VITAMIN C NUTRITION ON A BRITISH ANTARCTIC SURVEY BASE

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ABSTRACT. During a year at a British base in the Antarctic a dietary survey was undertaken in which the vitamin C contents of foods available at bases of the British Antarctic Survey were analysed. Dietary vitamin C intake of men at the base was established from diet sheets and the nutritional status of the men was measured by blood vitamin C analysis. The basic diet was found to be very deficient in vitamin C, due mainly to consisting of preserved foods. This resulted in low vitamin C intakes which were reflected in low blood vitamin C levels. A supply of concentrated orange syrup was found to be an excellent source of vitamin C. Methods of improving the diet are discussed; however, it was considered that the only means of guaranteeing a satisfactory vitamin C intake was to ensure that an adequate vitamin C supplement was taken in tablet form. Field food rations were assessed as containing only very small supplies of vitamin C (vitamin tablets excluded). Without vitamin C supplement tablets, it was considered that most men would present with signs and symptoms of vitamin C deficiency on the long summer sledging journeys.

VITAMIN C deficiency (scurvy) has been a cause of great concern to Antarctic expeditions. At the beginning of the twentieth century, when Antarctic exploration entered a very active phase, the cause of scurvy was unknown. Theories of the cause of scurvy were so rife that, though it was shown to be a deficiency disease in 1907, it was not until the 1920's that this was universally accepted. Vitamin C itself was isolated in 1928. The provisions required by the Antarctic expeditions of the beginning of this century consisted, necessarily, of preserved foods and such foods were (and still are) very poor sources of vitamin C. Consequently, cases of scurvy occurred in many expeditions, quite a number of which were fatal. It is now accepted that Scott's southern party died of scurvy rather than starvation, having spent 5 months on a diet completely deficient of vitamin C.

Since 1930 most if not all Antarctic expeditions have been supplied with known supplementary sources of vitamin C, which since the Second World War have been in the form of vitamin C or multivitamin tablets. At the present time the British Antarctic Survey supplies vitamin tablets BPC, which among other vitamins, contain 15 mg. vitamin C per capsule. Despite this supply, the annual reports of the Survey's medical officers over the past 10 years have included several cases of men presenting with signs and symptoms of vitamin C deficiency, some of which have responded to vitamin C therapy. However, biochemical proof of vitamin C deficiency was not available.

The work reported here was carried out at the Adelaide Island station between February 1972 and February 1973. It was designed to assess the vitamin C content of the base diet and the nutritional status of the men. A brief summary of the nature, properties, sources and human requirements of vitamin C is also given.

Vitamin C

Vitamin C (ascorbic acid) is a simple six carbon sugar molecule, $C_6H_8O_6$. Its metabolic importance depends on its properties as a very strong reducing agent, while in the presence of peroxide it can be a source of oxygen. It is essential to some metabolic processes of the body and of benefit to many others, its reducing properties stabilizing many metabolic reactions. Its most vital metabolic role is in the metabolism of the protein collagen, which is essential for the normal formation of the matrix of most body structures and organs. Scurvy, which results from a prolonged deficiency of vitamin C is (simply stated) a breakdown of the structure of many of the body's tissues, resulting (if not treated) in an often painful death.

Most animals synthesize their own vitamin C. Man, however, is one of the few animals (including the guinea pig) dependent on their diet for their vitamin C requirements. Animal foods are generally poor sources of the vitamin, whereas vegetables and fruit, especially green leaf vegetables (cabbage, lettuce, etc.) and citrous fruit are generally good sources of vitamin C.

Vitamin C is soluble in water and unstable to heat when in solution, though acid solutions are more stable than alkaline ones. When vegetables are cooked, losses of vitamin C occur not

only through heating but, more significantly, much of the vitamin is dissolved in the water in which vegetables are cooked and which is very often discarded. Bicarbonate of soda, an alkali, often added to water in which cabbage is cooked to maintain the colour of the vegetable, is very destructive to vitamin C.

The process of canning food causes severe losses of vitamin C, and dried foods generally contain negligible amounts of the vitamin unless supplement is added (a process which has recently been introduced to dried potato, though not available at the time this survey was undertaken).

Human requirements

A vitamin C intake of 10 mg./day not only prevents the occurrence of scurvy but heals the most severe signs of the disease (Bartley and others, 1953). On this intake, blood plasma levels of vitamin C would be less than 0·1 mg./100 ml. and leucocyte (white blood cell) vitamin C levels would be very low. (The plasma vitamin C level tends to reflect the vitamin C intake, whereas the leucocyte level reflects body tissue vitamin C status.) The first signs of vitamin C deficiency, petechial skin haemorrhages, occur when plasma vitamin C levels fall below 0·25 mg./100 ml. (Hodges and others, 1971), at which level the leucocyte vitamin C content would be in the order of 15 μg./10^8 leucocytes (Taylor, 1972). Such levels can only be assured on vitamin C intakes of 40 mg./day. Most authorities, at the present time, consider plasma vitamin C levels of less than 0·4 mg./100 ml. indicative of vitamin C deficiency (Goldsmith, 1961).

Animals which synthesize their own vitamin C maintain their tissue and leucocyte vitamin C levels such that any supplement of vitamin C to their diet, which will temporarily raise the plasma level, does not cause increases to these levels. This state of saturation occurs at very similar tissue levels for all animals, though the vitamin C requirements of different animals (per kg. weight) vary considerably (Burch, 1961). To maintain saturation, Man requires approximately 1 mg./kg. body weight/day, thus intakes of 70–100 mg. will saturate most adult humans; however, there is as yet no definite proof in Man that saturating intakes of vitamin C are of greater benefit than those which are prophylactic to the signs of deficiency.

Methods

Food was analysed by the 2 : 6 dichlorophenolindophenol method of Harris and Oliver (1942) in which ascorbic acid is oxidized to dehydroascorbic acid. The method uses a simple titration technique and has a light pink end point, which made the analysis of red or dark-coloured foods impossible. Canned foods were analysed before and after preparation for meals, i.e. as canned and as eaten. Those canned foods which could not be analysed at the base were assessed from food-table values (McCance and Widdowson, 1960), making allowance for mean losses incurred in food preparation. Dried foods were assessed as eaten, i.e. after re-hydration and heating, etc.

Dietary vitamin C intake was assessed from diet sheets completed on occasions throughout the year by all subjects, using the results established by analysis.

Blood vitamin C levels (plasma and leucocyte) were analysed by the 2 : 4 dinitrophenylhydrazine method of Denson and Bowers (1961) with slight modification to volumes. Colorimetry was performed on an EEL Spectra. Leucocyte counts were performed using a Thoma haemocytometer of 0·1 mm. depth and single-grid area 1/400 mm.^{2}, under a monocular field microscope with moving field adjustment.

Vitamin supplement tablets were not made available to the men throughout the year so that blood vitamin C levels reflected dietary intake only.

Results

The results of food analysis and the estimated content of foods not analysed were compiled into a table (Table I). This table only includes those foods which normally contain appreciable amounts of vitamin C. Canned vegetables were found to suffer a mean 20 per cent loss of vitamin C on heating prior to meals; food-table values were therefore modified by this amount. Canned fruit was often eaten as canned and these are the values given in the table. Pies and

TABLE I

Description of food	*Vitamin C content* (mg./100 g.)	*Description of food*	*Vitamin C content* (mg./100 g.)
VEGETABLES			
Asparagus, canned	15·3	Mustard and cress, fresh	80·0*
Beans, baked in tomato sauce, canned	2·5	Onion, dried	trace
Beans, broad, canned	8·5	Peas, canned	6·0
Beans, runner, dried	0·5	Peas, dried	0·5
Beetroot, canned	5·0*	Potatoes, canned, "boiled"	8·2
Brussels sprouts, canned	18·9	Potatoes, canned, fried	8·6
Cabbage, dried	trace	Potatoes, dried	1·0
Carrots, canned	2·1	Spaghetti, in tomato sauce, canned	1·0
Cauliflower, canned	33·5	Tomatoes, canned	15·9
Celery, canned	3·0	Spinach, canned	8·4
Mixed vegetables, canned	1·0	Turnips, canned	9·7*
Mushrooms, canned	1·0		
Mushrooms, dried	0·0		
FRUIT			
Apple, dried	0·0	Peaches, canned	4·5
Apricots, canned	2·0	Pears, canned	2·8
Blackberries, canned	15·0*	Pineapple, canned	2·2
Black currants, dried	trace	Plums, canned	2·0*
Cherries, canned	4·0*	Prunes, dried	trace*
Gooseberries, canned	30·0	Raspberries, canned	10·0*
Mandarin oranges, canned	18·0	Rhubarb, canned	2·1
CORDIALS, FRUIT JUICES, ETC.†			
Califorange, cordial	27·0	Milk, evaporated	1·0*
Grapefruit juice, canned	22·0	Orange cordial	4·8
Lemon crystal cordial	3·0	Orange crystal cordial	3·0
Lemon juice, canned	45·0	Orange juice, canned	35·0
Lime cordial	0·2	Pineapple juice, canned	11·5
Milk, dried	1·0	Tomato juice, canned	16·0*
MEATS			
Kidney, frozen	8·0*	Liver, frozen	20·0*

Values given are estimates of vitamin C content of foods as eaten.
*These values are taken directly or indirectly from the food tables in McCance and Widdowson (1960).
†Values given as mg. vitamin C/100 ml. of fruit juice, diluted cordial and reconstituted dried milk.

crumbles with fruit content were found difficult to analyse, but a 50 per cent loss of vitamin C was assumed in fruit included in such sweets.

Dietary intake and availability

The sources of vitamin available at the base were the main diet, i.e. foods available at meals, fruit juices and cordials (the latter two sources being only occasionally available). Mean daily intake of vitamin C from the main diet (excluding fruit juices and cordials) was $12 \cdot 3 \pm 8 \cdot 2$ mg./man/day. Mean individual intakes varied from $8 \cdot 3 \pm 5 \cdot 9$ to $15 \cdot 4 \pm 8 \cdot 8$ mg./day. Mean daily availability of vitamin C individual intake on each day that diet sheets were completed was $21 \cdot 5 \pm 9 \cdot 1$ mg./day.

From daily menus collected over a 3 month period, it was found that there was a significantly greater ($p < 0 \cdot 01$) mean availability of vitamin C in the main diet on Saturdays than on

other days of the week, the reason being that there was a formal evening meal on Saturdays with the menu frequently including the better vegetable sources of vitamin C such as cauliflower and Brussels sprouts (see Table I).

Fruit juices were supplied in a quantity which would allow approximately one glass (150 ml.) of juice per man per week. This was made available at the Saturday evening meal but only three of the eight men at the base regularly took these, the others preferring to drink only the wine usually available at Saturday dinner. When orange or grapefruit juice was available, the three juice drinkers could achieve intakes of over 100 mg. vitamin C at the meal from fruit juice alone.

Of the cordials, Califorange (a concentrated orange syrup) was the only one which contained significant quantities of vitamin C when diluted (Table I, dilution 1 : 10). During the first half of the year, cans (approx. 2 litre contents) of Califorange were placed in the bar at somewhat greater than monthly intervals. Men helped themselves to this until the can was empty, when no more would be available until the next can. The contents of the cans seldom survived 2 weeks, for some men would drink several pints of cordial in an evening and the neat cordial (vitamin C content 270 mg./100 ml.) was often added to alcoholic drinks. On occasions very large intakes (>300 mg.) of vitamin C were achieved from this source. During the latter half of the year (September 1972 onwards) the cook served cordials with meals, and Califorange was no longer placed in the bar. The cordials made from lemon and orange crystals were served as well as Califorange and though Califorange was not available on all days this change of procedure meant that Califorange was available more frequently than during the first half of the year though less quantity was drunk at one time. Even so, some men achieved vitamin C intakes of well over 100 mg./day on days that the Califorange was available.

While the base diet consisted mainly of canned foods with some dried foods, the field diet consisted totally of dried foods. The only two foods included in the field rations with any vitamin C content were dried milk (10 mg./100 g. dry weight—910 g. supplied) and dried potato (4 mg./100 g. dry weight—225 g. supplied), i.e. each 20 man/day food box (excluding vitamin tablets) contained only 100 mg. vitamin C or 5 mg./man/day. However, these boxes contain 100 multivite tablets (vitamin C content 12·5 mg./capsule) or 5 tablets/man/day, supplying 62·5 mg. vitamin C/day.

Blood vitamin C levels

The low dietary vitamin C intakes were reflected in the blood vitamin C levels. The eight wintering subjects had blood analysed for vitamin C on eight occasions, one subject not being available on the last occasion. Of the 63 results of plasma vitamin C levels, 22 (35 per cent) were below 0·25 mg./100 ml. and 38 (60 per cent) were below 0·4 mg./100 ml. These figures would have been even greater had not four of the subjects been given a course of 1 g. vitamin C/day for a week at the end of June 1972, and had another subject not take 500 mg. tablets of vitamin C from a private source on several occasions throughout the year (this subject's blood vitamin C levels did not, therefore, reflect dietary vitamin C intake).

The effect of the saturating course of vitamin C, which the four subjects received at the end of June, was short-lived. Plasma levels returned to pre-supplement levels within 1 month and leucocyte levels within 2 months. These effects are shown in Figs. 1 and 2 for plasma and leucocyte vitamin C levels, respectively. The supplement group figures are the pooled results of the four subjects who received supplement in June 1972, while the control group consisted of three of the four who did not (the omission being the subject who took his own supplement, for the reason given).

When those results of the supplemented group which were affected by the June supplement were excluded, but all other results were pooled, it was found that blood vitamin C levels, both plasma ($p < 0{\cdot}001$) and leucocyte ($p < 0{\cdot}002$) were significantly greater during the latter half of the year (September 1972 to January 1973) than during the first half of the year (March to August 1972). This can be seen in Figs. 1 and 2. The change in presentation of Califorange thus coincided with an improvement in the nutritional status of the men. However, low blood vitamin C levels were still found in some subjects during the latter half of the year.

When the effect of fruit juices was not overshadowed by vitamin supplement or high

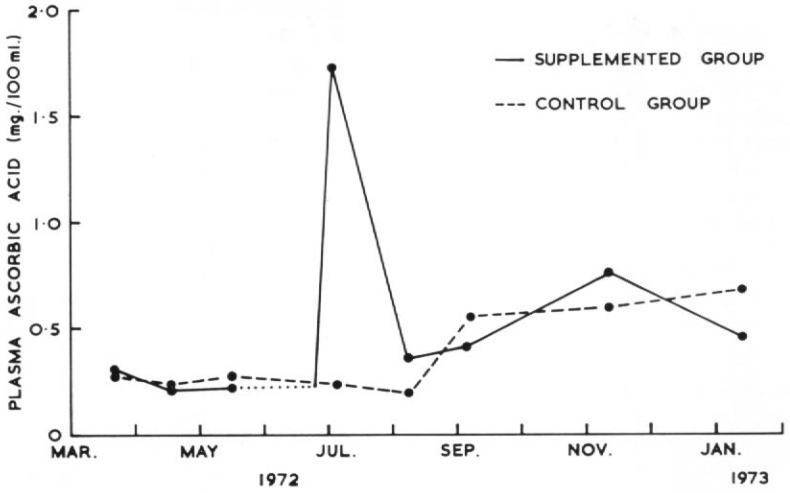

Fig. 1. Mean changes in the plasma vitamin C levels of the wintering personnel between March 1972 and January 1973.

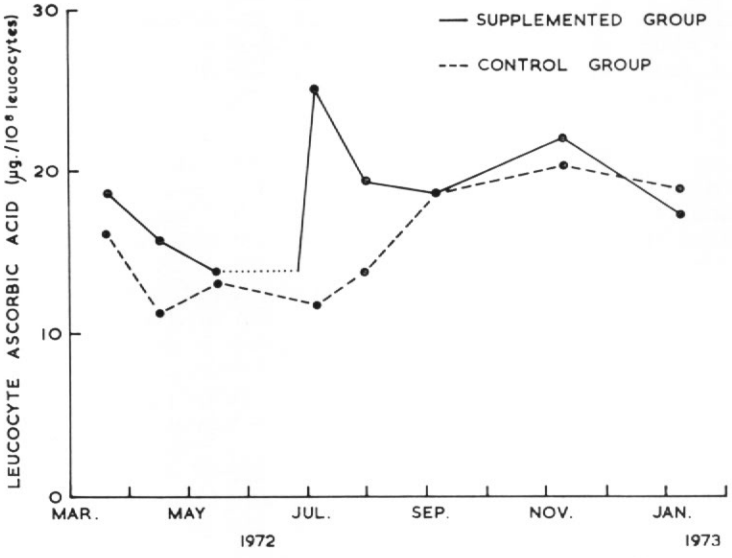

Fig. 2. Mean changes in the leucocyte vitamin C levels of the wintering personnel between March 1972 and January 1973.

Califorange intake, it was noticeable that the three subjects who regularly took fruit juices had noticeably (though not statistically significantly) higher blood vitamin C levels than those who did not.

Nutritional status of other subjects

The air party (four men) arrived at Adelaide Island, where they were based for the austral summer, towards the end of October 1972 and departed at the end of February 1973. During this period they experienced the same diet as the other Adelaide Island subjects. From the

beginning of November 1972 to the middle of January 1973 (a period of $2\frac{1}{2}$ months), plasma vitamin C levels of these men fell from a mean of $0{\cdot}61 \pm 0{\cdot}32$ mg./100 ml. to $0{\cdot}34 \pm 0{\cdot}12$ mg./100 ml., while leucocyte levels fell from a mean of $23{\cdot}4 \pm 9{\cdot}0$ μg./10^8 leucocytes to $19{\cdot}5 \pm 6{\cdot}7$ μg./10^8 leucocytes. Despite the considerable mean fall in plasma vitamin C levels, neither of these falls was statistically significant.

Two subjects from the Fossil Bluff field station had blood analysed, one subject on two occasions 2 months apart, the other on one occasion only. While at Fossil Bluff, the diet of these men was similar to that available at Adelaide Island, though periods were spent either in the field or at Spartan Glacier, when the diet consisted mainly of field rations. Mean plasma vitamin C levels of the three results was $0{\cdot}33 \pm 0{\cdot}05$ mg./100 ml. and that for leucocytes was $14{\cdot}4 \pm 2{\cdot}4$ μg./10^8 leucocytes. These men reported that, though available, vitamin tablets were rarely taken.

Clinical signs

At the time that this survey was carried out, the author was not aware that signs of vitamin C deficiency were detectable at plasma vitamin C levels above 0·1 mg./100 ml. No attempt therefore was made to observe such signs as petechial haemorrhages at higher plasma levels than this. None of the more gross signs or symptoms of scurvy, such as mouth ulcers or bleeding gums, were observed in base personnel.

A questionnaire was circularized to available personnel from Stonington Island who were involved in long summer sledging journeys (lasting for 5 months); two of the eight men who replied suffered from mouth ulcers in the field. Neither subject regularly took vitamin tablets, though one reported that his ulcers disappeared on taking vitamin tablets, only to return some time later after he had stopped doing so. However, two subjects who did take vitamin tablets regularly while in the field had blood taken for analysis while paying a "flying visit" to Adelaide Island. Both had satisfactory blood vitamin C levels.

Discussion

The diet available at British Antarctic Survey bases is mainly preserved, either canned or dried. There is a supply of frozen meat, of which only the liver and kidney included have any significant vitamin C content. Fresh or frozen vegetables cannot be supplied nor grown, though a small but nutritionally insignificant quantity of mustard and cress was grown by the base cook throughout the year.

The results of food analysis (Table I) showed that very few of the foods available at the base were good sources of vitamin C. The results of the diet sheets showed that, without fruit juices and cordials, the diet was very deficient of vitamin C, in fact so poor that, without vitamin supplement or other sources of vitamin C, some subjects might well have presented with the gross signs of scurvy, while the results of blood analysis suggested that, had an effort been made to observe for them, the less severe signs of vitamin C deficiency would almost certainly have been seen.

The best available sources of vitamin C were all of limited supply and were certainly not used to their best advantage. The fruit juices were only regularly taken by three of the eight wintering men and during the first 6 months of the year the Califorange was nutritionally wasted.

When large quantities of vitamin C are taken orally it is quickly absorbed, being such a small sugar molecule, and causes blood vitamin C levels (primarily that of the plasma) to rise quickly to high levels. Uptake of the vitamin by the tissues is much slower. Vitamin C is excreted by the kidneys and the higher the plasma vitamin C level the faster it is excreted. Thus one large intake of vitamin C will result in a much greater loss of the vitamin than the same amount given in divided portions over a period of time. This effect was very noticeable in respect of the use of the Califorange.

During the first 6 months of the year, when on occasions very large amounts were drunk over very short periods, the blood vitamin C levels, both plasma and leucocyte, were constantly low thus signifying deficiency. During the second half of the year, when smaller quantities were taken more frequently, the mean standard of vitamin C nutrition improved significantly,

six of the eight subjects who wintered maintaining satisfactory blood levels and two subjects maintaining saturated levels over considerable periods. The same amount of Califorange was drunk in the first and second halves of the year, yet satisfactory blood levels during the first half of the year were only achieved when vitamin C supplement was taken. (It should be noted that the change in presentation of the Califorange was brought about by the base cook, who was responsible for the way the cordials and in fact all foods were made available at the base, and not the author.)

The better utilization of Califorange during the second half year did not eliminate vitamin C deficiency, for two of the wintering men maintained deficient blood levels throughout the year and the men of the air party all recorded deficient blood plasma vitamin C levels after $2\frac{1}{2}$ months at the base. It was therefore obvious that the mere presence of a cordial with a high vitamin C content could not ensure against deficiency.

Too little information was able to be collected concerning the nutritional status of the men from Fossil Bluff. The similarity of the diet available at the Fossil Bluff field station to that at Adelaide Island, the very deficient nature of the sledging rations which they ate when away from the base, the fact that vitamin tablets were rarely taken by these men and the low blood vitamin C levels recorded when men were available for blood analysis indicated that these men were vitamin C deficient throughout the year. More definite conclusions could not be drawn.

The state of nutrition of the Stonington Island field parties was more variable. Most of those involved in long field trips took vitamin supplement regularly and probably maintained quite satisfactory vitamin C levels, as those of the two men who were available for blood analysis on one occasion showed. The very deficient nature of the sledging rations would be expected to cause vitamin C deficiency if the supplementary tablets were not taken. Vitamin C was almost certainly a contributory cause if not the only factor causing mouth ulcers reported by some of these men.

Conclusions of the survey

The diet available at the bases of the British Antarctic Survey has very few good sources of vitamin C. Even at those bases where vitamin C supplement was available, vitamin C deficiency was biochemically evident. The perennially low blood vitamin C levels found in some of the subjects of this survey vindicate the diagnoses of vitamin C deficiency made by past medical officers.

Addendum: improvement of the diet

The problems of supply and storage necessitate the type of preserved foods available at the bases. Little can be suggested, at present, which might improve the vitamin content of these supplies except perhaps for the supply of dried potato, which is frequently used for meals. Had the now obtainable vitamin C supplemented dried potato been available at the time of this survey, it was calculated from the diet sheets that mean daily intake of vitamin C would have improved from 12·3 mg./man/day to about 20 mg./man/day, a significant improvement. However, the supplementation of dried, or canned, foods with vitamin C is a costly procedure, suitable to only a few foods. It is at present unlikely to be introduced to other foods.

The best source of non-tablet vitamin C was the Califorange syrup. The total base supply of this, used most efficiently, would have produced 20 mg. vitamin C/man/day (half a glass/day at 1 : 10 dilution). Though ensuring this intake, along with providing supplemented dried potato would have assured an intake of about 40 mg. vitamin C/man/day, the practicality of implementing this regime would probably not be accepted on most if not all of the bases (the author certainly enjoyed a pint tankard of Califorange on occasions), remembering that the cordial was not universally appreciated.

On the evidence of this survey the only method by which a satisfactory vitamin C intake ($>$40 mg./man/day) can be guaranteed is to ensure that at least two of the supplied multi-vitamin tablets are taken by all men every day while at the base and at least three tablets per day while in the field. Whether the past reluctance of some men to take vitamin supplement can be overcome by the results of a survey such as this is a matter for conjecture.

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