Review article

Micronutrients: highlights and research challenges from the 1994–5 National Diet and Nutrition Survey of people aged 65 years and over

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The aims of the National Diet and Nutrition Survey series are summarized, and the new National Diet and Nutrition Survey of people aged 65 years and over is explored, with particular emphasis on micronutrient intakes and status indices. Mean nutrient intakes were generally satisfactory for most micronutrients, but intakes of vitamin D, Mg, K and Cu were low. Intakes of vitamin D were far below the reference nutrient intake for people aged 65 years and over, and there was also biochemical evidence of vitamin D deficiency, for 8 % of free-living and 37 % of institution participants, attributed partly to limited exposure to sunlight. A substantial proportion of people living in institutions had inadequate biochemical status indices, notably for vitamin C, Fe and folate. Relationships between intake and status were close for vitamins. Mineral intakes did not correlate well with currently used status indices. Some intakes and indices, especially those of vitamin C, carotenoids, Na and K, were strongly correlated with socio-economic status and with north–south gradients in Britain. Future research challenges should address the functional and health significance of low intakes and sub-optimal biochemical indices for certain micronutrients, especially for people living in institutions; the shortcomings of mineral status indices especially as indicators of mineral intake; the social and geographical inequalities of micronutrient intakes and status, and why micronutrient status deteriorates with increasing age. The answers to these questions will help to define the characteristics of nutritional risk for older people in Britain, and to clarify future needs for education and intervention.

Micronutrients: National Diet and Nutrition Survey: Elderly

The purpose of the present paper is to draw attention to the British Government's National Diet and Nutrition Survey of people aged 65 years and over, and the reports derived from it (Finch *et al*. 1998; Steele *et al*. 1998). It also considers some of the problems of interpretation and research challenges of this large dataset in order to encourage other researchers to continue this investigation. The primary data from the survey will be lodged with the University of Essex Archive (The Data Archive, University of Essex, Wivenhoe Park, Colchester, Essex CO4 3SQ, UK, telephone +44 (0)1206 872001, fax +44 (0)1206 872003, email archive@essex.ac.uk) and will be available to future researchers. A brief outline of the survey and a summary of its main findings are also available (Smithers *et al*. 1998).

The survey of a representative sample of people aged 65 years and over in Britain is the second in a series of cross-sectional surveys, being carried out at approximately 3-yearly intervals. The first, published in 1995, examined

Abbreviations: EGRAC, erythrocyte glutathione reductase activation coefficient; ETKAC, erythrocyte transketolase activation coefficient; LRNI, lower reference nutrient intake.

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the diet and nutrition of preschool children (Gregory *et al*. 1995). A survey of British adults aged 16–64 years (Gregory *et al*. 1990) using similar procedures preceded the main survey series. It is intended that each survey will examine a nationally-representative sample, drawn from one of four age groups: preschool children aged 1·5–4·5 years (completed), young people aged 4–18 years (fieldwork completed and report expected in 1999), adults aged 19–64 years (being commissioned) and adults aged 65 years or over (completed). The main objectives are to:

(1) assess food consumption, nutrient intakes and nutritional status of individuals and groups, as a basis for Government policies;
(2) establish reference ranges of nutrient intakes and status markers;
(3) monitor the population's diet for adequacy and variety;
(4) monitor progress towards dietary targets (Department of Health, 1991);
(5) examine evidence for relationships between diet, morbidity and mortality;
(6) estimate intakes of additives and contaminants for risk assessment;
(7) assess dental and oral health status, and its relation to diet and nutrition.

Each survey is preceded by its own feasibility study, whose purpose is to test and optimize the procedures to be used for the main survey. The findings of the feasibility study for the present survey have been documented (Hughes *et al*. 1995; Smith & Lowe, 1998). Each age group poses a distinct set of problems and challenges for survey design, and the reader is referred to the main Survey Report (Finch *et al*. 1998) for a discussion of these. Some considerations which are of particular importance for people aged 65 years or over are:

(1) the need to be sensitive to the economic, emotional, physical and mental vulnerability of many older people;
(2) the special needs and characteristics of those who are mentally frail, and who may require proxy consent and/or information from relatives or carers;
(3) the demographic profile of the older population, which requires special sampling and weighting procedures in order to achieve a representative picture;
(4) the special needs and characteristics of those who live in long-stay institutions such as sheltered accommodation and nursing homes (people in acute hospital beds were excluded from the survey);
(5) the high prevalence of chronic diseases and the extensive use of medicines, both of which may affect appetite and metabolism, and may thus affect dietary choices;
(6) poor dentition, and other physical disabilities, which may impinge on dietary choices and hence on nutrition.

The main elements of the survey were:

(1) a personal interview, conducted by a trained interviewer, designed to obtain demographic information on health and lifestyle, previous employment and sources of income, activities of daily living, memory and depression status, self-reported health status and disease experience, usual eating patterns, use of medications including prescribed nutrient supplements, alcohol and smoking habits, bowel movements, etc;
(2) a 4 d weighed diet (diary) record, including non-prescribed supplements. This information was then converted to daily nutrient intakes by means of a nutrient databank maintained by the Ministry of Agriculture, Fisheries and Food;
(3) anthropometric measurements (height, weight, demi-span, mid-upper-arm circumference, waist : hip ratio) and measurements of blood pressure, pulse rate and hand grip strength, obtained by a trained nurse;
(4) a 30 ml fasting blood sample, obtained by the nurse for haematology and biochemical measurements. The nutrition-related indices included: total plasma cholesterol, HDL-cholesterol, triacylglycerols; Fe, Fe-binding capacity, Ca, phosphate, Zn, Cu, vitamin C; serum ferritin, folate and vitamin B_{12}; erythrocyte folate, erythrocyte glutathione reductase (*EC* 1.6.4.1) activation coefficient (EGRAC; riboflavin status), and transketolase (*EC* 2.2.1.1) activation coefficient (ETKAC; thiamin status); and whole-blood glutathione peroxidase (*EC* 1.11.1.9; Se status). Also measured were plasma alkaline phosphatase (*EC* 3.1.3.1), urea, creatinine, α_1-antichymotrypsin, and albumin. The haematology and some biochemical measurements were performed at Addenbrookes' Hospital (Cambridge, UK) Clinical Haematology laboratory; others at the Medical Research Council's Dunn Nutrition Unit's laboratory in Cambridge, UK;
(5) a single early morning urine sample collected for Na, K and creatinine measurements;
(6) an oral health interview and dental examination (Steele *et al*. 1998).

The procedures, including selection and recruitment of the population sample, are described in the Survey Report (Finch *et al*. 1998). The survey protocol deliberately over-selected males and the older age groups in order to obtain sufficient numbers for statistical evaluation and then applied weighting procedures to ensure that the published data were representative of British people aged 65 years or over, as found by the most recent population census. It included both (a) free-living people (i.e. people living in the community), and (b) people living in institutions such as nursing homes and residential homes for the elderly (but not people in acute hospital beds). These two categories of participants are treated separately in the Survey Report (Finch *et al*. 1998), partly because the fieldwork procedures were somewhat different for each. Of an eligible free-living sample of 2172 participants, 1632 (75 %) provided a full or partial interview (the responding sample) and 1275 (59 %) provided a full dietary record (the diary sample). Of an eligible sample of 454 participants in institutions, the responding sample was 428 (94 %) and the diary sample was 412 (91 %). The survey was carried out in four fieldwork waves over 12 months, corresponding approximately to the four seasons of the year, and the sample was drawn from eighty randomly-selected postcode sectors, twenty per wave, each wave being geographically representative of mainland Britain. Permission for the survey was obtained from all of the National Health Service Local

Research Ethics Committees responsible for each of the eighty postcode sectors, and from the Medical Research Council's Dunn Nutrition Unit's ethics committee.

Dietary intakes

Table 1 shows, for each nutrient, the percentage of participants whose intakes (from all sources, including supplements) fell below: (a) the reference nutrient intake, (b) the estimated average requirement and (c) the lower reference nutrient intake (LRNI) (Department of Health, 1991). Four nutrients, for which there appeared to be a major shortfall by comparison with the dietary reference values, were vitamin D, Mg, K and Cu. Of the remaining fourteen nutrients for which an LRNI has been set, the percentage of participants receiving less than the LRNI was lower than 2 % for seven and between 2–9 % for the remaining seven, in the combined (free-living and institution) sample.

Of the four nutrients for which a potential problem of inadequate intakes was revealed, only K and Mg have an LRNI, and for both population groups shown in Table 1, more than 20 % appeared to be receiving less than this amount. For vitamin D there is no assigned LRNI, but the percentage of participants receiving less than the reference nutrient intake implies an extent of inadequacy as great, or greater, than that observed for K or Mg. An estimate of K excretion rates, based on the urinary K and creatinine concentrations and an approximate prediction of creatinine excretion rates in this age group, suggest that the K intakes are likely to be at least as low as those calculated from the diet records, and possibly lower (results not shown). However, we do not at present have conclusive evidence that the apparently low intakes of K, Mg and Cu adversely affect indices of health or function. Intakes below the reference nutrient intake, or even below the LRNI, do not necessarily imply functional deficiencies. It will be important to investigate further the dietary requirements for micronutrients by older people, in terms of functional status indices. With regard to the possible occurrence of undesirably high intakes, the only one for which there is potential concern here is Na. Of salt (NaCl) intakes, 44 % were above 6 g/d, which may be associated with an increased risk of high blood pressure (Department of Health, 1994). It is important to note that the assessed dietary Na and Cl^- intakes excluded salt added at the table or in cooking, and are therefore likely to be somewhat underestimated.

Biochemical status indices

The biochemical indices of nutritional status (Table 2) reveal apparent inadequacy for plasma 25-hydroxyvitamin D and for other nutrients, especially in the institutions, notably serum folate, riboflavin status, plasma vitamin C, percentage transferrin saturation with Fe, and blood haemoglobin, for all of which more than 25 % of the participants in institutions were in the range associated with deficiency. Thus, nutritional status was poor for a substantial number of nutrients for which intakes were not particularly low. Riboflavin status, as measured by EGRAC, was especially poor, both in the free-living and the institutional groups (Table 2),

Table 1. Percentages of survey sample receiving less than the reference nutrient intake (RNI)*, the estimated average requirement (EAR)*, and the lower reference nutrient intake (LRNI)* of selected micronutrients and of protein (Data derived from Finch *et al.* 1998†)

	Free-living participants (*n* 1310)‡			Participants in institutions (*n* 423)‡		
Nutrient	% below RNI	% below EAR	% below LRNI	% below RNI	% below EAR	% below LRNI
Total vitamin A§	44	20	4	26	7	1
Vitamin D	95	–	–	99	–	–
Vitamin B_1	8	2	<1	11	2	<1
Vitamin B_2	28	12	7	20	7	3
Vitamin B_6	9	4	2	13	5	1
Vitamin B_{12}	3	2	1	1	<1	<1
Folate	38	17	3	50	25	5
Niacin equivalents||	1	<1	<1	5	3	<1
Vitamin C	33	13	1	45	14	<1
Sodium	16	–	<1	16	–	<1
Potassium	92	–	30	97	–	37
Calcium	47	18	7	27	7	1
Magnesium	80	55	22	93	67	31
Iron	43	18	3	57	24	5
Zinc	62	28	7	54	28	8
Copper	82	–	–	90	–	–
Iodine	43	–	4	39	–	1
Phosphorus	2	<1	<1	<1	<1	<1
Protein	20	–	–	25	–	–

–, No reference value assigned.
* Department of Health (1991).
† All values are rounded to the nearest integer, and represent nutrient intakes from all sources, including supplements.
‡ Base: all participants who yielded a 4 d weighed food intake record (84 % of responding sample).
§ Retinol equivalents: retinol + (β-carotene/6) + (other convertible carotenoids/12) by weight.
|| Niacin equivalents: nicotinic acid + nicotinamide and its nucleotides + (tryptophan/60).

Table 2. Percentage of the sample of elderly people with biochemical indices in the range associated with tissue deficiency

Biochemical index	Cut-off for inadequate status*	Percentage with unacceptable status in: Free-living participants	Institution participants
Participant numbers*		794–944	232–267
Haemoglobin	< 130 g/l (men) < 120 g/l (women)	10	45
Transferrin saturation	< 15 %	11	28
Ferritin	< 12 μg/l	5·7	3·8
Plasma vitamin C	< 11 μmol/l	14	40
Serum folate	< 7 nmol/l	15	39
Erythrocyte folate	< 230 nmol/l	8	16
25-hydroxyvitamin D†	< 12·5 nmol/l	1·6	2·7
	< 25 nmol/l	8	37
EGRAC	> 1·30	41	35
Alkaline phosphatase‡	> 110 IU/l	16	32
ETKAC	> 1·25	9	14
Serum vitamin B_{12}	< 118 pmol/l	6	9
Plasma zinc	< 10 μmol/l	2	9
Plasma α_1-antichymotrypsin§	> 0·65 g/l	1·3	6·3
Plasma albumin	< 28 g/l	0·7	3·2
Plasma creatinine‖	> 160 μmol/l	2	3
Plasma cholesterol	> 7·8 mmol/l	9	1·2
Plasma retinol	< 0·35 μmol/l	0	0
α-Tocopherol : cholesterol	< 2·25	0	0

EGRAC, erythrocyte glutathione reductase activation coefficient (ratio of activities with and without the vitamin-derived cofactor); ETKAC, erythrocyte transketolase activation coefficient (ratio of activities with and without the vitamin-derived cofactor).

* Participant numbers are less than those in Table 1, and vary between the different indices, because not all the participants who provided food intake data (the 'diary sample') also provided a blood sample, and because limitations on the amount of blood available constrained the number of analyses. See Finch *et al.* (1998) for a detailed description of the biochemical assays and sources of the reference range values, from which the cut-off values quoted here were derived.

† Two cut-off values, corresponding to severe and moderate deficiency respectively.

‡ Indicator of bone health.

§ Indicator of acute-phase (inflammatory) status.

‖ Indicator of kidney function.

even though less than 10 % of riboflavin intakes were below the LRNI (Table 1). This paradox has also been noted in other recent studies of older people in the UK (Bailey *et al*. 1997; Madigan *et al*. 1998).

Table 3 lists mean values for the biochemical status indices where there were significant differences between free-living participants and those in institutions, and examines the percentage differences between these two population groups, adjusted for age (since there was a highly significant difference in age profile between the two groups) and for sex. The age-adjusted mean concentrations of vitamin C, plasma 25-hydroxyvitamin D, serum folate and plasma Fe were 19–38 % lower in the institution group than in the free-living group. Plasma α-tocopherol, β-carotene, retinol and Zn concentrations and transferrin saturation (age-adjusted) were 7–16 % lower in the institution group. Possible reasons why the institution group exhibited poorer biochemical status index values than the free-living group, despite only moderate recorded differences in their nutrient intakes, are that (a) the diet assessment procedures differed between the two groups (Finch *et al*. 1998); (b) greater use of medications may have affected status in the institution sample, independently of intakes, and (c) a greater burden of disease and age-related physiological abnormality may have compromised status in the institution sample, e.g. by reducing nutrient absorption or retention, or by increasing metabolic turnover. The percentage of participants with raised plasma α_1-antichymotrypsin concentrations, a proxy indicator for the acute-phase reaction associated with acute illness, was more than 4-fold greater in the institution group than the free-living group (Table 2), and this was a highly significant result (t 7·0, $P < 0·0001$, 1136 df after log transformation). In addition, the leucocyte count was 6 % higher in the institution group (t 2·9, $P = 0·004$, 1226 df after log transformation, results not shown). This suggests that intercurrent infections or other causes of metabolic stress were more common in the institution group. All of the status indices listed in Table 3 were significantly correlated with plasma α_1-antichymotrypsin, with the exception of the two carotenoid indices, the urine K : creatinine ratio, and ETKAC. The implied influence of the acute-phase reaction on a large number of nutrient status indices is an important potential confounder, which needs to be carefully considered when interpreting the results of micronutrient status measurements, especially in older people.

Another potential confounder is the effect of diuretic drugs, which are frequently prescribed for, and used by, older people, and which may affect status indices in a

Table 3. Significant differences between free-living and institution participants for biochemical status indices*

Index	Units	Free-living participants (*n* 785–969)†		Institution participants (*n* 231–282)†		Percentage difference‡
		Mean	SD	Mean	SD	
Plasma vitamin C	μmol/l	44·4	24·9	24·6	20·9	–44·6
Plasma 25-hydroxyvitamin D	nmol/l	55·5	26·9	32·8	15·7	–40·9
Serum folate	nmol/l	16·0	10·0	11·8	9·7	–26·2
Plasma iron	μmol/l	13·1	4·65	9·7	4·26	–25·4
Transferrin saturation	%	26·5	10·7	21·6	10·9	–18·5
Blood haemoglobin	g/l	13·9	1·36	12·4	1·50	–10·8
Plasma α-tocopherol	μmol/l	37·9	11·6	32·3	9·2	–14·8
Plasma cholesterol	mmol/l	5·95	1·40	5·30	1·26	–11·4
Plasma zinc	μmol/l	14·3	2·3	12·7	2·1	–11·2
Plasma retinol	μmol/l	2·20	0·62	1·97	0·67	–10·4
Plasma albumin	mmol/l	42·8	6·0	38·5	5·9	–10·0
Plasma α-carotene	μmol/l	0·074	0·076	0·067	0·071	–9·5
Plasma β-carotene	μmol/l	0·364	0·235	0·336	0·247	–7·7
Alkaline phosphatase	IU/l	91	63	106	59	+16·5
Urine sodium : creatinine	mol/mol	13·7	8·3	12·1	8·3	–12·0
Urine potassium : creatinine	mol/mol	4·99	2·31	5·46	2·07	+8·6
ETKAC	ratio	1·163	0·074	1·171	0·077	+6·9

ETKAC, erythrocyte transketolase activation coefficient (activity ratio).

* The indices included in this table are confined to those for which there was a significant difference ($P < 0{\cdot}05$, by Student's *t* test after log transformation) between free-living and institution participants after adjustment for differences in age and sex. The mean (weighted) age in the free-living group was 73·9 years, and in the institution group, 83·5 years.

† Participant numbers varied between tests, depending on the amount of sample available.

‡ Negative values for the percentage difference indicate that the institution participants had lower values than the free-living participants, and vice versa.

variety of ways (Bates *et al*. 1998*b*, 1999). Although it was not possible to assess the effects of diuretic drugs in isolation from the medical conditions which must have prompted their use, it was possible to compare status indices between diuretic drug-users and non-users. In free-living participants, urinary Na and K excretion rates were inversely correlated with the use of diuretic drugs, whereas the following blood indices were directly correlated with their use: plasma α_1-antichymotrypsin, Cu, creatinine and urea, plasma retinol, erythrocyte folate and EGRAC (see also Bates *et al*. 1999). These correlations cannot be explained in terms of increased urinary losses of micronutrients, but they nevertheless flag the existence of important but poorly understood factors which can affect certain status indices in older people. The remaining blood indices which are discussed in this paper were not significantly correlated with the use of diuretic drugs. Clearly, the observed correlations with acute-phase markers and drugs use (Bates *et al*. 1999) identify some of the probable reasons why the correlations between micronutrient intakes and their status indices are weaker than might otherwise be expected (Table 4).

The high percentage of participants with poor vitamin D status, especially in the institution group, is consistent with the intake data in Table 1. Many older people, especially those in institutions, fail to obtain adequate vitamin D either from diet or from sunlight and therefore require supplements (Department of Health, 1998). The Department of Health (1991, 1992) has consistently endorsed this advice.

In Table 4, linear correlations between nutrient intakes and biochemical indices within the two population groups are explored, by multivariate linear regression analysis of $\log_{10}$-transformed measures of intake and status, with age, sex and α_1-antichymotrypsin concentrations included in the model. For most of the intake : biochemical status comparisons, the inclusion of log transformation and of the multiple regression model made only minor differences to the strength of the correlations, and in most instances did not alter the conclusions (results not shown). Vitamin intakes, with the exception of preformed vitamin A (retinol) can generally be predicted from the corresponding vitamin status indices, at least on a group basis. Plasma retinol concentration is known to reflect vitamin A status only when the liver stores have fallen below a very low level, which is not often observed in adults in Western societies. The Survey Report (Finch *et al*. 1998) and the results of other published population surveys (e.g. Wright *et al*. 1995) showed that the following biochemical indices were strongly correlated with the corresponding nutrient intake estimates, in both population groups: urinary excretion rates of Na and K, plasma α- and β-carotenes, 25-hydroxyvitamin D, α-tocopherol, vitamin C, serum and erythrocyte folate, and the two erythrocyte enzyme activation coefficient indices: ETKAC (for thiamin) and EGRAC (for riboflavin). The strength of these correlations, as estimated by Pearson's partial correlation coefficients (*r* values), which, unlike the *t* ratios, are independent of the number of participants being compared, were generally fairly similar between the free-living and institution groups. For most of the mineral nutrients, apart from Na and K, however, the relationships observed between intakes and biochemical index values were generally weak and non-significant. The variance of the mineral indices is influenced little, if at all, by mineral intakes, and it is therefore not possible to predict mineral intakes from the biochemical indices in these participants.

Table 4. Correlations between micronutrient intakes and corresponding biochemical status indices in free-living elderly subjects and those living in institutions

Biochemical status index	Nutrient intake estimate†	Free-living participants (*n* 761–857)		Institution participants (*n* 218–245)	
		t‡	*r*‡	*t*‡	*r*‡
Urinary Na : creatinine	Sodium	+3·73***	+0·127	+1·99*	+0·134
Urinary K : creatinine	Potassium	+5·25***	+0·177	+2·66*	+0·176
Haemoglobin	Total iron	–1·34	–0·046	+0·75	+0·048
Transferrin saturation	Total iron	+1·69	+0·058	+1·46	+0·070
Plasma iron	Total iron	+1·19	+0·041	+0·95	+0·061
Serum ferritin	Total iron	+1·83	+0·063	+1·18	+0·078
Plasma iron	Haem iron	+2·22*	+0·076	+0·95	+0·061
Serum ferritin	Vitamin C	+2·30*	+0·079	–0·99	+0·065
Haemoglobin	Vitamin C	+1·35	+0·046	+1·30	+0·083
Transferrin saturation	Vitamin C	+0·45	+0·015	+1·18	+0·076
Plasma zinc	Zinc	+1·75	+0·063	–0·19	–0·013
Plasma copper	Copper	–0·49	–0·018	+0·36	+0·024
Plasma calcium	Calcium	–1·32	–0·048	+0·55	+0·037
Plasma phosphorus	Phosphorus	+0·48	+0·017	+1·13	+0·075
Plasma retinol	Retinol	+2·05*	+0·071	+0·53	+0·034
Plasma α-carotene	α-Carotene	+11·5***	+0·380	+4·45***	+0·280
Plasma β-carotene	β-Carotene	+9·70***	+0·321	+2·77*	+0·177
Plasma 25-hydroxyvitamin D	Vitamin D	+9·16***	+0·298	+4·95***	+0·302
Plasma α-tocopherol	Vitamin E	+8·45***	+0·283	+2·91*	+0·186
Plasma vitamin C	Vitamin C	+18·0***	+0·526	+7·05***	+0·419
ETKAC	Vitamin B_1	–4·75***	–0·162	–5·37***	–0·246
EGRAC	Vitamin B_2	–12·9***	–0·405	–6·03***	–0·367
Serum folate	Folate	+10·3***	+0·336	+7·79***	+0·458
Erythrocyte folate	Folate	+11·7***	+0·373	+7·39***	+0·431
Serum vitamin B_{12}	Vitamin B_{12}	+2·79*	+0·097	+0·37	+0·025

ETKAC, erythrocyte transketolase activation coefficient; EGRAC, erythrocyte glutathione reductase activation coefficient.
Values were statistically significant: * $P<0·05$, *** $P<0·001$.
† Includes all supplements, prescribed and non-prescribed, except injected vitamin B_{12} in which case (*n* 6) the participants were omitted. Participant numbers varied between tests, depending on the amount of sample available.
‡ Contribution of log(daily nutrient intake) to the multivariate linear regression model of log(biochemical index) *v.* log(daily nutrient intake), with age, sex, and plasma α_1-antichymotrypsin concentration included. *t* is the *t* ratio and *r* is the partial correlation coefficient for the log(nutrient intake) in this model.

Probably, this is frequently the result of powerful homeostatic mechanisms, which help to maintain constant blood levels of minerals, in the face of large variations in dietary intakes and turnover rates. More work clearly needs to be undertaken to identify better indices of mineral status.

It is valuable to explore whether individual, or combinations of, nutrients correlate with socio-economic status or with geographical variations, thus predicting the probability of socio-economic risk, and whether appropriate nutrition interventions can be developed from a study of the characteristic patterns of nutrient intake and status. Table 5 explores this question, through evidence from the Survey which confirmed that there were nutritional differences dependent on (a) socio-economic status of the head of household; (b) receipt of state benefits; (c) household income, and (d) region of domicile. Living in Scotland or the north of England, being manual social class and with relatively low income, and receiving State benefits (group 1) appeared to be associated with nutritional disadvantage in regard to poorer vitamin C status, lower consumption of vitamins present in fruit and vegetables, especially carotenoids, higher Na intakes and urinary Na : creatinine ratios, and lower K intakes and urinary K : creatinine ratios. Intakes of B-vitamins were also relatively low in this group, but apart from EGRAC (the index of riboflavin status), this was not reflected in significant differences in B-vitamin status. Only plasma γ-tocopherol was higher in group 1, whereas α-tocopherol (results not shown) showed no significant difference (group 1: 35·7 μmol/l; group 2: 37·7 μmol/l; $P=0·32$). Likewise, the total plasma vitamin E : cholesterol ratio did not differ significantly between the two groups; indeed there was less than 2 % difference between them. Socio-economic factors were not associated with variations in serum and erythrocyte folate, serum vitamin B_{12}, ETKAC, plasma retinol, 25-hydroxyvitamin D, serum ferritin, plasma Fe or the percentage saturation of transferrin, plasma Zn, Cu, Ca, phosphate, cholesterol, HDL-cholesterol, triacylglycerols, urea, albumin, α-antichymotrypsin, γ-glutamyl-transferase or alkaline phosphatase, nor with intakes of fat, cholesterol, vitamins D and E, Zn, haem Fe or sucrose (after adjustment for energy intakes). It was considered possible that group differences in status might be attributable to differences in use of vitamin supplements. Although participants living in households whose head was non-manual were significantly more likely to use supplements than those whose head was classified as manual socio-economic status ($P=0·0003$ by logistic regression), the significant inter-group differences in status indices in Table 5 persisted, in the (major) subgroup of non-supplement-users (results not shown). Therefore, the differences cannot be ascribed to supplement use alone but insufficient information on supplements was collected in the survey to resolve this question. Further

Table 5. Differences in biochemical status indices and nutrient intakes between two subgroups* of free-living participants (age range 65–95 years) who differed in socio-economic status and in geographical location

Index	Units	Group 1		Group 2		*P* for inter-group comparison
		Mean†	*n*	Mean†	*n*	
Biochemical status						
Plasma vitamin C	μmol/l	10·7	54	37·1	182	< 0·000001
Plasma β-cryptoxanthin	μmol/l	0·049	45	0·116	163	0·000005
Plasma β-carotene	μmol/l	0·218	49	0·337	170	0·0003
Plasma lutein	μmol/l	0·293	49	0·407	170	0·0002
Plasma lycopene	μmol/l	0·139	48	0·204	170	0·009
Plasma γ-tocopherol	μmol/l	2·69	49	2·17	169	0·008
EGRAC	activity ratio	1·351	53	1·301	182	0·05
Plasma creatinine	μmol/l	94·6	52	83·9	178	0·01
Urine Na : creatinine	molar ratio	14·5	65	11·9	214	0·02
Urine K : creatinine	molar ratio	4·2	65	4·8	214	0·03
Dietary intakes						
Energy	MJ/d	6·16	71	6·78	213	0·01
Protein	g/d	55·0	71	60·9	213	0·005
Carbohydrate	g/d	175	71	194	213	0·02
Fibre	g/d	13·1	71	15·1	213	0·006
Vitamin C	mg/d	30·8	71	58·5	213	< 0·000001
β-Cryptoxanthin	μg/d	10·3	71	18·7	213	0·0003
β-Carotene	μg/d	745	71	1072	213	0·002
Retinol	μg/d	434	71	627	213	0·003
Riboflavin	mg/d	1·27	71	1·63	213	0·0002
Folate	μg/d	193	71	234	213	0·002
Vitamin B_{12}	μg/d	3·7	71	4·7	213	0·003
Thiamin	mg/d	1·10	71	1·29	213	0·015
Sodium	mg/d	2570	71	2109	213	< 0·000001
Potassium	mg/d	2037	71	2382	213	0·000006
Calcium	mg/d	640	71	744	213	0·0004
Magnesium	mg/d	190	71	215	213	0·002
Iron	mg/d	8·3	71	9·4	213	0·03

EGRAC, erythrocyte glutathione reductase activation coefficient.

* Analysis was confined to free-living participants. These were subdivided into: (1a) those living in the north of England or Scotland; (1b) those living in the remainder of mainland Britain; (2a) those receiving State benefits; (2b) those not receiving State benefits; (3a) those with family income < £6000 per annum; (3b) those with family income > £6000 per annum; (4a) those where head of household's social class was manual; (4b) those where head of household's social class was non-manual. Those who were in category (a) for all of the factors were defined as being in group 1, and those who were in category (b) for all of the factors were defined as being in group 2, for the purpose of this analysis.

† In order to reduce the skewness of data distribution, all variables except intakes of energy, protein and carbohydrate were log-transformed before the analysis, and the mean values in the table are the anti-logs of the log-means. Further adjustment was made, by multivariate regression, for sex, age, self-reported health and current smoking habit, and for all intakes except those of energy, protein and carbohydrate; the means were also adjusted for energy intake.

analyses of the complex questions surrounding supplement use are addressed elsewhere (Bates *et al*. 1998*a*).

Table 6 presents the mean biochemical index values from several earlier British population surveys (Department of Health and Social Security, 1972, 1979; Gregory *et al*. 1990, 1995) and those of the present survey (free-living sample only). The purpose of the comparisons was to identify age-related differences and/or secular trends, although some of the apparent differences between surveys may be attributable to unavoidable differences in assay methodology over time or between laboratories. There appeared to be an age-related trend for haemoglobin, serum ferritin, plasma retinol, carotenoids, tocopherols, vitamin C, serum and erythrocyte folates, serum vitamin B_{12}, and total and HDL-cholesterol. In contrast, the following were almost identical between the age-groups: plasma Ca, Zn, albumin and creatinine concentrations, and EGRAC. These observations suggest that age-specific reference ranges may need to be considered. Comparison between the three surveys of older people suggests that vitamin C and folate status may, on average, be somewhat better than it was in the 1970s, but this conclusion must be considered as tentative, because of the differences in methodology, and of the age and geographical profiles etc., between the three surveys.

In conclusion, the National Diet and Nutrition Survey of people aged 65 years and over has added to the findings of earlier British surveys and studies of older people (Department of Health and Social Security, 1972, 1979; Bates *et al*. 1979, 1980; Rutishauser *et al*. 1979; Department of Health, 1992). People aged 65 years or over living in mainland Britain had micronutrient intakes which were, with the possible exception of four nutrients, generally within the range considered adequate by comparison with the dietary reference values (Department of Health, 1991). These estimates are based on groups of people and reflect average intakes. However, in any group of people there may be individuals who fail to meet their nutrient needs for various reasons, and ill health and disability, including dental inadequacy, are more likely in older people (Steele *et al*. 1998). The biochemical status indices revealed more prevalent inadequacy than the intake estimates, especially for people living in institutions. Some frail elderly people may

Table 6. Comparisons between mean values for nutrient status indices in five British population surveys*

Biochemical status index	Survey				
	Children aged 1·5–4·5 years†	Adults aged 16–64 years‡	People aged 65 years and over:		
			DHSS (1972)	DHSS (1979)§	NDNS (1998)||
Haemoglobin (g/l)	12·2	13·2	14·4	–	13·9
Transferrin saturation (%)	–	–	–	22·1	26·5
Serum ferritin (μg/l)	24	46·8	–	–	98
Plasma calcium (mmol/l)	–	2·29	2·37	2·37	2·35
Plasma zinc (μmol/l)	13·0	–	–	–	14·3
Plasma retinol (μmol/l)	1·02	1·9	–	–	2·20
Plasma β-carotene (μmol/l)	0·603	0·38	–	–	0·364
Plasma α-carotene (μmol/l)	0·102	0·09	–	–	0·074
Plasma β-cryptoxanthin (μmol/l)	0·194	0·21	–	–	0·152
Plasma lutein (μmol/l)	0·229	–	–	–	0·384
Plasma lycopene (μmol/l)	0·523	0·28	–	–	0·290
Plasma α-tocopherol (μmol/l)	18·8	26·2	–	–	37·9
Plasma α-tocopherol : cholesterol (μmol/mmol)	4·4	4·6			6·4
Plasma γ-tocopherol (μmol/l)	1·6	–	–	–	2·4
Plasma 25 hydroxyvitamin D (nmol/l)	68·1	–	–	–	55·5
Plasma vitamin C (μmol/l)	67·6	–	–	29·1	44·4
ETKAC (ratio)	–	–	–	1·13	1·16
EGRAC (ratio)	1·24	–	–	1·26	1·30
Serum folate (nmol/l)	21·1	–	13·8	14·1	16·0
Erythrocyte folate (nmol/l)	914	488	–	373	498
Serum vitamin B_{12} (pmol/l)	636	312	310	237	237
Plasma albumin (g/l)	44·7	44·2	40·3	42·9	42·8
Plasma α_1-antichymotrypsin (g/l)	0·48	–	–	–	0·39
Plasma creatinine (μmol/l)	–	85·9	–	–	87
Plasma cholesterol (mmol/l)	4·28	5·8	–	–	5·95
Plasma HDL-cholesterol (mmol/l)	1·14	1·4	–	–	1·30

DHSS, Department of Health and Social Security; NDNS, National Diet and Nutrition Survey; ETKAC, erythrocyte transketolase activation coefficient; EGRAC, erythrocyte glutathione reductase activation coefficient.
* Where necessary, values in weight units in the original publications have been converted to SI units to permit direct comparison.
† Gregory *et al.* (1995).
‡ Gregory *et al.* (1990).
§ Participants were aged 70 years and over.
|| Finch *et al.* (1998) (free-living only).

have greater nutrient requirements, which accounts for their poorer blood nutrient levels for a given level of nutrient intake than their more healthy counterparts, and which only supplements or special nutrient-dense diets can provide adequately. Of the status indices that were measured, there was a stronger correlation between the vitamin status indices and vitamin intakes, than that between mineral status indices and mineral intakes. In free-living people, vitamin C intake and status were more strongly correlated with socio-economic status differences and the north–south gradient, than other nutrient status indices or nutrient intakes, although several other nutrients also reflected these differences. It will be important to determine whether the well-established socio-economic and geographical gradients in disease risk within the UK are to a significant extent attributable to differences in nutrition, which should be amenable to improvement through intervention. Research should also be directed towards determining whether the changes in status indices in older people are evidence of deficiency, or are the normal physiological effects of tissue and organ ageing. Such observations will help to define the future needs for research on micronutrient status indices (Table 7). The results from this survey should thereby help to define public health policies and the need for public health research in this age group, particularly the need for nutrition education, and possible nutrition interventions, including dietary supplementation.

Table 7. Micronutrients: the research challenges

1. Do micronutrient requirements to achieve protection against tissue deficiency increase with age, and if so, what are the metabolic mechanisms?
2. Do the relationships in adults between micronutrient status and health status change with increasing age?
3. Why is there a poor correlation between some nutrient intakes and their status indices (Table 4)? Does this have an implication for health?
4. To develop better status indices for minerals.
5. To assess the apparent shortfalls for K and Mg between the dietary intake and the respective dietary reference values.
6. To address the significance of the social and geographical inequalities in nutritional status and to develop public health measures as necessary.
7. How best to improve the poor micronutrient status of older people living in institutions.

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