Absorptions of Carbohydrates, Lipids, Proteins, Water, Minerals And Vitamins

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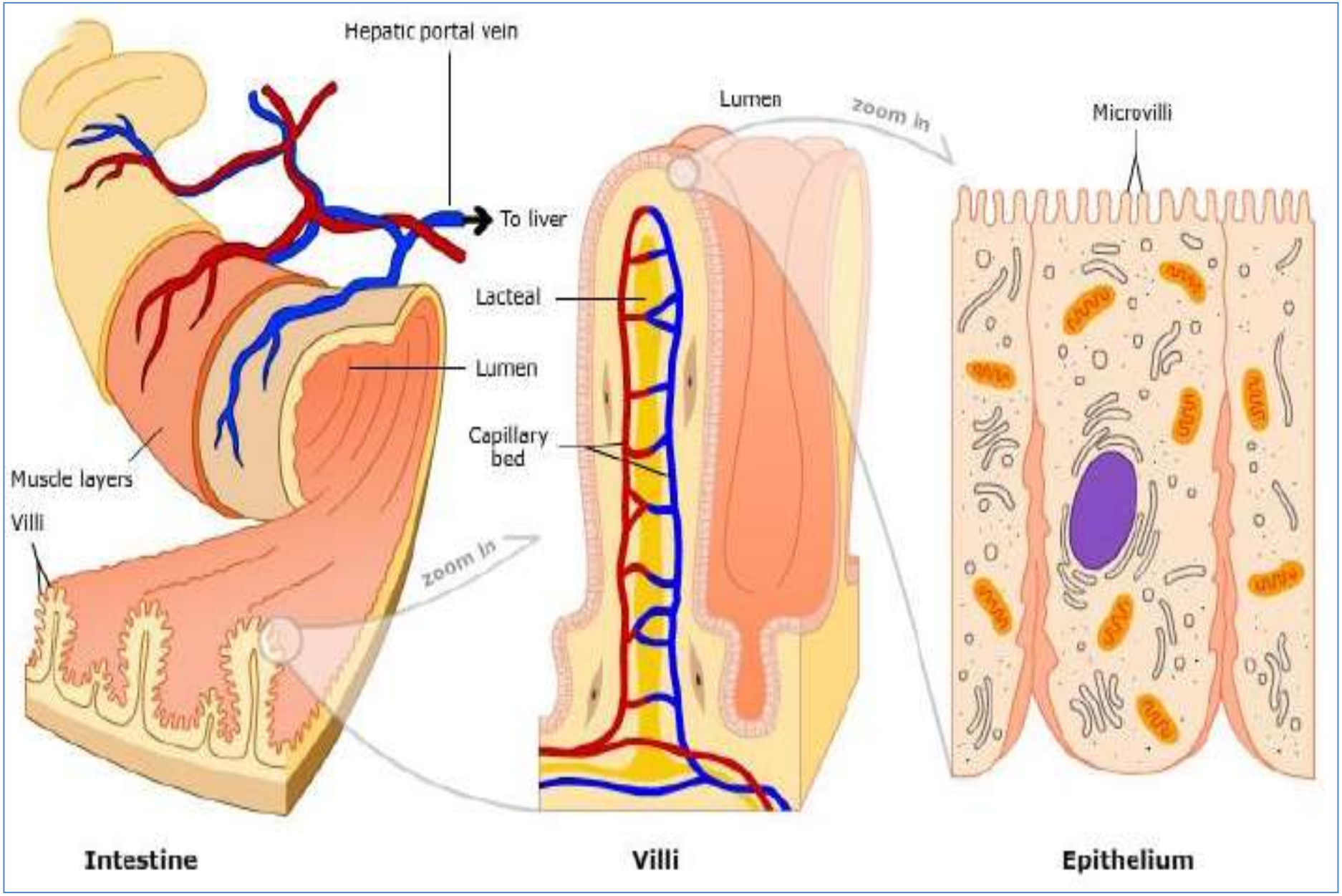
Digestion and Absorption

- Digestion is a process essential for the conversion of food into a small and simple form.
  - Mechanical digestion by mastication and swallowing
  - Chemical digestion by enzymes
- Absorption is the process of transporting small molecules from the lumen of the gut into blood stream or lymphatic vessel.

- Small intestine is primary site for digestion and absorption of food.
- Digestion occurs in the GI lumen by secreted enzymes and on surface of enterocytes by membrane-bound enzymes.
- Absorption occurs by simple diffusion, facilitated diffusion, active transport, endocytosis, and paracellular transport.
- Surface area of small intestine is greatly increased by extensive folding and the projection of fingerlike villi covered with microvilli.


Hepatic portal vein
To liver
Lacteal
Lumen
Capillary bed
Muscle layers
Villi
zoom in
Lumen
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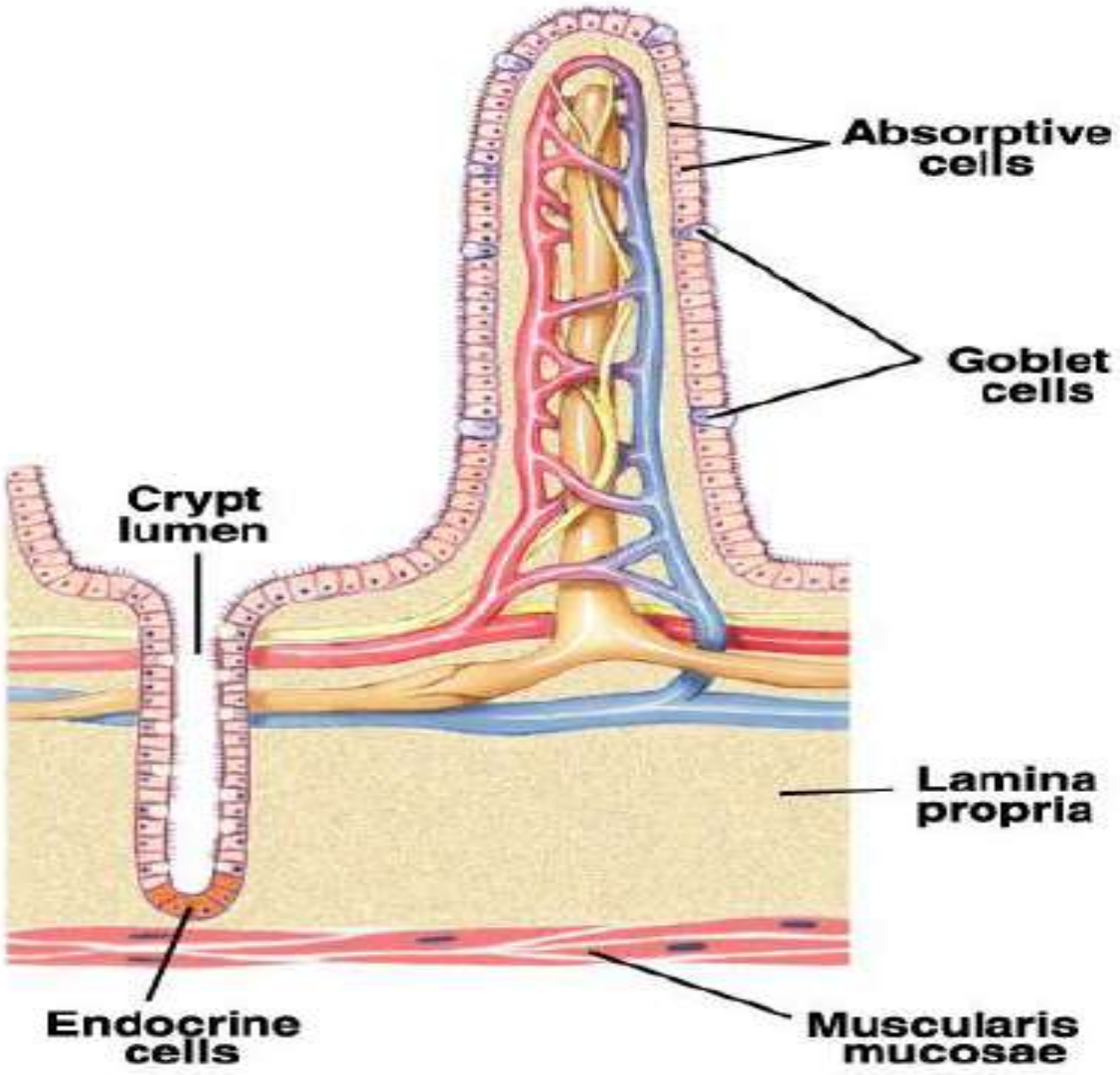
Microvilli
Intestine
Villi
Epithelium

Intestinal Villi



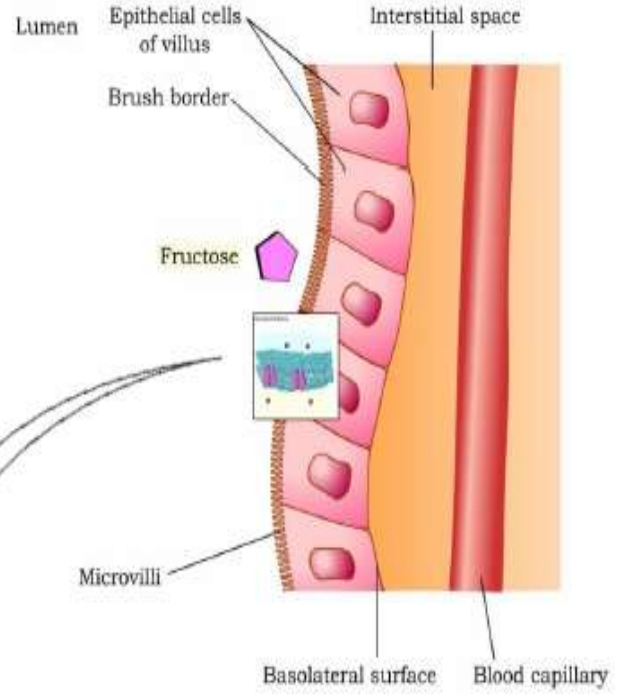
The movement of substances into or across tissues, in particular, the passage of nutrients and other substances into the walls of the gastrointestinal tract and then into the bloodstream is referred to as absorption. The small intestine is the main digestive and absorptive organ. Most absorption occurs in the duodenum and jejunum (second third of the small intestine).

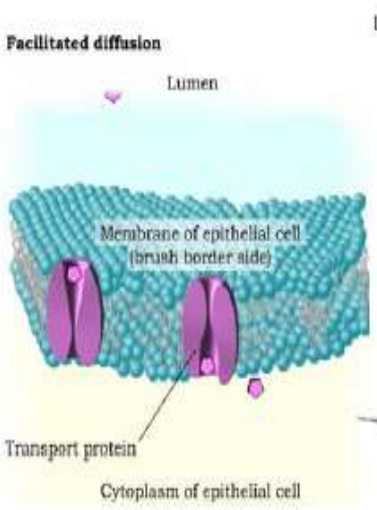
Transport across the intestine may be *active* or *passive*. Active transport requires energy, whereas passive transport does not. Also, active transport may involve movement of a substance *against* a concentration gradient (that is, from a region of lower to higher concentration), while substances that are passively transported always move *with* the concentration gradient. *Facilitated diffusion* is a type of passive transport which, unlike simple diffusion, uses a *carrier*. It is therefore more rapid than simple diffusion. *Active transport* mechanisms have been identified for intestinal absorption of many substances including glucose, galactose, amino acids, calcium, iron, folic acid, ascorbic acid, thiamin and bile acids. Fructose, riboflavin and vitamin B12 (in combination with intrinsic factor) are among the substances absorbed by facilitated diffusion.

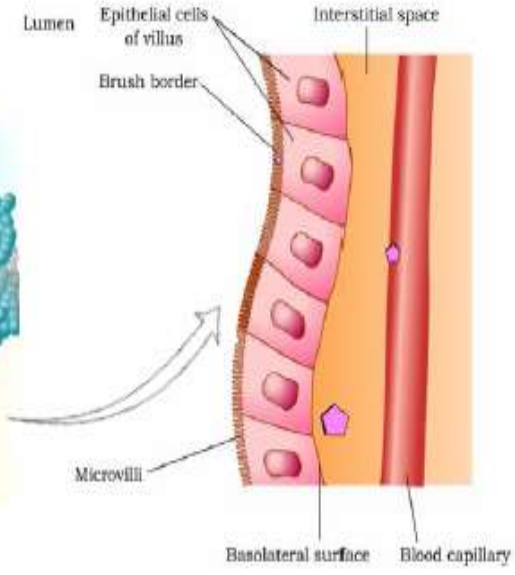
Carbohydrate absorption

Fructose

- Facilitated diffusion:
  - Transport fructose from lumen into epithelial cells of intestinal villi.
  - Transport monosaccharides out of epithelial cells into the interstitial fluid.
  - The monosaccharide eventually diffuses into the blood stream without using ATP in the process.







Glucose and Galactose

- Secondary active transport :
  - Transport glucose and galactose into epithelial cells of intestinal villi.
  - Couples transport of glucose or galactose with that of sodium ions.
  - Transports materials in the same direction, down the concentration gradient for at least one substance.
- Glucose and Galactose are then transported from epithelial cells to the interstitial fluid and eventually into the blood via facilitated diffusion

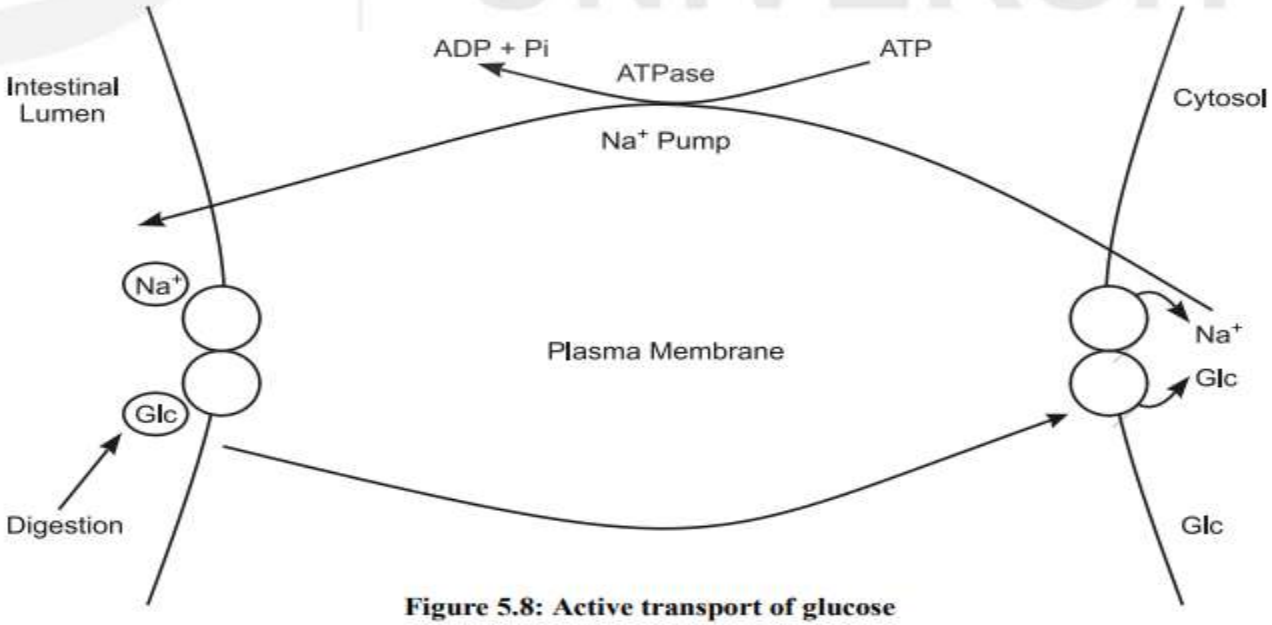


Figure 5.8: Active transport of glucose

ABSORPTION OF CARBOHYDRATES

Carbohydrates are absorbed from the GIT in the form of monosaccharides. The monosaccharides include those formed at the brush border (described above) and also those ingested as such (e.g. glucose and fructose in fruits).

Site of absorption

Most of the monosaccharides are absorbed from the mucosal surface of jejunum and upper ileum. The absorption is almost completed before the remains of meal reach the terminal ileum. Negligible absorption also occurs in stomach and colon.

Mechanism of absorption

Various monosaccharides are absorbed by following mechanisms:

- *Glucose* and *galactose* are absorbed by a common *Na^+ dependent active transport* system:
- *Fructose* is absorbed by *facilitated diffusion*. Fructose absorption occurs readily, because most of the fructose is rapidly converted into glucose and lactic acid within the epithelial cells, thus maintaining a high concentration gradient for diffusion.
- *Pentoses* are absorbed by simple diffusion.

Absorption of glucose and galactose

Glucose and galactose are absorbed into the epithelial cells (enterocytes) lining the mucous membrane of small intestine from their brush border surface (luminal surface) by an *active transport mechanism* – the *sodium co-transport* mechanism. Salient points of glucose absorption are (Fig. 7.7-2):

Binding of glucose and Na^+ to carrier protein. The carrier protein (present in the cell membrane) has two binding sites one for sodium and another for glucose. It is called *sodium dependent glucose transporter-1 (SGLT-1)*. The conformational change in the carrier protein occurs only when the binding sites are occupied by the sodium and glucose present in the gut lumen forming the sodium-glucose-carrier complex.

Creation of electrochemical gradient across the epithelial cell. The active transport of sodium by Na^+-K^+-ATPase pump through the basolateral membrane into the paracellular spaces lowers the intracellular Na^+ concentration. This creates an electrochemical gradient.

Movement of sodium and glucose inside the cell. Because of the electrochemical gradient created, the sodium moves into the cell (downhill transport). The flow of sodium ions down the gradient is so forceful that glucose (or galactose) molecule attached to the carrier protein also enters the cell even against concentration

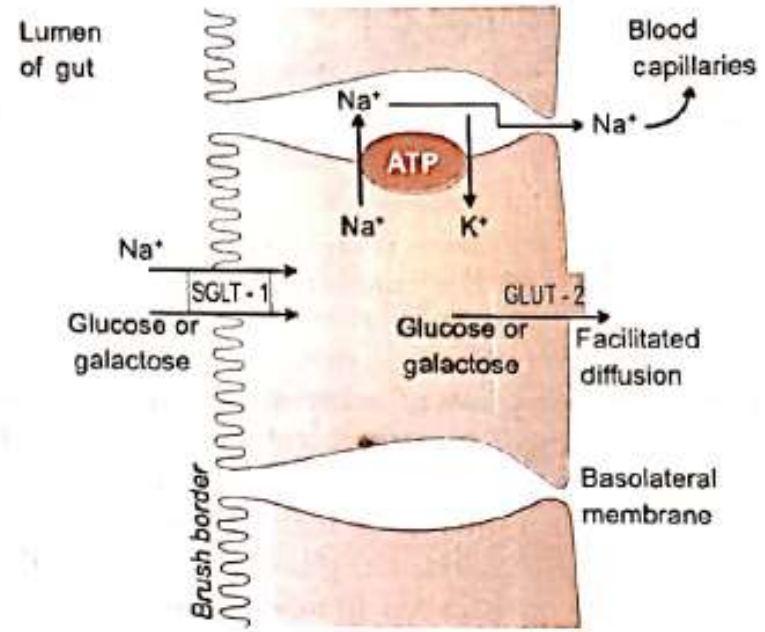


Fig. 7.7-2. *Mechanism of glucose absorption across intestinal epithelial cell.*

gradient for glucose (uphill movement). Because two Na^+ are transported down their electrochemical gradient, a large amount of energy is available for transport. Thus almost all of the glucose and galactose present in the intestine can be absorbed (against the concentration gradient). The energy so released is required for Na^+-K^+ pump activity to maintain the sodium gradient.

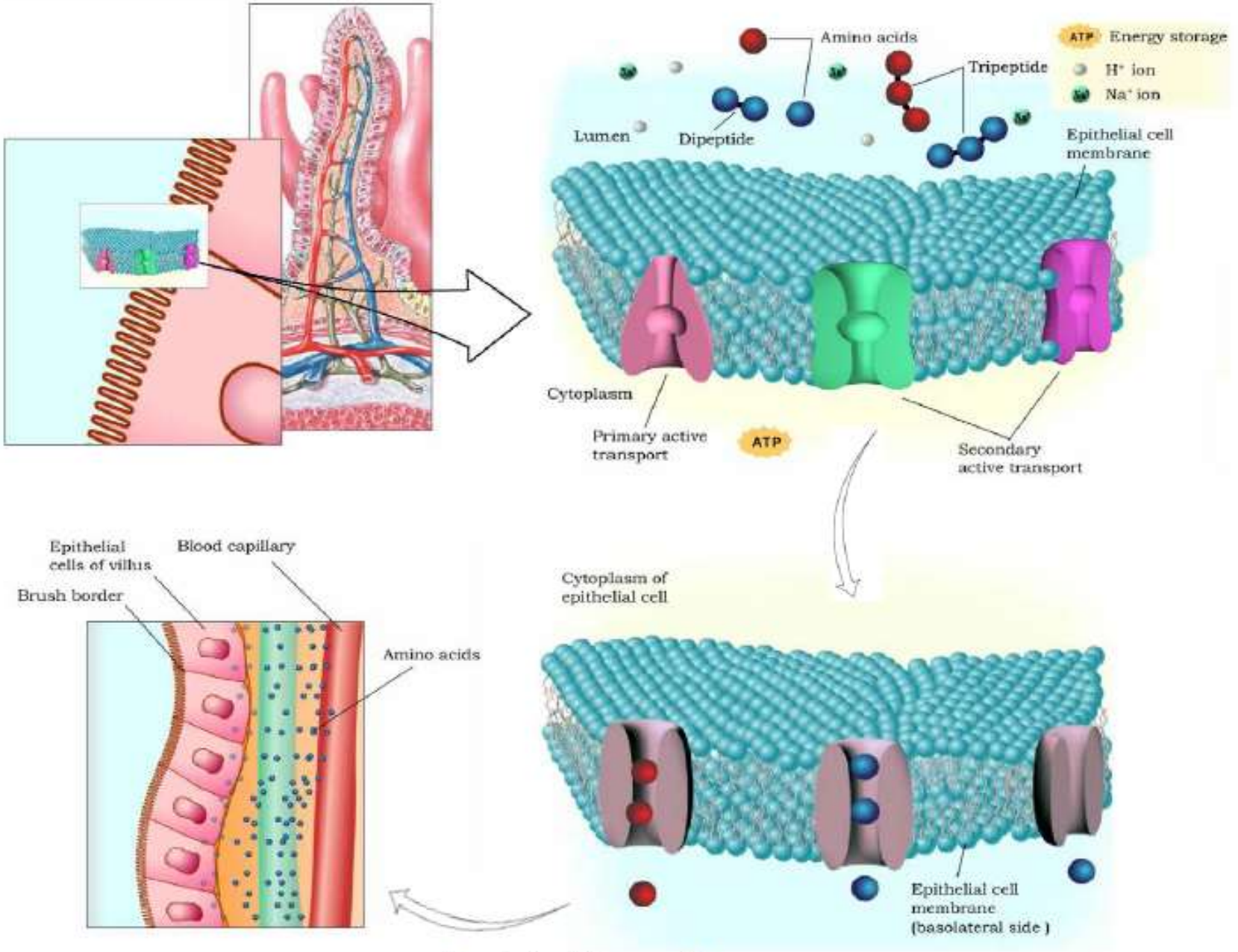
Transport of glucose into blood capillaries. From the epithelial cell the glucose is transported into the interstitial space and thence to blood capillaries of portal system through *facilitated diffusion* by *glucose transporter-2 (GLUT-2).*

Protein Absorption

- End product of protein digestion – amino acids, dipeptide, tripeptides .
- The end products , amino acids, dipeptides and tripeptides are absorbed at the intestinal villus.
- Absorption depends upon three mechanisms:
  - **Active transport.**
  - **Na+- dependent secondary active transport.**
  - **H+ dependent secondary active transport.**

Protein Absorption – transport mechanisms

- Most amino acids enter epithelial cells via active transport.
- Some amino acids enter epithelial cells via Na+ dependent secondary active transport.
- Dipeptides and tripeptides enter epithelial cells via H+ dependent secondary active transport.
- The peptides are then hydrolyzed to single amino acids inside of the epithelial cells.
- Amino acids can diffuse out of the epithelial cells, through the intestinal fluid, and enter the blood capillaries of the villus .



Protein Absorption

ABSORPTION OF PROTEINS

Mechanisms of absorption into the intestinal epithelial cells

The end products of protein digestion (amino acids, dipeptides and tripeptides) are absorbed through the luminal membrane of the epithelial cells of small intestine. Absorption of amino acids is faster in duodenum and jejunum and slower in ileum. Following mechanisms of absorption are known:

1. ***Na⁺ dependent active transport mechanism.*** The levo amino acids, dipeptides and tripeptides are absorbed by a Na^+ dependent active transport mechanism.

- Separate transporters (carriers) are present for the absorption of basic, acidic and neutral amino acids. At least two different polypeptide transporters exist.
- Steps of active transport mechanism are similar to those described for glucose absorption (see page 659). these include (Fig. 7.7-4):
  - Binding of amino acid and Na^+ to carrier protein
  - *Creation of electrochemical gradient across the epithelial cells.*
  - *Movement of Na^+ and amino acids inside the cell.*

2. ***Simple diffusion.*** The dextro amino acids are absorbed solely by passive diffusion.

3. ***Endocytosis.*** Larger polypeptides cannot be absorbed into the epithelial cells. Occasionally, small amounts of larger polypeptides are absorbed by endocytosis. Proteins absorbed by endocytosis usually excite immunological/ allergic reaction. In newborn infants, immunoglobulins present in the colostrum are absorbed in the intestinal mucosa by endocytosis and impart passive immunity to child.

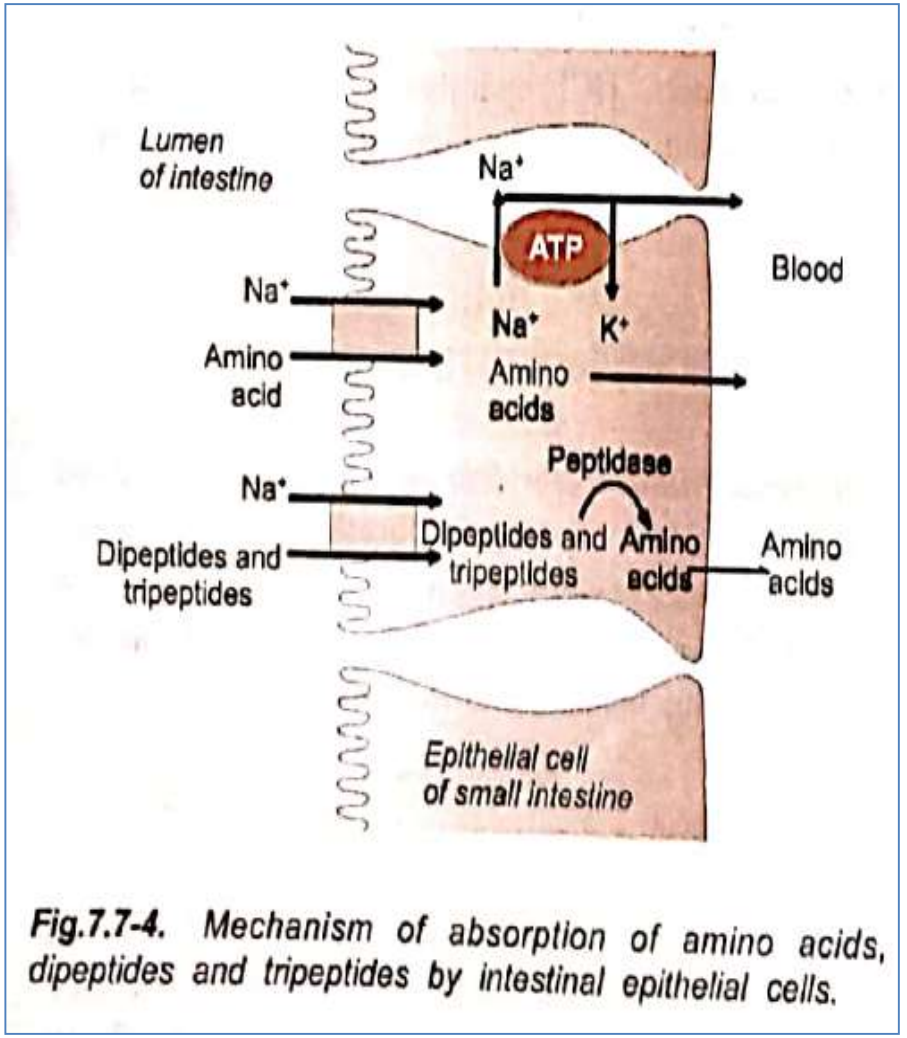


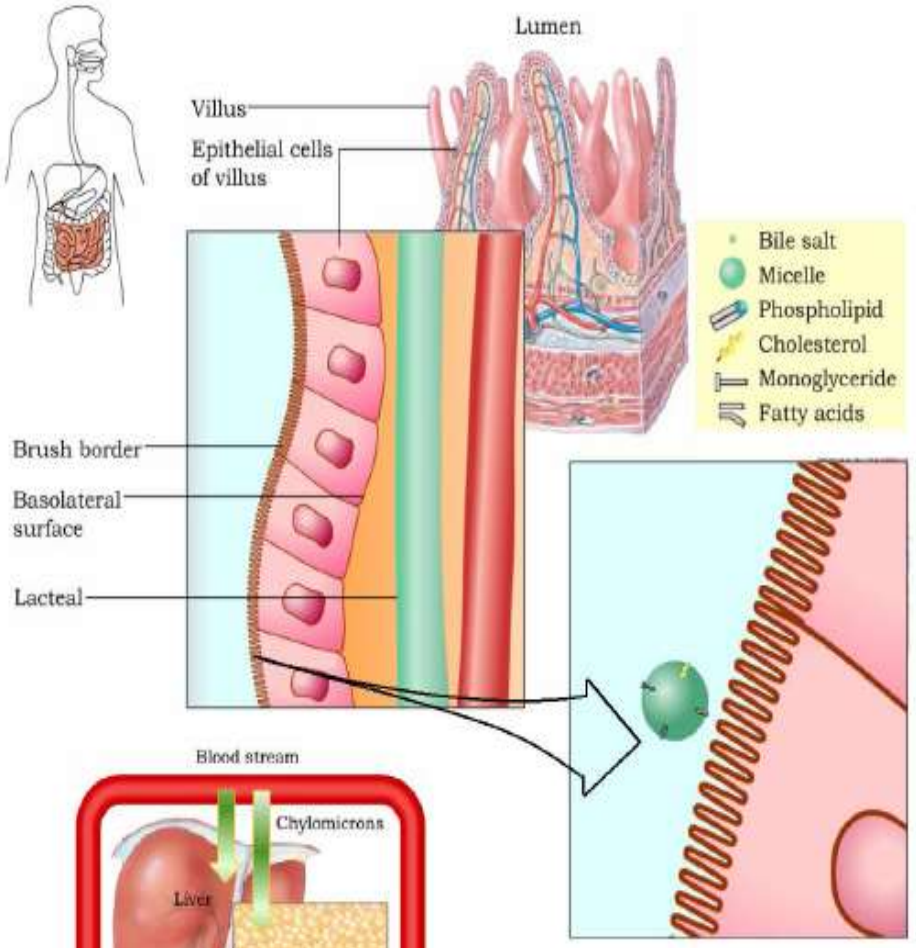
Fig.7.7-4. *Mechanism of absorption of amino acids, dipeptides and tripeptides by intestinal epithelial cells.*

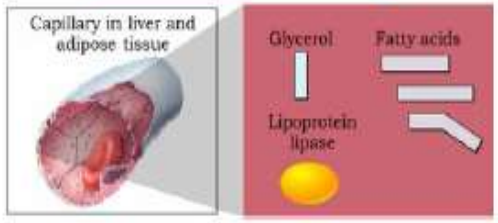
Lipid Absorption

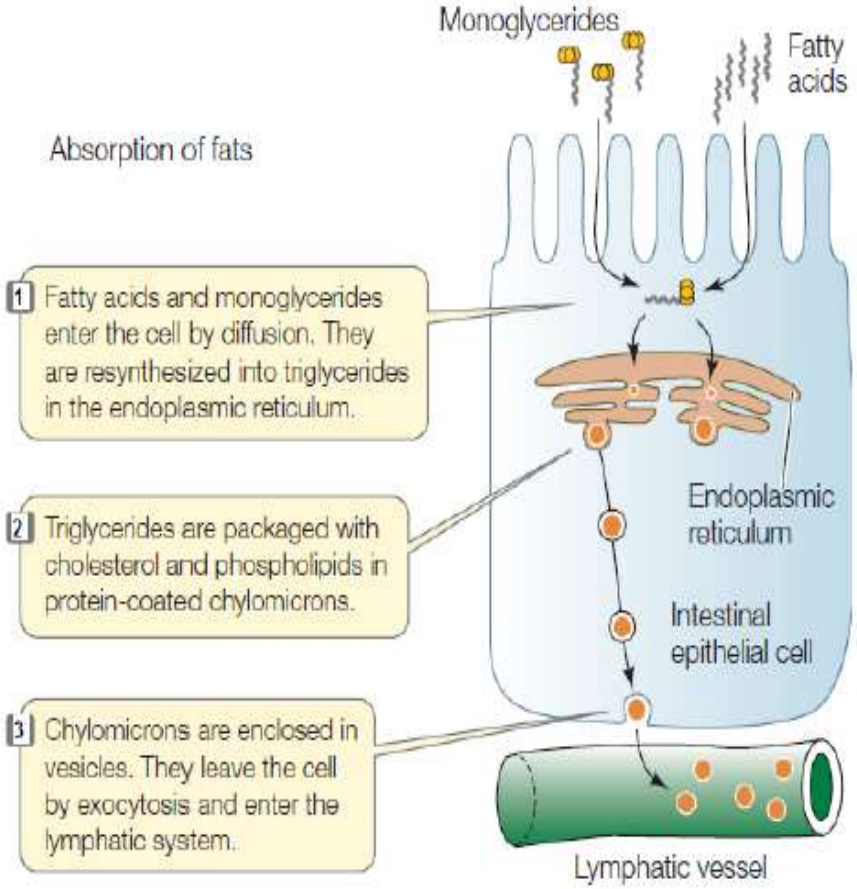
- The end products fatty acids ad monoglycerides, depend on bile salts for absorption.

Lipid Absorption – transport mechanism

- Bile salts from micelles which ferry fatty acids and monoglycerides to epithelial cells.
- Free fatty acids, monoglycerides and some phospholipids and cholesterol molecules , diffuses freely into epithelial cells.
- **Micelles** diffuse back into the chyme and continue transporting end products.
- Monoglycerides are commonly digested further by lipases, producing glycerol and fatty acids.
- Glycerol and fatty acids then recombine to form triglycerides.
- Triglycerides then aggregate with phospholipids and cholesterol to form chylomicrons.
- **Chylomicrons** are the coated with proteins and leave the epithelial cell via **exocytosis**.
- Chylomicrons are too bulky to enter blood capillaries directly.
- They enter lacteals, travel through lymphatic vessels and enter the bloodstream at the left subclavian vein.
- Chylomicrons are quickly removed from the blood and broken down by lipoprotein lipases in capillary endothelial cells in the liver and adipose tissue.







The products of fat digestion are absorbed by intestinal mucosal cells, where they are resynthesized into triglycerides and exported to lymphatic vessels.

Lipid Absorption

ABSORPTION OF FATS

Most of the fat absorption occurs in the duodenum; almost all the digested lipids are totally absorbed by the time the chyme reaches the mid jejunum. Absorption of fats is accomplished by following steps (Fig. 7.7-7):

1. Transportation as micelles to the brush border membrane. The micelle so formed (as described above) not only accelerates the fat digestion, but are also essential for the fat absorption as explained.

The insolubility of fat globules prevents their diffusion through the aqueous medium of the intestinal lumen to reach the brush border. This problem is solved by the bile salts by forming the micelle. As described above (Fig. 7.7-6) the outer surface of micelle is formed by water-soluble polar ends of bile salts, which helps the micelle to diffuse through the aqueous medium to reach the brush border membrane. Thus, the bile salt micelle acts as a transport vehicle for the products of fat digestion.

2. Diffusion of lipids across the enterocyte cell membrane. Once the micelle comes in contact with the cell membrane, the monoglycerides, free fatty acids, cholesterol and fat soluble vitamins (being soluble in the cell membrane) *diffuse passively* at a rapid speed through the enterocyte cell membrane to the interior of the cell, leaving bile salts in the intestinal lumen. Thus the *rate-limiting* step in lipid absorption is the formation and migration of the micelles from the intestinal chyme to the microvilli surface. It is important to note that the bile salts must be present in certain minimum concentration called *critical micellar concentration* before micelles are formed.

The bile salts released from micelle after diffusion of their associated lipids, are absorbed in the terminal ileum by a Na^+ dependent active transport process.

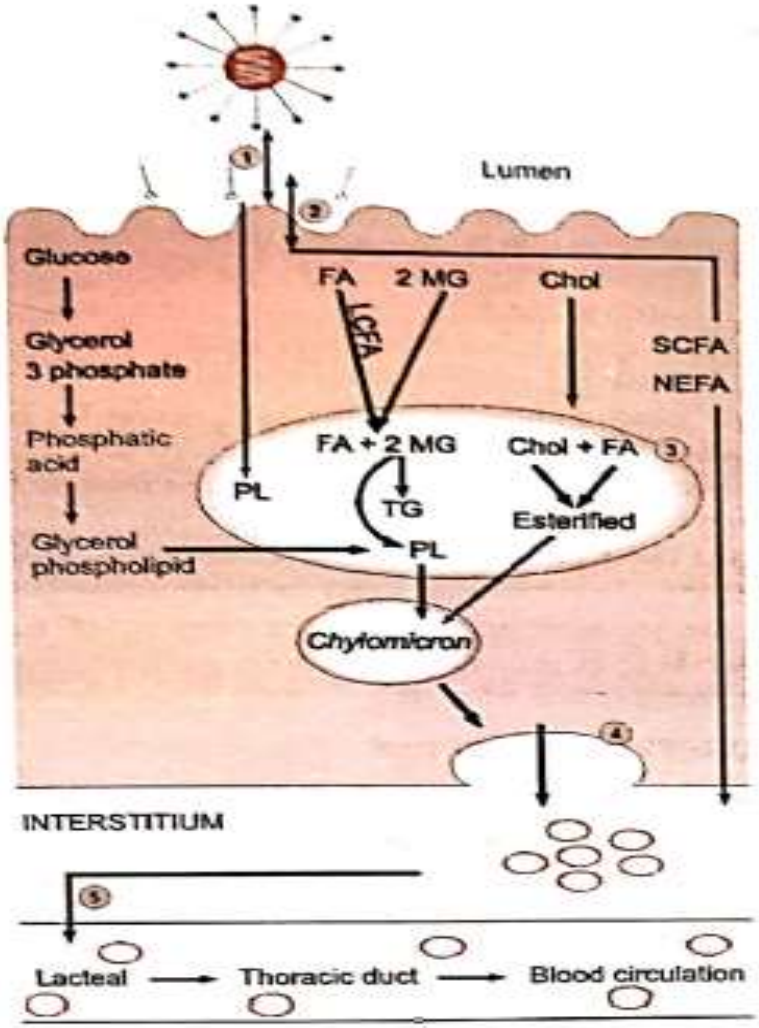


Fig. 7.7-7. Steps of fat absorption: 1, transportation of micelle to enterocytes brush border; 2, diffusion of lipids across the enterocyte membrane leaving bile salt in the lumen; 3, formation of chylomicron in the endoplasmic reticulum; 4, release of lipids into interstitium by exocytosis; and 5, diffusion of lipids from interstitium into lacteal (from where lipids enter into lymphatic circulation) and through thoracic duct into circulation. FA: fatty acid, MG: monoglycerides, chol: cholesterol, TG: triglycerides, LCFA: long chain fatty acid, SCFA: short chain fatty acids, NEFA: non-esterified fatty acids, and PL: phospholipid.

3. Transport of lipids from inside the enterocytes to the interstitial space. Once inside the cell, the end products of fat digestion enter the interstitium by two mechanisms:

i. Diffusion across the basal border of enterocyte. The small chain fatty acids (SCFA) with less than 12-14 carbon atoms are able to diffuse across the basal border of enterocytes to enter the interstitium.

ii. Formation and excretion of chylomicrons from enterocytes by exocytosis. The large chain fatty acids, cholesterol and lysophosphatides, enter the smooth endoplasmic reticulum, where they are reconstituted:

- 2-Monoglycerides are combined with fatty acids to produce triglycerides,
- Lysophosphatides are combined with fatty acids to form phospholipids, and
- Cholesterol is re-esterified.

The re-formed lipids coalesce to form a small lipid droplets (about 1 nm in diameter) called chylomicrons which are lined by β-lipoproteins synthesized. The chylomicrons are then excreted into the interstitium by *exocytosis* from the basolateral membrane of enterocyte. Covering of β-lipoproteins is essential for the exocytosis to occur. Therefore, in the absence of β-lipoprotein, exocytosis will not occur, and the enterocytes become engorged with lipids.

4. Transport of lipids into circulation. After exiting the enterocytes (i.e. in the interstitium), the chylomicrons merge into larger droplets that vary in size from 50-500 nm, depending on the amount of lipid being absorbed. From the interstitium the lipids diffuse into the *lacteals*, from which they enter the lymphatic circulation and via thoracic duct gain access into the blood circulation.

Water, minerals, and vitamins are absorbed through different mechanisms in the body. Water is absorbed via osmosis, passively moving across cell membranes from areas of low solute concentration to areas of high solute concentration. Minerals are absorbed through active transport, which requires energy, and facilitated diffusion, which doesn't require energy. Vitamins are absorbed through both passive and active transport mechanisms, with fat-soluble vitamins being absorbed with dietary fats and water-soluble vitamins primarily absorbed via passive diffusion.

Water Absorption:

Passive Transport (Osmosis):

Water moves across cell membranes to equalize solute concentrations, driven by osmotic pressure.

Small Intestine:

Absorbs most of the water ingested, with the large intestine absorbing some additional water.

Mineral Absorption:

- **Active Transport:** Requires energy (ATP) to move minerals against a concentration gradient.
- **Facilitated Diffusion:** Minerals move down a concentration gradient, with the help of carrier proteins.
- **Small Intestine (Duodenum):** Absorbs most minerals.

Vitamin Absorption:

- **Fat-Soluble Vitamins (A, D, E, K):** Absorbed with dietary fats, forming micelles and then absorbed into the lymphatic system.
- **Water-Soluble Vitamins (B vitamins, C):** Primarily absorbed via passive diffusion or active transport.
- **Small Intestine:** Absorbs most vitamins, with some absorption occurring in the large intestine.

The gastrointestinal (GI) tract plays a crucial role in the absorption of water, minerals, and vitamins. Water is primarily absorbed in the small and large intestines through osmosis. Minerals and vitamins, particularly those that are fat-soluble, are absorbed in the small intestine, while some are also absorbed in the large intestine.

Water Absorption:

Small Intestine:

The small intestine absorbs a significant amount of water, along with electrolytes, through the process of osmosis. This is facilitated by the absorption of solutes like sodium and chloride.

Large Intestine:

The large intestine also absorbs water, but the amount is less than in the small intestine. It plays a role in maintaining proper hydration levels.

Mineral Absorption:

Small Intestine:

The small intestine is the primary site for mineral absorption. Minerals are absorbed through various mechanisms, including passive diffusion, active transport, and facilitated transport.

Large Intestine:

Some minerals, like those produced by gut bacteria, can be absorbed in the large intestine.

Examples:

Various minerals, including zinc, copper, manganese, and selenium, are absorbed in the small intestine.

Vitamin Absorption:

- **Small Intestine:** The small intestine is the primary site for vitamin absorption.
- **Fat-soluble vitamins (A, D, E, K):** These vitamins are absorbed with dietary fats, becoming part of micelles for transport across the intestinal lining.
- **Water-soluble vitamins (B and C):** These vitamins are primarily absorbed through passive diffusion.
- **Large Intestine:** Gut bacteria in the large intestine can produce and absorb certain vitamins, particularly B and K vitamins.