

# The Bioavailability to Humans of Ascorbic Acid from Oranges, Orange Juice and Cooked Broccoli Is Similar to That of Synthetic Ascorbic Acid<sup>1,2,3</sup>

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**ABSTRACT** The relative bioavailability of ascorbic acid from several sources was compared in 68 male non-smokers. Subjects underwent two 8-wk ascorbic acid depletion-repletion cycles. In repletion, subjects were randomized to receive 108 mg/d ascorbic acid as tablets with or without iron, as orange segments or juice, or as raw or cooked broccoli with a crossover within each major treatment group (e.g., cooked to raw broccoli) for the second repletion. Relative ascorbic acid bioavailability was estimated based on the slope obtained from linear regression of plasma ascorbic acid on time during each repletion. In the first repletion, slopes for all groups were similar except for the group consuming raw broccoli (20% lower response,  $P < 0.01$ ). Second repletion responses were attenuated, but were similar to the first repletion. Ascorbic acid ingested as cooked broccoli, orange juice or fruit, or in synthetic form seems to be equally bioavailable. The lower relative bioavailability of ascorbic acid from raw broccoli is unlikely to be of practical importance in mixed diets. *J. Nutr.* 123: 1054-1061, 1993.

#### INDEXING KEY WORDS:

- ascorbic acid • vitamin C
- bioavailability • fruits
- vegetables

Ascorbic acid is an essential nutrient for humans. It plays a role in the synthesis of collagen, hormones and neurotransmitters. Both ascorbic acid's function as an antioxidant and free radical scavenger (Bendich et al. 1986, Frei et al. 1989) and epidemiologic studies showing that consumption of generous amounts of vitamin C-rich foods such as fruits and vegetables seems to be associated with a lower risk of various

cancers (Block 1991) suggest that ascorbic acid may also have cancer-preventive properties.

Early reports have suggested little difference in ascorbic acid bioavailability from fruits or vegetables compared with synthetic ascorbic acid (Clayton and Borden 1943, Clayton and Folsom 1940, Hartzler 1945, Hawley et al. 1936, Todhunter and Fatzer 1940). Small numbers of subjects and insensitive techniques may, however, have obscured differences in these studies. Although few studies have assessed the impact of such factors as the fiber or mineral content of a meal or the presence or absence of other substances including bioflavonoids (Jones and Hughes 1984) on vitamin C absorption *in vivo*, the bioavailability of other substances, such as carotenoids, does seem to be affected by dietary factors (Brown et al. 1989).

Approximately 86% of the dietary vitamin C in the average U.S. diet is supplied by fruits and vegetables

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(Block et al. 1985). In addition to dietary sources of vitamin C, 17.4% of adults in the United States take multivitamins daily and 7.6% take vitamin C supplements daily with some overlap between users of multivitamins and users of vitamin C supplements (Subar and Block 1990).

Survey data and epidemiologic studies are currently based on the assumption that ascorbic acid from all sources is equally bioavailable. However, populations and subgroups do differ in the contribution of different food sources to their total dietary ascorbic acid intake. For example, dark leafy green vegetables such as collard greens and turnip greens are an important ascorbic acid source for black Americans but not for whites, whereas fortified cereals and vitamin supplements are more important sources for whites than blacks (Block and Sorenson 1987). If the bioavailability of these various sources of vitamin C is not equivalent, then epidemiologic studies could be affected by bias and misinterpretation.

The purpose of this study was to examine the relative bioavailability to adult males of ascorbic acid from fruits, vegetables and synthetic sources. Improved knowledge of the relative bioavailability of ascorbic acid from such commonly consumed sources as fruits, vegetables and vitamin supplements would aid in the assessment of vitamin C nutriture in the U.S. and could allow clarification of the relationship between fruit and vegetable consumption and the incidence of chronic disease. After ascorbic acid depletion we measured the response rate of plasma ascorbic acid to an equivalent dose of ascorbic acid ingested from various sources as the means for comparing relative bioavailability of ascorbic acid from these sources.

## MATERIALS AND METHODS

**Subjects.** Healthy male non-smokers age 30–59 y were recruited from the Beltsville, MD area. Screening procedures eliminated those with chronic health problems, those who had smoked cigarettes within the past 6 mo, regular users of prescription medications, those with body weight >100 kg and these with dietary habits that were not representative of the general population. All subjects underwent medical evaluation by a physician and preliminary blood and urine tests. Height and weight were measured using standard procedures. Body fat was determined by bioelectrical impedance analysis (Kushner and Schoeller 1986). All study procedures were approved by Human Studies Review Committees of the USDA, The Georgetown University School of Medicine and the National Cancer Institute. Informed consent was obtained from each subject. From the initial pool of eligible applicants, 71

subjects were selected for participation in the study. Of these, 68 completed the study. Because withdrawals from the study occurred in the first 2 wk, before repletion, only data from the 68 subjects completing the study were used.

Use of aspirin or aspirin-containing drugs was not permitted during the study, nor were vitamin or mineral supplements, except as part of the study protocol. Subjects recorded any medications used during the study. Use was generally of short duration and was primarily allergy medication or an occasional analgesic.

**Diets.** All subjects underwent a 3-wk free-living pre-study period. Before beginning this period, they were provided with dietary guidelines to achieve a dietary ascorbic acid intake of approximately 60 mg/d. This was followed by a 1-wk controlled diet baseline period providing 60 mg/d of ascorbic acid. Subjects then underwent two cycles, each consisting of a 4-wk ascorbic acid depletion (9 mg/d) period followed by a 4-wk ascorbic acid repletion (117 mg/d) period. Subjects consumed a controlled diet throughout the two cycles.

The controlled diet was selected to reflect typical dietary patterns (except for ascorbic acid content) of Beltsville area volunteers (Kim et al. 1984). This diet was fed to subjects throughout the 17-wk study with specific food or tablet sources of ascorbic acid added in repletion. The ascorbic acid intake during the baseline diet was 5–10 mg/d. A 14-d menu cycle was used. Breakfast and dinner from Monday through Friday were eaten at the Human Studies Facility of the Beltsville Human Nutrition Research Center under the supervision of a dietitian. Lunches and weekend and holiday meals were packaged for home consumption. Tea, coffee, energy-free carbonated beverages and water were allowed as desired. The energy level of the diet was adjusted in 1.7-MJ increments, as needed, to maintain body weight of subjects throughout the study. Energy levels ranged from 8.4 to 16.8 MJ. The baseline diet provided approximately 35% of energy from fat, 15% from protein and 50% from carbohydrate; dietary fiber was approximately 5 g/4.2 MJ. Nutrient content was calculated by using a USDA data set (USDA 1986). Dietary composites were analyzed by HPLC (Vanderslice and Higgs 1988 and 1990, Vanderslice et al. 1990) to confirm the calculated ascorbic acid content. Analyzed ascorbic acid content was similar to calculated content.

The diet was planned to exclude foods known to contain erythorbic acid (D-isoascorbic acid, a stereoisomer of ascorbic acid possessing negligible vitamin C activity). The presence of erythorbic acid in plasma will interfere with the determination of plasma ascorbic acid concentration when it is measured by certain methods, including those used in this study (Sauberlich et al. 1991).

Subjects were grouped into strata by age, lean body mass and initial plasma ascorbic acid concentration

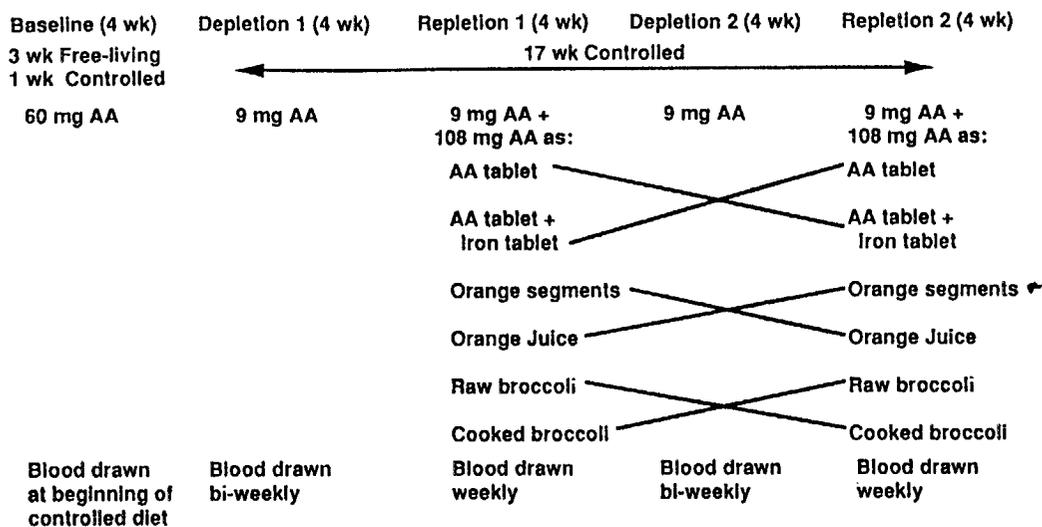


FIGURE 1 Experimental design. AA = ascorbic acid.

and then were randomly assigned within the strata to three major groups to receive ascorbic acid during the repletion period in tablets, a fruit or a vegetable. Within each of these three major treatment groups, subjects were further randomized to two subgroups per group for the crossover design (Fig. 1).

In the crossover design, based on group assignment, subjects received one form of ascorbic acid throughout the first repletion period and a second form throughout the second repletion period. During repletion, along with the controlled diet (9 mg ascorbic acid/d), an additional 108 mg ascorbic acid/d was consumed in the form of either a tablet (G504AC, Perrigo Company, Greenville, SC) or the tablet plus an iron tablet (63 mg of ferrous fumarate to release 20 mg of elemental iron; Femiron<sup>®</sup>, Beecham Products, Pittsburgh, PA), frozen reconstituted orange juice or fresh orange sections, or raw or cooked broccoli, depending on group assignment. For example, in the first repletion period, half the subjects in the group given tablets were randomized to receive ascorbic acid alone and half to receive ascorbic acid with iron. Those receiving ascorbic acid alone in the first repletion received ascorbic acid with iron in the second; those receiving ascorbic acid with iron in the first repletion received ascorbic acid alone in the second repletion.

Ascorbic acid-rich foods or tablets were consumed by subjects as a part of their evening meal, which was selected to improve compliance and to prevent any differential diurnal effects on absorption or metabolism. Vitamin C tablets were given in addition to the baseline diet, and oranges, orange juice and broccoli replaced one vegetable in the baseline diet. This was done so that each group would have relatively similar intakes of energy and other nutrients such as  $\beta$ -carotene and vitamin E.

The amount of ascorbic acid and dehydroascorbic acid in foods and the ascorbic acid tablets was determined using HPLC methods (Vanderslice and Higgs 1988 and 1990, Vanderslice et al. 1990). Samples from each lot of each food were randomly selected and prepared so that only the edible portion was analyzed.

The frozen juice and tablets were obtained from a single lot and stored under conditions that ensured stability throughout the study. Frozen orange juice was reconstituted with tap water (3:1, v/v) and mixed well before serving and analysis. The ascorbic acid content of juice and vitamin C tablets was analyzed by HPLC several times during the study and did not vary (Vanderslice and Higgs 1991, Vanderslice et al. 1990). Oranges were purchased 1-2 times per week and fresh broccoli was purchased 2-3 times per week. Two to three samples from each lot of oranges and broccoli were randomly selected and analyzed before feeding. This number of samples was chosen to ensure that results would be available in a timely fashion. Preliminary studies assessing variability within lots (Vanderslice and Higgs 1991) were also used to determine the number of samples needed. Navel oranges were peeled and sectioned before serving or analysis. Broccoli was analyzed in both raw and cooked form. Broccoli was washed and trimmed and only florets were served or analyzed. For cooked broccoli, the appropriate portion was weighed, cooked in a sealed plastic bag in boiling water for 12 min and served or analyzed immediately after preparation. Subjects consumed the entire contents of the bag so that minimal water losses occurred. Subjects were given instructions for cooking broccoli on weekends and holidays using the same technique. The amount of each test food fed to subjects was adjusted twice weekly based on the analyzed ascorbic acid content,

TABLE 1

Variability of the ascorbic acid (AA) concentration of oranges, broccoli and orange juice as analyzed by HPLC<sup>1</sup>

AA source	AA concentration	
	Repletion 1 <sup>2</sup>	Repletion 2
	mg/100 g	
Oranges, navel	74.0 ± 10.1 (6)	82.5 ± 4.4 (4)
Broccoli, raw	121.1 ± 19.2 (20)	98.6 ± 12.9 (17)
Broccoli, cooked	71.7 ± 10.7 (19)	62.2 ± 8.9 (17)
Orange juice, reconstituted <sup>3</sup>	46.5 (1)	46.5 (1)

<sup>1</sup>Values are means ± SD, number of lots analyzed in parentheses; two to three samples were analyzed per lot.

<sup>2</sup>Repletion 1 took place from February 15 to March 14, 1990. Repletion 2 was from April 12 to May 10, 1990.

<sup>3</sup>Orange juice was obtained from a single lot. Analysis throughout the study revealed little variability.

which was quite variable (Vanderslice and Higgs 1991), Table 1. Table 2 shows the ascorbic acid content of the supplemental tablets and foods.

**Plasma analysis.** Venous blood was collected from each subject following an overnight fast, 13 times during the study: at the end of the 60 mg vitamin C baseline period, biweekly during both depletion periods and weekly during both repletion periods. Blood was collected in vacutainers containing EDTA, iced and centrifuged within 30 min. The resulting plasma was stabilized with freshly prepared 0.44 mol/L meta-phosphoric acid (1:1, v/v), capped, mixed by vortex, stored at -70°C, and analyzed within 10 d of collection. Preliminary experiments and published reports indicated that total ascorbic acid concentrations are stable in meta-phosphoric acid stabilized plasma under the described conditions (Bradley et al.

1973, Tolbert and Ward 1982). The analyst was unaware of the phase of the study or of subject treatment group assignment.

Plasma total ascorbic acid concentration was determined spectrophotometrically using 2,4-dinitrophenylhydrazine as a chromagen (Roe 1954, U.S. Department of Health and Human Services 1980). The intra-assay precision (CV) for 14 duplicate samples was 2.4%, whereas the inter-assay precision (CV) for repeated analysis of samples was 7.8% (n = 25).

**Statistical analysis.** A measure of relative bioavailability should reflect the relative rates of increase in plasma ascorbic acid concentrations of subjects during repletion; several measures were considered. For each repletion period, only five plasma determinations (end of depletion and after each week of repletion) were available for each subject. Individual plasma ascorbic acid data for these periods suggested a curvilinear increase in plasma concentrations as well as a plateau at the end of repletion. However, due to the short duration of the repletion period and the sparsity of data points, we considered summary measures of repletion that do not rely heavily either on parametric assumptions or on the subjects reaching a plateau.

With a longer repletion period, it would have been of interest to fit a logistic curve to each subject's repletion data and compare scale and shape parameters. Alternately, area under the plasma curve was considered as a summary response measure. Although area under the plasma curve has the advantage of being an integrated measure over the entire 4-wk repletion period, it too is sensitive to whether a plateau is reached. Therefore, a linear rate of acquisition was calculated for each subject during the first 3 wk of each repletion period, while plasma ascorbic acid levels were increasing in all subjects. The acquisition rate, or rate of change, is the slope obtained by

TABLE 2

Average ascorbic acid (AA) intake from foods and vitamin tablets by treatment groups<sup>1</sup>

Source	Avg. total AA		Avg. DHAA		Amount of test food to achieve target <sup>2</sup>	
	Repl 1	Repl 2	Repl 1	Repl 2	Repl 1	Repl 2
	mg/(subject·d)				g/(subject·d)	
AA tablet	107.4	107.4	0	0	—	—
Orange juice	109.7 ± 0.7	109.7 ± 0.7	7.6 ± 1.5	7.6 ± 1.5	236 <sup>3</sup>	236
Orange sections	109.7 ± 5.3	108.8 ± 0.9	1.8 ± 2.8	7.2 ± 1.3	150 ± 22	132 ± 5
Raw broccoli	108.6 ± 1.0	108.6 ± 0.6	6.9 ± 2.5	7.7 ± 0.7	91 ± 14	112 ± 15
Cooked broccoli	108.3 ± 3.1	108.3 ± 3.6	6.7 ± 5.4	13.3 ± 6.1	154 ± 24	178 ± 24

<sup>1</sup>Values are means ± SD; see Table 1 for the number of lots analyzed for each food. DHAA = dehydroascorbic acid.

<sup>2</sup>Target = 107.5 mg/d; because the total AA concentration in foods varied, the amount of food was adjusted twice weekly to ensure a consistent AA dose.

<sup>3</sup>Amount of orange juice given to subjects did not vary during study.

regressing plasma ascorbic acid on study week for the first 3 wk of each repletion period.

In general, two measurements taken on a single individual may be assumed to be correlated. Therefore, a multivariate ANOVA model, which takes into account such correlation (Muller and Barton 1989), was fitted to subjects' pairs of repletion slopes using the SAS statistical software package (SAS Institute, Cary, NC) in order to estimate and compare treatment group plasma ascorbic acid acquisition rates. Differences were considered significant at  $P < 0.05$ .

## RESULTS

Based on ANOVA, mean plasma ascorbic acid concentrations at the start of the study (Table 3) did not differ significantly ( $P = 0.72$ ) among treatment groups, as would be expected, based on the random assignment of subjects to treatments. For all subjects, plasma ascorbic acid fell during depletion and rose during repletion; means for each treatment group are shown in Figure 2.

In the first repletion, the means of the slopes were similar in all groups except the raw broccoli group, in which the rate of change was 20% lower than for any of the other groups ( $P < 0.01$ ) (Table 4). Second repletion response rates were significantly lower than those of the first period ( $P < 0.0001$ ), although the same pattern across treatment groups was observed.

No significant difference was seen when comparing the major treatment groups of fruit vs. vegetable vs. tablet both when averaged over the two repletion periods and when each period was considered separately. Within each major treatment group the comparisons of ascorbate sources (orange segments vs. juice, raw vs. cooked broccoli, and tablet with vs. tablet without iron) revealed significant differences in relative bioavailability as measured by rates of change (slopes) only in raw vs. cooked broccoli in repletion 1 ( $P = 0.0096$ ) and overall ( $P < 0.0001$ ). Similar results were obtained when response was examined as area under the repletion curve or as plasma ascorbic acid concentration attained at the end of repletion (data not shown).

## DISCUSSION

Our results, which show little difference in relative bioavailability of ascorbic acid given as synthetic ascorbic acid with or without iron, as orange juice or orange sections, or as cooked broccoli, are similar to those seen in earlier studies. In these earlier studies, food forms of ascorbic acid were as effective as synthetic ascorbic acid in maintaining blood or urine ascorbic acid levels in subjects who were deemed to

TABLE 3

*Physical characteristics of the subjects assigned to the three major treatment groups at baseline<sup>1</sup>*

	Tablet	Fruit	Vegetable
Weight, kg	81 ± 12	80 ± 10	81 ± 12
Height, cm	177 ± 6	179 ± 6	178 ± 8
Age, y	42 ± 9	40 ± 8	40 ± 8
Body fat, <sup>2</sup> kg	17 ± 5	17 ± 4	17 ± 5
BMI <sup>3</sup>	26 ± 3	25 ± 3	26 ± 3
Plasma AA, <sup>4</sup> μmol/L	56 ± 13	58 ± 11	55 ± 12
n	23	22	23

<sup>1</sup>Values are means ± SD. AA = ascorbic acid.

<sup>2</sup>Estimated by bioelectrical impedance.

<sup>3</sup>BMI = body mass index (kg/m<sup>2</sup>).

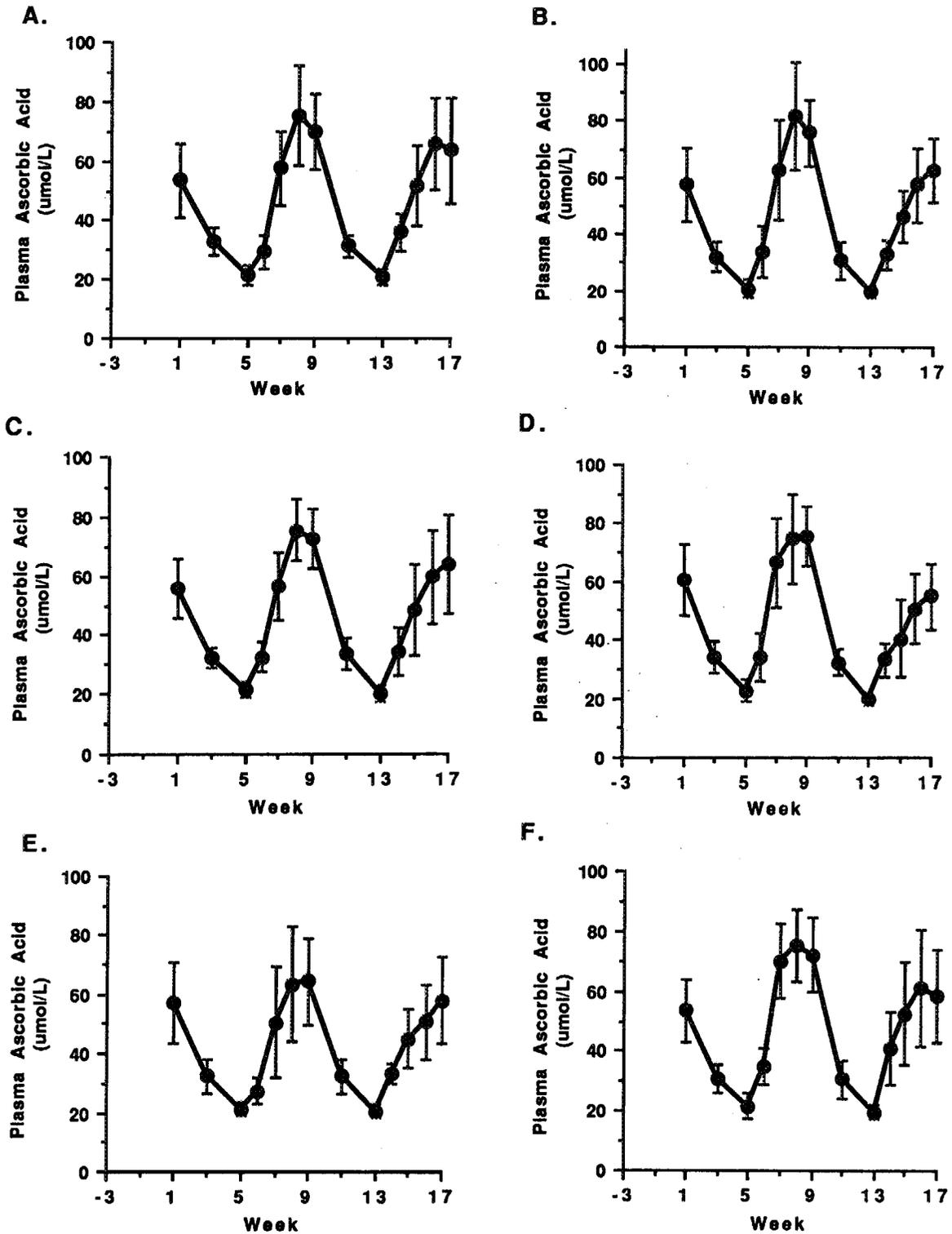
<sup>4</sup>At end of baseline period.

have a similar vitamin status with an apparent saturation of vitamin C stores (Clayton and Borden 1943, Clayton and Folsom 1940, Hartzler 1945, Hawley et al. 1936, Todhunter and Fatzer 1940). These studies were generally conducted with small numbers of subjects and with limited food analysis. Wide variability in response was noted, possibly due to individual differences in absorption or retention of ascorbic acid, because of differences in body pool size or due to variability in dietary ascorbic acid content. Our study was unique in its size, similar levels of ascorbic acid depletion in all subjects based on plasma ascorbic acid values, and on-going analysis of ascorbic acid content of foods.

We chose to provide synthetic vitamin C in tablet form because this is the most common supplemental form used by adults. Supplemental vitamin C is commonly consumed in the form of a multiple vitamin-mineral preparation in which the presence of minerals could potentially affect ascorbic acid absorption. Additionally, although ascorbic acid is known to enhance the absorption of iron when the two nutrients are ingested together, the effect of iron on ascorbic acid bioavailability has apparently not been examined previously. Based on our results, low doses of iron have a negligible effect on ascorbic acid relative bioavailability.

We compared plasma ascorbic acid response to orange segments vs. orange juice because orange juice is a major contributor of vitamin C to the United States diet. Based on NHANES II data, orange juice alone provided 26.5% of the vitamin C consumed by United States adults (Block et al. 1985). Oranges are also major contributors of vitamin C, providing close to 5% of the daily vitamin C in the United States diet. Our results suggest that ascorbic acid from orange fruit or juice is equally available and is not significantly different in availability from ascorbic acid obtained in synthetic form.

FIGURE 1 to week 1 when supplied and week 2 when first depleted and week 3 when first repleted and week 4 when repletion was completed.



**FIGURE 2** Plasma ascorbic acid during two depletion and repletion cycles by treatment group. Points are mean  $\pm$  SD. Week 1 to wk 5 is the first depletion period when ascorbic acid (AA) intake was 9 mg/d, wk 5 to wk 9 was the first repletion period when subjects received 117 mg AA/d in a form based on their treatment group assignment; wk 9–13 is Depletion 2 (9 mg AA/d) and wk 13–17 is Repletion 2 (117 mg AA/d), again in form based on treatment group. A) AA supplied as AA tablet,  $n = 11$  in first depletion and repletion,  $n = 12$  in second depletion and repletion. B) AA supplied as AA tablet and iron tablet,  $n = 12$  in first depletion and repletion,  $n = 11$  in second depletion and repletion. C) AA supplied as orange juice,  $n = 11$  in both of the depletion and repletion cycles. D) AA supplied as orange segments,  $n = 11$  in both of the depletion and repletion cycles. E) AA supplied as raw broccoli,  $n = 12$  in first depletion and repletion,  $n = 11$  in second depletion and repletion. F) AA supplied as cooked broccoli,  $n = 11$  in first depletion and repletion,  $n = 12$  in second depletion and repletion.

TABLE 4  
Rate of change of plasma ascorbic acid (AA) with time (slope) after repletion with various AA sources<sup>1,2</sup>

Treatment	Repletion 1		Repletion 2 <sup>3</sup>	
	n	Slope <sup>4</sup> μmol/(L.wk)	n	Slope μmol/(L.wk)
AA tablet	11	19 ± 6	12	15 ± 5
AA + Fe tablet	12	21 ± 5	11	13 ± 4
Orange juice	11	19 ± 3	11	13 ± 5
Orange sections	11	19 ± 5	11	10 ± 4
Cooked broccoli	11	19 ± 4	12	14 ± 6
Raw broccoli	12	15 ± 7 <sup>5</sup>	11	10 ± 5

<sup>1</sup>Values are means ± SD.

<sup>2</sup>Due to the crossover nature of the experimental design, treatment group sizes varied from Repletion 1 to Repletion 2. For example, those receiving cooked broccoli in Repletion 1 received raw broccoli in Repletion 2.

<sup>3</sup>Significantly lower than first period slopes ( $P < 0.0001$ ). Slopes of treatment groups not significantly different ( $P = 0.25$ ).

<sup>4</sup>Based on first 3 wk of each repletion period.

<sup>5</sup>Mean slope of raw broccoli group 20% lower than the other groups in Repletion 1 ( $P < 0.01$ ).

Ascorbic acid from raw broccoli was slightly less available for repletion of plasma ascorbic acid than was ascorbic acid from cooked broccoli. Similar findings have been reported for carotenes from cooked carrots compared with carotenes from raw carrots (Van Zeben and Hendriks 1946). A number of explanations can be suggested for our observation. One possibility is that the raw broccoli was not chewed as well as the cooked broccoli, leading to the loss of ascorbic acid via undigested raw broccoli. Mechanical homogenization of carrots has been shown to increase carotene absorption (Van Zeben and Hendriks 1946); perhaps more thorough chewing has a similar effect on ascorbic acid from broccoli. A second possibility is that there is some as yet unidentified substance in raw broccoli that inhibits ascorbic acid absorption and that is inactivated by cooking. Dietary fiber, which could potentially reduce ascorbic acid absorption, was not markedly different among the treatment groups (mean daily dietary fiber ranged from 14 g/d in depletion and in groups receiving ascorbic acid tablets to 19 g/d in the cooked broccoli group in repletion 2). A third possibility is that a substance in broccoli could enhance ascorbic acid absorption. Subjects receiving cooked broccoli were required to eat 50% more broccoli than those receiving raw broccoli due to ascorbic acid losses in cooking. Thus, if such a substance were present, the group receiving cooked broccoli would have received more of this as yet unidentified enhancing factor. Another possibility is that cooking activates an unidentified enhancing factor in broccoli. An analytical error in the determination of ascorbic acid in foods could have led to the group difference seen. However, a systematic error of this type seems unlikely because of the quality control procedures that were used. In addition, it is unlikely that a single

analytical error would have a significant impact, because broccoli was analyzed two to three times weekly and the results of a specific analysis were used to determine the amount of an ascorbic acid source to feed.

The lower effectiveness of raw broccoli at repleting plasma ascorbic acid is not likely to be of practical nutritional significance in a mixed diet. Broccoli, either raw or cooked, provided 2.31% of the ascorbic acid in the diet of United States whites age 30–54 y and 1.57% for blacks (Block and Sorenson 1987). The median United States daily dietary intake of ascorbic acid has been estimated to be 68 mg for white males age 30–54 y and 55 mg for black males in the same age range (Block and Sorenson 1987). Thus, approximately 1.6 mg ascorbic acid/d, on average, can be calculated to come from broccoli for white males and 0.9 mg for black males. Assuming a 20% lower bio-availability of ascorbic acid from raw broccoli, an effective reduction of no more than 0.3 mg of ascorbic acid daily (white males) or 0.2 mg (black males) would be expected. Because raw and cooked broccoli are grouped together in tables of food consumption and the majority of broccoli consumed is probably in the cooked form, this is an upper estimate.

One question that may arise in examination of the effect of various food forms on blood ascorbic acid concentrations is that of the dehydroascorbic acid content of the diet. Raw vegetables, especially those with low levels of ascorbic acid, may have as much as 20% of total ascorbic acid present as dehydroascorbic acid (Vanderslice et al. 1990). Cooking causes destruction of dehydroascorbic acid, so ascorbic acid in cooked vegetables is primarily in the reduced form. Fruits contain a majority of their ascorbic acid in the reduced form. Although early reports suggested that dehydroascorbic acid is as well utilized by humans as

ascorbic acid (Linkswiler 1957, Sabry et al. 1958, Todhunter et al. 1950), studies in this area have generally involved small numbers of subjects, and their designs make interpretation of results difficult. Our results do not permit the determination of the effect of dehydroascorbic acid on plasma response to various food sources of ascorbic acid, because levels of dehydroascorbic acid in foods fed were generally low (0–29% of total ascorbic acid, median for samples analyzed was 7.2%). Little difference was seen in the level of dehydroascorbic acid or reduced ascorbic acid fed to each treatment group (Table 2).

The results of this study support the assumption, in survey data and epidemiologic research, that ascorbic acid from different food sources produces similar plasma ascorbic acid concentrations. The usual assumption that ascorbic acid from food sources has a bioavailability similar to that of synthetic ascorbic acid seems to be valid.

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