

## Variable bioavailability of carotenoids from vegetables<sup>1,2</sup>

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Interest in carotenoids has increased over the past decade from scientists involved in a variety of disciplines. Although some human nutritionists have focused their efforts on the potential role of carotenoids in chronic disease prevention, others have been concerned about the millions of children worldwide who have increased risk of blindness, other illnesses, and death because of inadequate dietary vitamin A. Vitamin A deficiency exists in populations consuming foods with little preformed vitamin A and provitamin A carotenoids with insufficient bioavailability. In vitro and ex vivo tests suggest that carotenoids are excellent antioxidants and may have other biological properties that are unrelated their vitamin A activity. For example, the dihydroxylated carotenoids lutein and zeaxanthin, which do not have vitamin A activity, are deposited in the macular region of the eye. Age-related macular degeneration is the leading cause of irreversible blindness in people >65 y of age (1) and epidemiologic studies suggest that higher intakes of certain green leafy vegetables containing these 2 carotenoids decrease the risk of macular degeneration (2).

The epidemiologic associations of increased consumption of carotenoid-containing fruit and vegetables with lower risk of certain cancers, age-related macular degeneration, and cardiovascular disease are compelling. However, whether it is the carotenoids themselves or the fact that carotenoid intake or blood carotenoid concentrations are markers for other protective, bioactive components of those fruit and vegetables is yet to be determined. Critical to the alleviation of vitamin A deficiency or the determination of the potential role of carotenoids in prevention of chronic diseases is a better understanding of the relative bioavailability of carotenoids from foods. Whereas other researchers have primarily focused on  $\beta$ -carotene, van het Hof et al (3) have made a unique contribution by comparing the relative bioavailability of lutein and  $\beta$ -carotene in a well-designed, 24-d study.

In the study, healthy young men and women (mean age: 22 y) in Netherlands consumed carefully controlled diets high (490 g/d) or low (130 g/d) in vegetables, the latter being provided with and without a supplement of highly bioavailable  $\beta$ -carotene (6 mg/d) and lutein (9 mg/d). The diets provided equivalent amounts of protein, fat, fiber, and vitamin E, but differed in vitamin C and carotenoid contents. Measured outcomes included changes in plasma carotenoids and vitamin C, ex vivo estimation of the oxidizability of LDL, and an estimation of the relative bioavailability of  $\beta$ -carotene and lutein from vegetables. The authors point out that the low-vegetable diet was similar to the average vegetable intake of the Dutch population. Intakes of carotenoids provided in the report suggest that this vegetable intake would be

close to but lower than the average US intake from foods for this age group. The vitamin E ( $\approx$ 25 mg/d) and fiber ( $\approx$ 4.3 g/MJ) intakes would be considerably higher than those generally consumed by young adults in the United States.

Among the key findings was the substantial difference between the relative bioavailabilities of  $\beta$ -carotene (14%) and lutein (67%) when comparing the high-vegetable diet with the low-vegetable diet plus the supplemental carotenoids. The low relative bioavailability of  $\beta$ -carotene from vegetables is in line with other reports. De Pee et al (4) reported only 7% relative bioavailability of  $\beta$ -carotene from green leafy vegetables compared with a fortified wafer in Indonesian women who were anemic and had low vitamin A status. Later, de Pee et al (5) reported a relative bioavailability of 23% for  $\beta$ -carotene from leafy vegetables plus carrots in Indonesian schoolchildren, who also were anemic and had low vitamin A status. The Dutch population in this study presumably had no nutritional deficiencies. Thus, the relative bioavailability of  $\beta$ -carotene from vegetables is low even in a healthy population.

The relative bioavailability of lutein was not measured previously in such an extensive trial. The higher bioavailability of lutein compared with  $\beta$ -carotene is most likely due to several factors. First, some  $\beta$ -carotene converts to vitamin A (serum retinol did not change in the groups), although there is no reason to think that the conversion efficiency would dramatically differ between the 3 diet groups. Second, lutein is a lipophilic molecule but is considerably more polar than  $\beta$ -carotene. Consequently, lutein may be more easily incorporated into the outer portions of lipid micelles within the gastrointestinal tract and may be more easily taken up by enterocyte membranes and eventually by chylomicrons, which would increase its bioavailability. Third, the lutein in the supplement (the control) may have been partially crystallized, reducing the bioavailability of the control and therefore increasing the relative bioavailability of lutein from the high-vegetable diet. Finally,  $\beta$ -carotene may be more difficult to digest and absorb from the food matrix than is lutein.

van het Hof et al were unable to detect significant effects of the high-vegetable diet or carotenoid-supplemented diet on the total antioxidant activity of plasma or on the susceptibility of LDL to oxidation ex vivo. A survey of the literature reveals that


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the effect of increasing dietary carotenoids on ex vivo LDL oxidation is equivocal. Vitamin E appears to be much more effective in this regard and I note that the dietary  $\alpha$ -tocopherol intakes of this population were above the current recommended dietary allowances (6) and above the average intake from foods by young adults in the United States.

Thus, the lack of effect on measures of plasma oxidation could be due to 1) the high vitamin E status in all groups; 2) the relative ineffectiveness of carotenoids as antioxidants; 3) the fact that the antioxidant status of the volunteers may have been adequate before the study; 4) the reduction of plasma lycopene, a very effective in vitro antioxidant, in groups receiving the high-vegetable and the carotenoid-fortified diets compared with the increase in the low-vegetable group; and 5) the overwhelming antioxidant effects of the numerous polyphenols from the fruit and vegetables in all of the groups. Many vegetables and fruit are rich in polyphenols. Note that grape juice was provided in the low-vegetable diet whereas orange juice was provided to the other groups. The high polyphenol content of grape juice may have helped to equalize the effects of other polyphenols in the high-vegetable group or the added carotenoids in the carotenoid-supplemented group.

Carotenoids from foods often have low bioavailability because of a variety of food matrix effects (7). Identification of the specific positive and negative effectors from food matrixes, the variable effects of different food-processing techniques, and the

effects of variable nutritional status on carotenoid bioavailability are sorely needed. This current report is an important advancement showing the substantial difference in bioavailability between the most important vitamin A precursor,  $\beta$ -carotene, and one of the components of the macular pigment, lutein. 

## REFERENCES

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