4. ABSORPTION

**ABSORPTION MECHANISMS**

Once the digestive process is completed, the nutrients have to be transferred across the digestive tract epithelium into the intracellular space and eventually into circulation for distribution throughout the body.

Absorption can take place by several means (Fig. 4-1). It can be carried out by pinocytosis, active transport and passive diffusion. Some elements such as water are absorbed exclusively by diffusion using osmotic forces. Ions can enter enterocytes by diffusion, but may need to be transported actively to the intracellular space.

### Absorption

- **Nutrients can be absorbed by**
  - Pinocytosis
  - Active transport
  - Diffusion
- **Water is absorbed entirely by diffusion (osmosis)**
  - Can also be secreted that way
- **Ions diffuse into enterocytes and are transported to intracellular space**
- **Molecules move across membranes following gradient**
  - Concentration (to lower)
  - Electric (to opposite charge)

### Active transport

There are several active transport mechanisms (Fig. 4-2). One uses metabolic energy in the form of ATP to drive

Na⁺, K⁺: The ATPase pump creates an intracellular electronegative environment by lowering the concentration of Na⁺ as a result of being pumped out into the intracellular space.

### Transport mechanisms

- **Active transport uses metabolic energy**
  - Na⁺, K⁺, ATPase pump
  - Create intracellular electronegative environment
  - Lower Na⁺ concentration
- **Co-transport or symport**
  - Carries two Na⁺ and one glucose
  - Depends on Na⁺ gradient
- **Exchangers or antiports**
  - Switch Na⁺ for H⁺
  - Uses Na⁺ gradients

By pumping Na⁺ out, K⁺ is brought into the cell. To prevent accumulation of intracellular K⁺, the cell has leak channels that permit the escape of K⁺ into the intracellular space (Fig. 4-3).
Co-transport
A second mechanism called co-transport or symport consists of using the lower Na⁺ concentration in the cell to attract two Na⁺ at the same time that a third molecule, which could be a monosaccharide or an amino acid. A special membrane-bound protein binds all three components in the outside of the cell. As the Na⁺ enters into the cell, it flips the protein and internalizes the desired molecule. Upon release of the Na⁺, the protein changes its conformation and releases the molecule inside the cell. Finally, the empty molecule reverts to its original position, ready to pick up more cargo outside the cell (Fig. 4-3).

Antiports
The third mechanism of transport is the use of exchangers or antiports. In these cases, a Na⁺ is exchanged with an H⁺ generating a Na⁺ gradient, which is used to move molecules across the cell membrane.

CARBOHYDRATE ABSORPTION
All molecules of glucose are internalized using the co-transport system using Na⁺ gradient. The passage of glucose from the epithelial cell to the intracellular space is done through facilitated diffusion via leak channels of the basolateral membrane (Fig. 4-4).

Galactose is absorbed using the same mechanism of Na⁺ co-transport that permit the absorption of glucose (Figs. 4-3, 4-5). Fructose, however, operates in a different manner. Fructose is internalized by facilitated diffusion.

Figure 4-5. Internalization of monosaccharides after membranous digestion

This is a much slower system than the co-transport, thus, less fructose can be absorbed in a given time. Once fructose is in the cell, it is phosphorylated and converted to glucose before it is released into the intracellular space (Fig. 4-5).

PROTEIN ABSORPTION
The absorption of protein is very similar to that of carbohydrates. The main difference is that at the end of the membranous digestion there are still many di and tripeptides, which can be absorbed into the enterocytes. These peptides are hydrolyzed by enzymes located inside the enterocytes and the individual amino acids released by passive diffusion through the basolateral membrane into the intracellular space (Figs. 4-7, 4-8).
LIPID ABSORPTION

The mechanism for lipid absorption is a little more complex than that of carbohydrates or proteins. After digestion is completed, we find micelles in the lumen of the small intestine. The micelle contacts the apical membrane of the enterocytes. The monoglycerides, as well as the cholesterol and vitamin A, diffuse from the micelle into the enterocyte. The free fatty acids have to be carried out by a series of membrane bound proteins called fatty acid binding proteins (Figs. 4-9, 4-10).

Lipid absorption in the jejunum

- Micelles contact enterocytes
- Most lipid components diffuse into enterocyte
  - Monoglycerides
  - Cholesterol
  - Vitamin A
- Free fatty acids are transported by membrane bound proteins
  - Fatty acid binding protein
- Bile acids continue in lumen

Protein absorption

- Similar to carbohydrates
- Also di and tripeptides internalized into enterocytes
- Digested by internal enzymes
- Released to intracellular space as free amino acids

Protein absorption

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What is left of the micelle, in the lumen of the small intestine, are the bile salts which are immediately reused in the formation of new micelles during the digestive process.

Eventually, the bile salts reach the ileum where they are absorbed by a Na⁺ co-transport system and routed through the portal system to the liver. In the liver, they are recycled into the lumen of the intestine or to the gallbladder forming the previously described enterohepatic circulation (Fig. 4-10). After the incorporation of all digested components into the enterocyte, the fatty acids and monoglycerides are transported to the endoplasmic reticulum where they are reconverted to triglycerides (Fig. 4-11).

The chylomicrons (Fig. 4-14) are released through the basolateral membrane into the intracellular space where they are picked up in the lymphatics to reach the thoracic duct which empties into the vena cava. High concentrations of chylomicrons, as a result of a fatty meal, can generate lipemia or a white colour in plasma (Fig. 4-15).

Here the cholesterol is re-esterified and all of these are packed into chylomicrons (Fig. 4-12) in such a way that the cholesterol esters and the triglycerides form the core which is surrounded by phospholipids, cholesterol and proteins. The entire surface component makes the chylomicron water-soluble (Fig. 4-13).
WATER AND ELECTROLYTES ABSORPTION

The absorption of water takes place by osmosis and may follow the paracellular route (moves between the cells through the tight junctions) or the intracellular route (enters the cell through the apical membrane and leaves the cell to the intracellular space through the basolateral membrane). Usually, when the nutrients are absorbed and diffuse to the intercellular space (monosaccharides, amino acids, chylomicrons) they create an osmotic gradient which brings water from the ingesta.

When these particles enter the capillaries, they again create an osmotic pressure which attracts water into the villi microcirculation. (Figs. 4-16, 4-17). Furthermore, within the villi there is counter-current transfer of water from the incoming arterial blood to the closely apposed venous return. This generates a more concentrated blood at the tip of the villi, where water is drawn by osmosis from the intracellular space. This process is similar to that used in the kidney. In the villi, the concentration at the entry point is 300 mOsm while at the tip it may reach a concentration of 600 mOsm (Fig. 4-18).

All the water absorption takes place in a transcellular manner (Fig. 4-19).

Under abnormal conditions, when there is an inflammation and there is more intracellular water, the reverse process is created by transporting water from the intracellular space to the lumen of the intestine. This transport takes
place exclusively through the paracellular route (Fig. 4-20).

Water is also secreted by the endothelial cells in the crypt area. Usually, the majority of the ingested and secreted water is absorbed by the small intestine, leaving a relatively small amount to be excreted in the feces. A disruption to this balance causes diarrhoea.