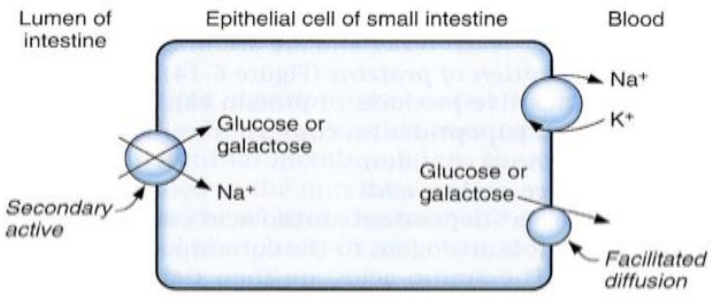


Fig. 8.27 **Mechanism of absorption of monosaccharides by epithelial cells of the small intestine.** *ATP*, Adenosine triphosphate; *Glut*, glucose transporter; *SGLT*, Na-glucose cotransporter.



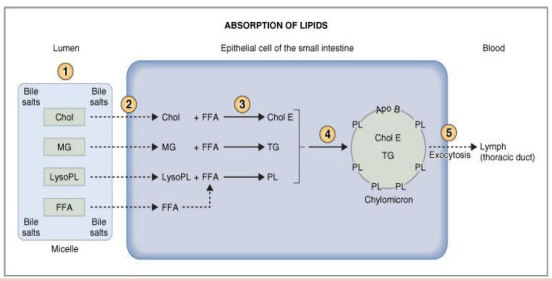
Just know that there's different carrier for each one which has significant role in the drugs that used for diabetic patients. No need to memorize the names.

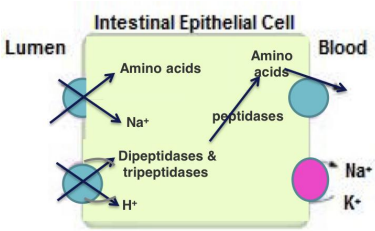
Absorption of Proteins

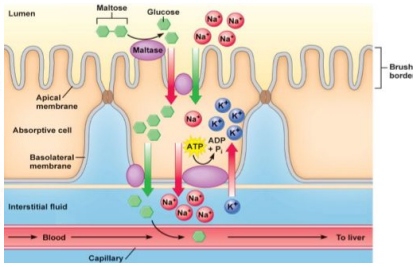
- Proteins are absorbed as dipeptides, tripeptides, and a few free amino acids.
- D- AA (Amino Acids) are transported by passive diffusion.
- L- AA are transported by 2ry active transport.
- Di and tripeptides cross the brush border by active transport protein carrier. They are hydrolyzed by brush border and cytoplasmic oligopeptides.
- AA leaves the cell at the basolateral membrane by facilitated transport.

Absorption of Fats

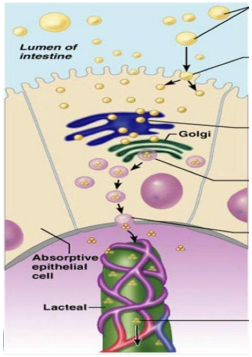
- In the <u>presence</u> of an abundance of bile micelles, about **97 %** of the fat is absorbed.
- In the <u>absence</u> of the bile micelles, only **40 to 50 %** can be absorbed.



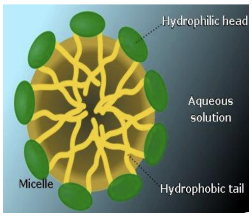


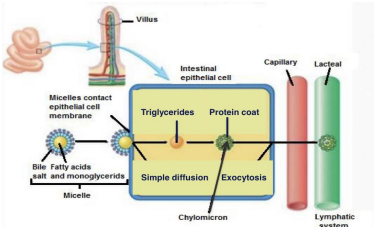


Role of Micelles in Fat Absorption



- Bile salts are amphipathic molecules,each composed of a sterol nucleus (fat-soluble) and a polar group (water-soluble).
- The polar parts are (-) charged, they allow the entire micelle globule to dissolve in the water of the digestive fluids.
- Micelles are small spherical, cylindrical globules composed of 20 to 40 molecules of bile salts.
- Long chain FA, MG, cholesterol and fat soluble vitamins are incorporated into the interior of the micelle.
- In the presence of micelles, about 97 % of the fat is absorbed in the small intestine.
- The micelles carry FA & MG to the luminal borders of the intestinal epithelial cells.





Steps of Fat Absorption

FA & MG leave micelles and enter epithelial cell by **diffusion**.

→

FA are used to synthesise triglycerides in agranular endoplasmic reticulum.

↓

Fatty globules are combined with proteins to form **chylomicrons** within Golgi apparatus.

←

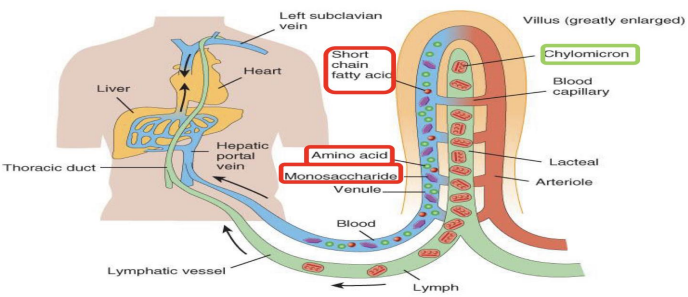
Vesicles containing chylomicrons leave epithelial cells by **exocytosis** and enter **a lacteal** (lymph capillary).

Short chain FA will transport directly to the bloodstream.

↓

Lymph in the lacteal transports chylomicrons away from the intestine.

Where will the absorbed nutrients go?



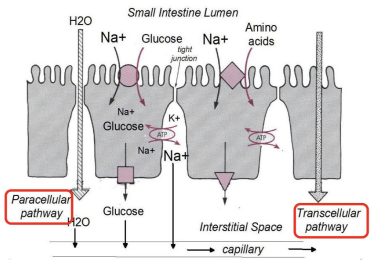
Absorption of Vitamins

A. Fat-soluble vitamins (A, D, E, & K) are incorporated into micelles and absorbed along with other lipids.
B. Most water-soluble vitamins (C, B and folic acid) are absorbed by Na^+-dependent cotransport mechanisms.
C. Vitamin B12 is absorbed in the terminal part of ileum and requires intrinsic factor.

- Ileal resection can cause vitamin B12 deficiency .
- Gastrectomy results in the loss of parietal cells and loss of intrinsic factor —> pernicious anemia

Absorption and Secretion of Electrolytes and Water :

1. Electrolytes and H2O intestinal epithelial cells by either transcellular or paracellular route cross.
2. The permeability of the tight junctions varies with the type of epithelium

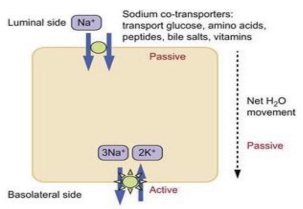


- Leaky epithelia are in the small intestine and gallbladder.
- A tight epithelium is in the colon

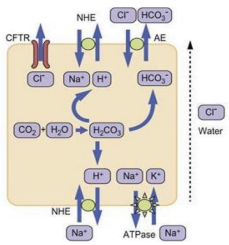
Absorption of Na+ :

Na+ moves into the intestinal cells by the following mechanisms:

1. Passive diffusion.
2. Na^+-glucose or Na+-amino acid co-transport.
3. Na^+-Cl^- exchange.
4. Na^+-H^+ exchange.

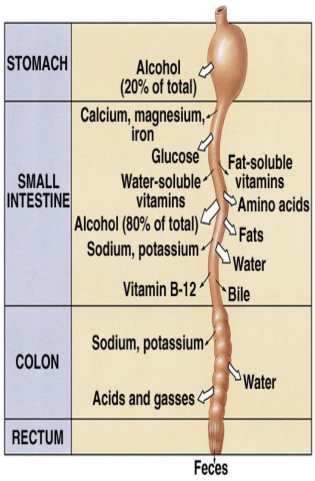


- The next step is osmosis of water into the paracellular spaces.
- **Aldosterone Greatly Enhances Na^+ Absorption.** This effect is especially important in the colon because it allows virtually no loss of NaCl and water.



Absorption of Cl^-

Cl^- absorption accompanies Na+ absorption by the following mechanisms:
1) Passive diffusion
2) Na^+-Cl^- cotransport
3) Cl^--HCO_3^- exchange



Absorption and secretion of K^+

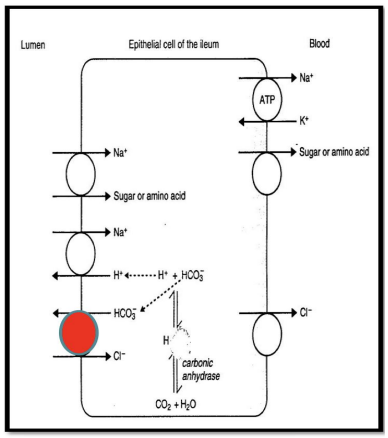
- K^+ is absorbed in the small intestine by passive diffusion.
- K^+ secretion in the colon is stimulated by aldosterone
- Excessive loss of K^+ in diarrheal fluids causes hypokalemia

Secretion of HCO_3^- in the Ileum

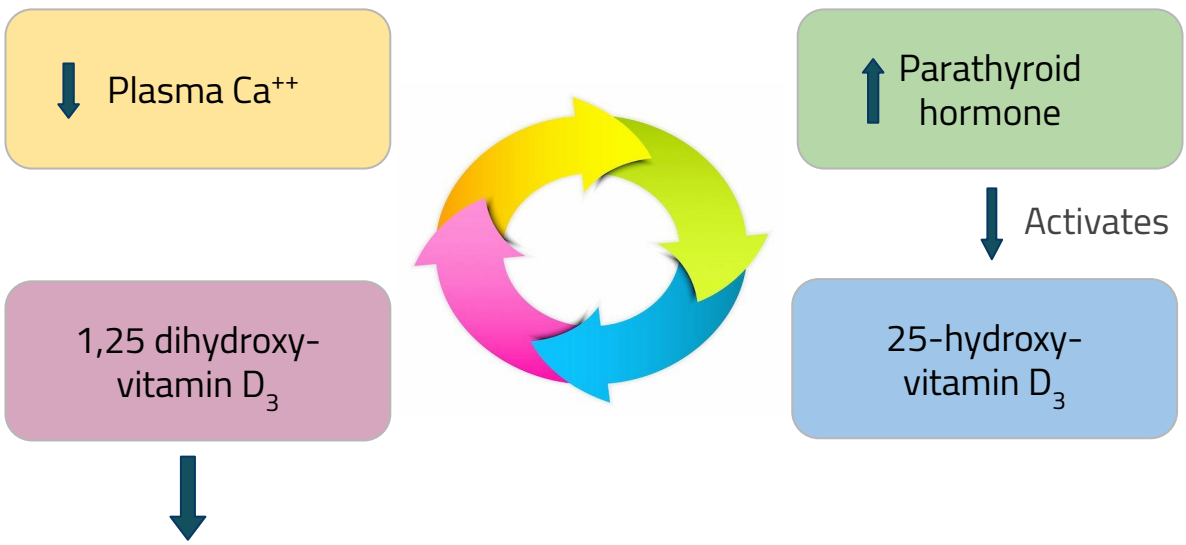
Always secretion not absorption

- The epithelial cells on the surfaces of the villi in the ileum and large intestine have a special capability of secreting HCO3- exchange for absorption of Cl-.

- This provides alkaline HCO that neutralize acid products formed by bacteria in the large intestine.



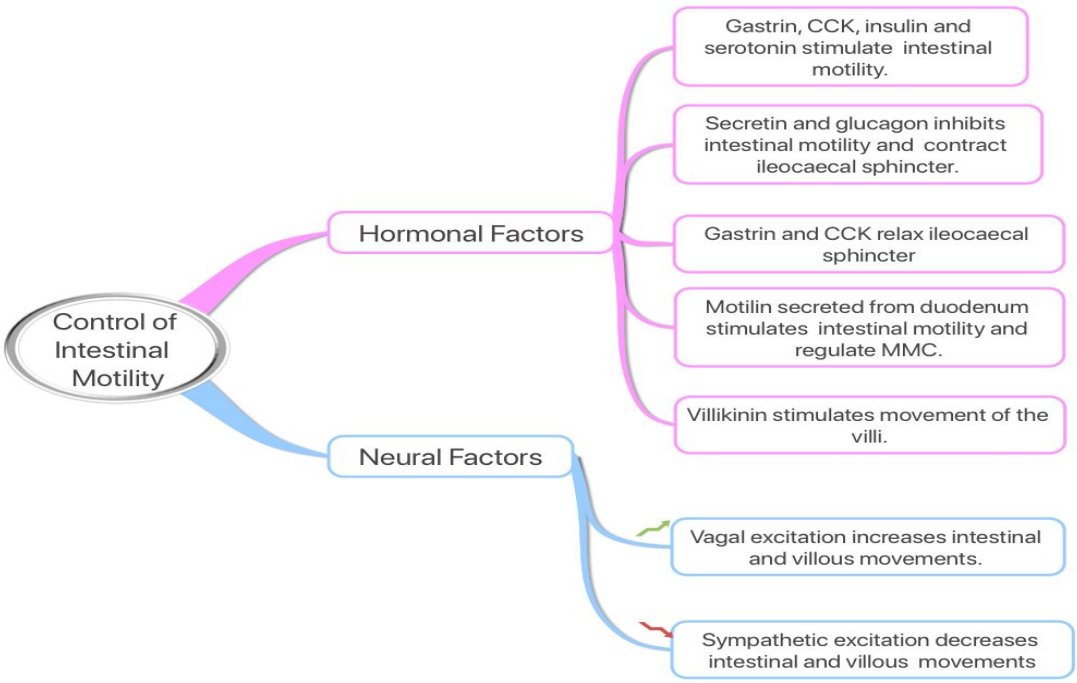
Ca^{++} Absorption by Enterocytes



Synthesis of Ca^{++}-binding protein and Ca^{++}-ATPase in enterocytes

Summary

Motility in the Small Intestine	
1) Propulsive Peristaltic Movement	A contraction ring appears around gut, then moves forward. Usual stimulus is distention.They can be blocked by atropine.
2) Segmentation (Mixing) Contractions	A localized contraction of circular smooth muscles that constricts the intestine into spaced segments.It last for fraction of min.
3) Migrating Motor Complex	Bursts of depolarization accompanied by peristaltic contraction that begins in empty stomach during interdigestive period
4) Anti-Peristalsis	A wave of contraction in the alimentary canal that passes in an oral
5) Peristaltic Rush	Powerful rapid peristalsis due to intense irritation of intestinal mucosa (as in infectious diarrhea).



Secretions of the small intestine:	
Brunner's Glands in the Duodenum	**Intestinal Juices (Succus Entericus)**
secrete large amounts of alkaline mucus, which contains a large amount of bicarbonate ions (Mucus protects the mucosa) **Stimulated by:** Secretin,Irritating stimuli on the duodenal mucosa,Vagal stimulation **Inhibited by:** Sympathetic stimulation	Secreted from intestinal crypts (small pits which lie between intestinal villi). **Stimulated by:** -Distension, tactile and vagal stimulation. -Hormones as: gastrin, secretin, CCK, glucagons, enterocrinin. **Inhibited by:** Sympathetic stimulation

Summary

Digestion	
Carbohydrates	Pancreatic secretion has a-amylase The enterocytes contain enzymes (lactase, sucrase, maltase, and a-dextrinase) they are capable of splitting the disaccharides lactose, sucrose, and maltose, into monosaccharides
Proteins	proteins remain as dipeptides and tripeptides. To be digested by peptidase in the enterocytes protein digestion occurs the duodenum and jejunum by Both trypsin and chymotrypsin split protein molecules into smaller polypeptides
Fats	Bile salts and lecithin in the bile help fat digestion,Bile salts break the fat globules into very small sizes, so that the water-soluble digestive enzymes can act on the globule (emulsification of fat)
Nucleotides	Intestinal juice also contains nucleotidases for splitting nucleotides into nitrogenous bases (purine and pyrimidine), pentose sugar and phosphates.
Absorption	
Carbohydrates	All the carbohydrates absorbed in the form of monosaccharides .Glucose and galactose absorption with active transport of Na+ . Fructose is transported in luminal membrane via facilitated diffusion Pentose is transported by passive diffusion
Proteins	Proteins are absorbed in the form of dipeptides, tripeptides , and a few free amino acids . Di and tripeptides cross by active transport protein carrier. They are hydrolyzed by oligopeptides in the enterocyte AA leaves the cell at the basolateral membrane by facilitated transport
Fats	in the presence of an abundance of bile micelles , about 97 % of the fat is absorbed . In the absence of the bile micelles , only 40 to 50 % can be absorbed
Vitamins	-Fat-soluble vitamins (A, D, E, & K) are incorporated into micelles and absorbed along with other lipids -Most water-soluble vitamins (C, B and folic acid) are absorbed by Na+-dependent cotransport mechanisms -Vitamin B12 is absorbed in the terminal part of ileum & requires intrinsic factor.

TABLE 8.6 Summary of Mechanisms of Digestion and Absorption of Nutrients

Nutrient	Products of Digestion	Site of Absorption	Mechanism
Carbohydrates	Glucose Galactose Fructose	Small intestine	Na^+-glucose cotransport Na^+-galactose cotransport Facilitated diffusion
Proteins	Amino acids Dipeptides Tripeptides	Small intestine	Na^+-amino acid cotransport H^+-dipeptide cotransport H^+-tripeptide cotransport
Lipids	Fatty acids Monoglycerides Cholesterol	Small intestine	Bile salts form micelles in the small intestine Diffusion of fatty acids, monoglycerides, and cholesterol into intestinal cells Reesterification in the cell to triglycerides and phospholipids Chylomicrons form in the cell (requiring apoprotein) and are transferred to lymph
Fat-soluble vitamins		Small intestine	Micelles form with bile salts and products of lipid digestion Diffusion into the intestinal cell
Water-soluble vitamins Vitamin B_{12}		Small intestine Ileum	Na^+-dependent cotransport Intrinsic factor
Bile salts		Ileum	Na^+-bile salt cotransport
Ca^{2+}		Small intestine	Vitamin D–dependent Ca^{2+}-binding protein
Fe^{2+}	Fe^{3+} reduced to Fe^{2+}	Small intestine	Binds to apoferritin in the intestinal cell Binds to transferrin in blood

MCQs

1) Migrating motility complexes (MMC) occur about every 90 min between meals and are thought to be stimulated by the gastrointestinal hormone, motilin. An absence of MMCs causes an increase in which of the following?
A. Duodenal motility.
B. Gastric emptying.
C. Intestinal bacteria.
D. Swallowing.

2) A 57-years old man undergoes resection of the terminal ileum as a part of treatment for his chronic inflammatory bowl disease. Removal of the terminal ileum will most likely result in witch of the following?
A. Decreased glucose absorption.
B. Decreased water content of feces.
C. Increased bile acids concentration in enterohepatic circulation.
D. Increase excretion of the fatty acid.

3) At which one of the following locations is vitamin B12 most likely to be absorbed?
A. Stomach
B. Duodenum.
C. Jejunum.
D. Ileum.

4) Removal of the proximal part of small intestine would most likely result in decrease of which of the following?
A. Maximal acid output.
B. Pancreatic enzyme secretion.
C. Gastric emptying.
D. Basal acid output.

5) Which of the following is a major mechanism for absorption of sodium from the small intestine?
A. Co-transport with bicarbonate.
B. Na-k exchange.
C. Neutral NaCl absorption.
D. Solvent drag.

6) Which of the following hormones relax ileocaecal sphincter?
A. Secretin.
B. Glucagon.
C. Villikinin.
D. Gastrin.

SAQ

What are the mechanisms of Cl absorption?

1. Passive diffusion.
2. Na-Cl co-transporter.
3. Cl-HCO3 exchange.

Answers:
1- C
2- D
3- D
4- B
5- C
6- D