Factors Influencing the Uptake and Absorption of Carotenoids (44275)

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In his classic book entitled *Vitamin A,* Thomas Moore wrote, "There are many complicating factors, both chemical and physiological, which will make it difficult to give an account of the absorption of vitamin A and its provitamins (carotenoids) which is both clear and reasonably comprehensive (1)." Although this statement accurately depicts our current ability to describe carotenoid absorption, it was written in 1957. In the last four decades, thousands of papers have been written about carotenoids, yet many questions still remain unanswered regarding the absorption of both provitamin A active carotenoids such as α- and β-carotene (BC), and carotenoids such as lycopene that do not have vitamin A activity.

Carotenoids are a family of over 600 fat-soluble pigments. The two subclasses of carotenoids are the oxygenated xanthophylls and the hydrocarbon carotenes. In nature, carotenoids are responsible for some of the characteristic colors in fall leaves, birds, fruits, vegetables, and shellfish. For example, tomatoes are red and carrots are orange primarily because of lycopene and β-carotene, respectively. Lutein, BC, and lycopene, shown in Figure 1, are the predominant carotenoids in our diet, serum, and tissues.

Emerging evidence that lycopene may have a role in reducing risk of both prostate cancer (2) and myocardial infarction (3) has rekindled interest in the factors that influence its absorption. Most of the research investigating carotenoid absorption has utilized BC as a model carotenoid, assuming that all carotenoids behave similarly during digestion. For the most part, this is probably true. However, the degree of influence a particular factor has may vary with the structural characteristics of each carotenoid. Because BC and lycopene are both hydrocarbon carotenes, it is expected that modification of dietary conditions affects each in a similar manner. The reviews by Erdman *et al.*, Wang, and Parker are recommended for further detail on the factors that affect BC absorption (4–6).

Carotenoid absorption can be divided into four parts: digestion of the food matrix, formation of lipid-mixed micelles, uptake of carotenoids into the intestinal mucosal cells, and transport of carotenoids into the general circulation *via* the lymph system. At each stage, fat is required. To obtain adequate carotenoid absorption, these compounds must be extracted from the food matrix into the lipid phase of the chyme in the gastrointestinal tract. Dietary fat stimulates bile secretion to aid the formation of lipid micelles. Carotenoids taken up into the mucosal cell are packaged into chylomicrons with phospholipids and triglycerides from the meal for transport out of mucosal cells.

Data from human studies in India have suggested that at least 5–10 g of fat in a meal are required for adequate absorption of β-carotene (7). A number of other investigators have demonstrated that carotenoids are absorbed from a fat-free meal (8).

Researchers have monitored the serum appearance of lycopene after feeding subjects tomato juice. Only subjects consuming tomato juice, preheated for 1 hr with 1% corn oil, had increased serum concentrations of lycopene. The authors speculated that the preheating step induced the rupture of cell walls, thereby releasing lycopene into the oil carrier (9). Since the U.S. diet contains about 30% of calories from fat, one assumes that most meals are adequate for carotenoid absorption. However, very low-fat meals or snacks with less than 10 g of total fat may be too low to facilitate carotenoid absorption.

Figure 2 is a cartoon that illustrates carotenoid uptake into a mucosal cell from the lumen of the small intestine. Only a small to moderate percentage of the carotenoid from the meal will be taken up by the intestinal cell. Estimates for β-carotene absorption from a meal have ranged from 3%–50% (4). If the carotenoid is not repackaged into chylomicrons for distribution within approximately 3 days, it is lost when the mucosal cells are sloughed off into the lumen of the gastrointestinal tract. Provitamin A carotenoids can be absorbed intact or can be cleaved to vitamin A as shown in Figure 2. Retinol is subsequently esterified by lecithin:retinol acyl transferase (LRAT) or acyl coenzyme A:retinol acyl transferase (ARAT). Lycopene and its isomers lack provitamin A activity but may be absorbed intact. Several

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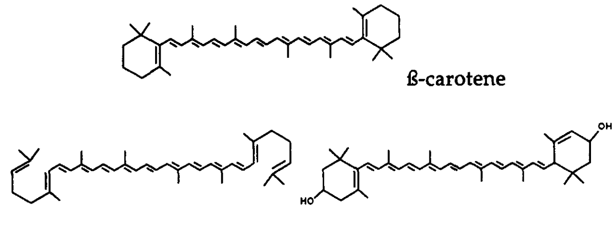

Figure 1. Chemical structures of β-carotene, lycopene, and lutein.

oxidation products of lycopene have been identified in human serum (10). The mechanisms of formation and site of formation of these lycopene metabolites are unknown.

Carotenoids in fruits and vegetables can be found as crystals or may be bound in protein complexes. Mild thermal processing can denature or weaken the protein-carotenoid complexes making carotenoids more available for absorption (4). Thermal processing may also improve the dispersion or dissolution of crystalline carotenoids into the lipid portion of the food matrix. For instance, ingestion of tomato paste versus fresh, uncooked tomatoes resulted in 2.5-fold higher serum-chylomicron, lycopene concentrations in human subjects (11). The thermally processed tomatoes are more bioavailable than fresh tomatoes (9). In the same respect, carotenoids from smaller food particles (finely chopped or pureed) or juices are more efficiently absorbed (4). Carotenoids are most poorly absorbed from green leafy vegetables (12). Lycopene is uniquely found concentrated in tomatoes and tomato products where digestibility seems to be much better than for other vegetables.

Certain types of dietary fiber, particularly pectin, have been shown to reduce β-carotene absorption in both humans and animals (13). Similarly, drugs that affect cholesterol absorption (14) and nonabsorbable fat analogs like sucrose polyesters (15) have been found to inhibit carotenoid absorption. Serum β-carotene and lycopene concentrations were reduced 30%–50% from baseline in subjects consuming 12 g of Olestra, a sucrose polyester, with their main carotenoid-containing meal for 4 weeks (15). However, the impact of Olestra from salty snacks on serum carotenoids is expected to be less dramatic, on the order of a 10% reduction (16), because snacks are not usually consumed in combination with carotenoid-rich foods. Thus, any substance that disrupts the bile-acid/micelle-formation process can inhibit carotenoid absorption.

The health of the individual can also impact carotenoid absorption and utilization (4). Poor iron, zinc, and protein status have also been correlated with reduced absorption, transport, and/or metabolism. Additionally, intestinal parasites, malabsorption diseases, and liver or kidney diseases could reduce carotenoid absorption. Hormone status may play a role, but is not well understood. Hyperthyroidism has been associated with low serum carotenoids, whereas the hypothyroidism associated with anorexia nervosa often results in elevated carotenoids in serum and in fatty derived areas (17).

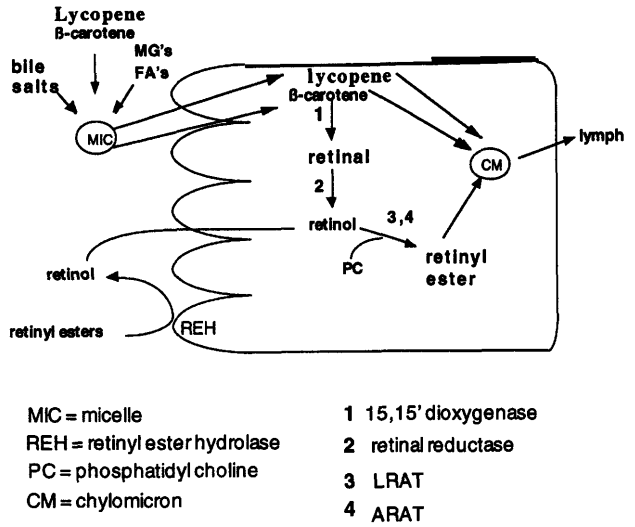

Figure 2. Carotenoid metabolism in the intestinal mucosal cell.

Specific studies on lycopene bioavailability from foods have only recently been carried out. As previously mentioned, Stahl *et al.* have shown that lycopene from tomato juice is much better absorbed if ingested with fat and if the food matrix has been heated.

Sakamoto *et al.* (18) studied the uptake of both β-carotene and lycopene from tomato juice. Subjects ingested either one, two, or three cans of tomato juice (195 g tomato juice/can) per day for 4 weeks with breakfast. Serum lycopene rose to three times that of baseline level in those subjects who consumed two or three cans of juice per day. Interestingly, subjects who consumed three cans of juice per day had double the serum β-carotene from baseline even though the β-carotene content of the juice was one thirtieth that of lycopene. This suggests selective absorption and/or serum accumulation of β-carotene.

Conversely, Johnson *et al.* (19) have found that administering crystalline lycopene and β-carotene (60 mg each) together in oil in gelatin capsules to humans resulted in no increase in serum β-carotene. Serum lycopene was significantly greater in the combined dose than when it was administered alone.

It can be concluded that the bioavailability from the food matrix including the effects of mild heat, the presence of fat, and the level of fiber in a meal are the leading factors that influence carotenoid absorption. Lycopene and tomato products have been associated with certain reduced health risks whereas other carotenoids in a variety of foods may affect other health outcomes (e.g., macular degeneration) (20). Thus, an optimal mix of carotenoid-rich foods, including tomatoes and tomato products, should be obtained by following the dietary guidelines depicted in the food pyramid.

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