

mentioned that this subject was not well adapted to the experimental routine, and the data in her protocol possibly were complicated by this factor. L. K. was the first subject studied and it is conceivable that there was some lack of smoothness in experimental technique. Six out of eight subjects also showed a decrease in plasma vitamin C in the second exercise period, although the rate of drop was not as marked in this period of higher vitamin intake.

Plasma ascorbic acid values in some cases continued to fall in the post-exercise period. This failure to return to the pre-exercise concentration might be explained as an effect of lag of exercise. If the recovery period had been extended for a longer time, the plasma concentration of ascorbic acid should have returned to pre-exercise values.

The rate of change of plasma vitamin C concentration with exercise appeared to differ with individual subjects, some showing a more marked decrease than others. An attempt was made in table 20 to correlate the difference in degree of change in plasma vitamin C during exercise with progressively increasing intakes of vitamin C. The factor of individual variation appears to overshadow the effect of absolute intake. When 100 mg. of crystalline ascorbic acid were added to a generous dietary allowance, the response was much more varied. Subject R. P. showed a slight rise in plasma concentration of vitamin, subjects A. S., E. C., and M. F. practically no change, and the rest of the group a change consistent with

Changes in Plasma Ascorbic Acid Concentrations
During Exercise as Compared with Increasing Intakes
of the Vitamin

Subject	Average Intake of Ascorbic Acid During Exercise Period mg./24 hrs.	Plasma Ascorbic Acid Concentrations at End of Exercise Period mg. per cent
First Exercise Period		
R. P.	69.02*	0.41
A. S.	69.02*	0.52
D. A.	69.02*	0.46
B. H.	71.63	0.44
L. K.	81.60	0.72
M. T.	87.74	0.50
D. H.	89.24	0.54
M. F.	117.58	0.10
E. C.	119.88	0.14
Average	85.64	0.43
Second Exercise Period		
R. P.	165.99*	0.53
A. S.	165.99*	0.46
D. A.	165.99*	0.39
M. T.	176.26	0.60
D. H.	177.29	0.77
B. H.	180.66	0.28
E. C.	221.00	0.15
M. F.	221.00	0.12
Average	184.27	0.41

*Intakes determined by chemical analysis. Other intakes were calculated.

that observed during the first exercise period.

Changes in plasma ascorbic acid concentrations during exercise have been compared with average plasma concentrations

of the vitamin during the pre-exercise period (table 21). It will be noticed that there was a definite tendency towards a greater decrease in plasma concentrations of vitamin during exercise in subjects who maintained higher concentrations of ascorbic acid in plasma in the preliminary period. This probably represents a greater inefficiency in vitamin C utilization at higher plasma concentrations of the vitamin. As has been pointed out, plasma concentrations of ascorbic acid apparently are a function both of intake and of the individual response.

Table 21

Changes in Plasma Ascorbic Acid Concentrations During Exercise as Compared with Average Pre-exercise Plasma Concentrations of the Vitamin

Subject	Average Pre-exercise Plasma Ascorbic Acid Concentrations	Plasma Ascorbic Acid Concentrations at End of Exercise Period
	mg. per cent	mg. per cent
First Exercise Period		
M. T.	0.97	0.50
D. H.	0.94	0.54
A. S.	0.80	0.52
L. K.	0.66	0.72
B. H.	0.56	0.44
D. A.	0.55	0.46
R. P.	0.53	0.41
M. P.	0.46	0.10
E. C.	0.38	0.14
Second Exercise Period		
M. T.	0.95	0.60
D. H.	0.86	0.77
D. A.	0.51	0.39
B. H.	0.46	0.28
R. P.	0.45	0.53
A. S.	0.44	0.46
M. P.	0.16	0.12
E. C.	0.14	0.15

Table 22, which summarizes values for all subjects, shows again the pattern of change of plasma ascorbic acid during exercise.

Table 22
Average Intake¹, Plasma Concentrations, and
Urinary Excretion of Ascorbic Acid for All Subjects
in Each Experimental Period

Experimental Period	Intake of Ascorbic Acid mg./24 hrs.	Plasma Ascorbic Acid mg. per cent	Urinary Ascorbic Acid mg./24 hrs.
Research diet	68.14	0.64	29.3
Research diet; exercise	86.04	0.50	62.4
Research diet; post- exercise	97.34	0.39	47.7
Research diet plus 100 mg. ascorbic acid daily	79.43	0.79	132.9
Research diet plus 100 mg. ascorbic acid daily; exercise	84.49	0.46	141.8
Research diet plus 100 mg. ascorbic acid daily; post-exercise	81.24	0.57	136.7

1. Chemically determined intakes when available were used to obtain average.

2. Urinary ascorbic acid

Urinary excretion of ascorbic acid during exercise presents a rather puzzling contrast to the decrease found in plasma vitamin C concentrations. Unfortunately, urine collections were not made during the first year of study.

However, all subjects for whom urinary excretions are reported showed an increased loss of ascorbic acid during exercise. The only exceptions to this observation were values obtained on B. H. during the first and on E. C. during the second exercise period. B. H. showed a slightly higher excretion of ascorbic acid during the pre-exercise period, but excretion during exercise was higher than the average excretion for the post-exercise period. A higher value for excretion of vitamin C was noted for E. C. in the recovery period on high vitamin intake, but this figure was based on only one 24-hour specimen. Table 22, which summarizes values for all subjects in each experimental period also demonstrates the increased excretion of ascorbic acid during exercise in both exercise periods. Since it is thought that vitamin C is a threshold substance, a greater excretion of vitamin in urine occurring simultaneously with a marked drop in plasma concentration of ascorbic acid is difficult to explain. It was thought at first that exercise, by heightening metabolism, might have caused a temporary release of vitamin C into the blood stream from body stores so that plasma concentrations showed an increase and high urinary losses of the vitamin resulted. In two instances, a blood sample was taken from one subject at 6:00 p.m. during the preliminary period and at 6:00 p.m. after exercise, but the plasma vitamin C value in the latter case was not startlingly different. However, the timing of the collection of blood

samples in relation to exercise was not entirely satisfactory, and the urinary excretion of vitamin during exercise was not analyzed separately. More study is needed to determine the mechanism of excretion of ascorbic acid during periods of increased activity.

In table 23 are given the percentage returns of a test dose of crystalline ascorbic acid for four subjects at the end of the initial recovery period in which all showed a plasma ascorbic acid concentration less than that of the preliminary period. If excretion of 50 per cent of a test dose in 24 hours is taken as the criterion for saturation, all four of these subjects apparently were somewhat desaturated after exercise if allowance is made for the average basal excretion of ascorbic acid of the subject.

Table 23

Excretion of a Test Dose of Crystalline Ascorbic Acid

Sub- ject	Intake of ascorbic acid during recovery period	Absolute reduction in plasma ascorbic acid during exercise	Average excre- tion of ascorbic acid during recovery period	Size of test dose of ascor- bic acid	Excre- tion follow- ing adminis- tration of test dose	Test dose ex- creted %
	mg./24 hrs.	mg.%	mg./24 hrs.	mg.	mg./24 hrs.	%
E.C.	124.87	0.32	54.9	500	214.3	31.9
M.F.	124.87	0.26	64.5	500	257.2	38.5
R.P.	77.33	0.16	34.6	400	220.6	46.5
A.S.	80.20	0.18	38.4	400	153.4	28.8

No saturation test dose figures are available for other periods or for other subjects, but this evidence of partial desaturation after exercise in four subjects is very interesting in view of plasma ascorbic acid decreases during exercise. It is recommended that further experimental work include saturation tests at regular intervals.

Since there were no apparent symptoms of a C avitaminosis in any of the subjects even at the low plasma vitamin C concentrations reached during exercise in certain subjects (E. C. and M. F.), it might be concluded that exercise per se did not drastically deplete vitamin stores. However, if intake remained constant and strenuous exercise became a long-continued procedure, there might eventually result a clinical vitamin C deficiency.

3. Food ascorbic acid

The comparatively few chemically determined dietary intakes of vitamin C are regrettable, but experimental conditions were such that more food analyses were not feasible. Where chemically determined intakes were not done, the vitamin C ingested was estimated by calculation (Thompson and Ohlson, 1942). In certain cases, chemically determined intakes have been compared with calculated values for ascorbic acid content of the diet. The comparative figures which may be seen in tables 11 to 19 inclusive, show a wide deviation in ascorbic acid content between calculated and found intakes.

Equally striking is the marked variation occurring within the found intakes. Certainly a 100 per cent difference in absolute ascorbic acid content between dietaries planned to furnish the same amount of vitamin would emphasize the difficulty of providing a constant amount of vitamin C from natural food stuffs. Variations in ascorbic acid content of food stuffs as influenced by such factors as variety, storage, and methods of cooking and processing have been reviewed by Olliver (1943).

Despite the wide deviation in vitamin C intake from day to day, which the dietary data would indicate, average intakes for each period were not too far different. The estimated intakes averaged somewhat higher than intake as chemically determined. It would appear that, on an average, subjects were getting the vitamin allotment that had been planned for them, even though day-by-day variations in intake undoubtedly were wide.

4. Respiratory infections

Since there are some studies in the literature that would suggest a heightened vitamin C requirement during the course of an infectious disease (Hausberger and Neuenschwander-Lemmer, 1939; Finkle, 1937), it is interesting to note in the individual protocols that respiratory infections which occasionally were reported (D. A., A. S., E. E.) did not appear

to alter significantly the pattern of vitamin C metabolism in any of the subjects studied.

C. Diuretic Effect of Increased Ascorbic Acid Intake

It has been reported in the literature that a diuresis results with increased ingestion of vitamin C. Since it is reasonable to suppose that increased plasma concentrations of vitamin would be the precipitating factor in a diuresis and it is not known what the immediate effect of exercise on plasma concentration would be, it was interesting to examine the data for that effect.

Average urinary volumes in 24 hours for each subject and for all subjects in each experimental period are given in tables 24 and 25. Average urinary volumes for all subjects when on the basal diet and when on the basal diet supplemented with crystalline ascorbic acid are contained in table 26.

There does not appear to be any noticeable diuretic effect of ascorbic acid either when subjects are studied singly or when an average is taken for the group. Although some rinsing of funnels with redistilled water was done by subjects during collection of urine samples and all specimens were made up to the nearest convenient volume, the volumes for any one subject are comparative.

Table 24

Average Urinary Volume in 24 Hours for Each Subject in Each Experimental Period

Experimental Period	Subjects								
	L.K.	M.T.	D.H.	B.H.	E.C.	M.F.	H.P.	A.S.	D.A.
Diet: <u>ad libitum</u>	1160								
Diet: <u>ad libitum</u> plus 100 mg. ascorbic acid daily		986	1317						
Research diet	1198	1183	1578	1635	1474	1284	1577	1463	1566
Research diet; exercise	1010	1228	1388	1533	1350	1046	1770	1602	1827
Research diet; post- exercise		1250	1875	1583	1450	1375	1555	1700	2263
Research diet plus 100 mg. ascorbic acid daily	1155	1233	1561	1420					
Research diet plus 400- to 500-mg. dose of ascorbic acid					1300	1100	1500	1500	
Research diet plus 100 mg. ascorbic acid daily; exercise		1108	1410	1106	1240	1182	1445	1540	1815
Research diet plus 100 mg. ascorbic acid daily; post-exercise		995	1310	1045	1750	1300	1475	1890	2115

Table 25

Average 24-Hour Urinary Volume for All Subjects
in Each Experimental Period

Experimental Period	ml. per 24 hrs.
Diet self-chosen	1160
Diet self-chosen plus 100 mg. ascorbic acid daily	1152
Research diet	1440
Research diet; exercise	1417
Research diet; post-exercise	1631
Research diet plus 100 mg. ascorbic acid daily	1343
Research diet plus 400- to 500-mg. dose of ascorbic acid	1362
Research diet plus 100 mg. ascorbic acid daily; exercise	1356
Research diet plus 100 mg. ascorbic acid daily; post-exercise	1485

Average 24-Hour Urinary Volume for All Subjects
on Basal Diet and on Basal Diet Supplemented
with Crystalline Ascorbic Acid

Subject	Basal Diet ml./24 hrs.	Supplemented Basal Diet ml./24 hrs.
L. K.	1123	1155
M. T.	1220	1081
D. H.	1614	1400
E. H.	1583	1190
M. F.	1235	1194
E. C.	1425	1430
D. A.	1885	1965
R. P.	1634	1473
A. S.	1588	1660

These data for urinary volumes after increased ingestion of ascorbic acid do not substantiate the findings of Shaffer (1944), Evans (1938), and others who report a diuretic effect of vitamin C.

D. Discussion

This study gives some indication that the body is extravagant in its use of vitamin C when intake is liberal and when high plasma concentrations of vitamin are maintained. There is evidence that during the second exercise periods on high vitamin intakes, subjects were approximately saturated with vitamin C, since they excreted over 50 per cent of their daily intake of vitamin even when plasma concentrations seldom attained the accepted value of 0.8 mg. per cent. It is granted that tissue saturation of vitamin C probably represents a luxury allowance of vitamin. However, almost nothing is known of the degree of desaturation compatible with continued good health.

The relative small amount of exercise imposed by this experiment appeared to have a specific lowering effect on plasma concentrations of the vitamin and perhaps on the degree of saturation of the subject. Since chemical methods did not determine dehydroascorbic acid there are no data available as to a possible shift in the form of ascorbic acid in plasma during exercise. However, there is nothing in the literature to indicate that such a shift takes place.

Until more study has been made therefore of the effect of activity on vitamin C requirement, it would seem safer to provide a generous intake of the vitamin to people engaging in strenuous exercise. Somewhere between 100 and 200 mg.

per day would seem to be a safe allowance since this study has suggested that at intakes over 100 mg., exercise has less effect on plasma concentrations of the vitamin. This is a generous recommendation. However, there is no known disadvantage to intakes of this quantity except that of the economic difficulty of providing such an allowance. Some lesser amount of the vitamin might be sufficient to maintain optimal nutrition in unusual physical conditions, but that quantity has yet to be defined.

V. SUMMARY

The purpose of this study was to determine the effect of controlled exercise on plasma concentrations and urinary excretions of ascorbic acid in nine normal subjects.

A wide range of ascorbic acid values was found among subjects in the preliminary period. These differences in plasma concentration of vitamin at comparable intakes of ascorbic acid apparently measured individual variations.

Eight subjects showed a decrease in plasma ascorbic acid during exercise when on the basal diet. Six subjects showed a decrease in plasma ascorbic acid during exercise when receiving the basal diet plus 100 mg. crystalline ascorbic acid daily. The effect of exercise on plasma values was not as marked at the higher intakes of vitamin.

The effect of exercise on plasma concentrations of ascorbic acid varied with individual subjects and subjects with higher concentrations of ascorbic acid in plasma showed a greater decrease in plasma vitamin during exercise.

All subjects for whom urinary excretions are reported showed an increased loss of ascorbic acid in urine during exercise. Four subjects appeared to be somewhat desaturated after exercise as determined by excretion of less than 50 per cent of a test dose of ascorbic acid in 24 hours.

It would appear from the results of this investigation that in subjects with ample vitamin C stores there is some cost of exercise. At higher plasma concentrations of the vitamin the wastage during exercise seems to increase, which is an observation that would emphasize the need for determining the lowest plasma concentration of vitamin compatible with optimal body functioning.