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Nutrient intake and biochemical status of non-institutionalized elderly subjects in Norwich: comparison with younger adults and adolescents from the same general community

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The Department of Health (1992) has recently stated that 'Nutritional reviews concerning elderly people are especially constrained by lack of data', and that much of the emphasis in the nutritional literature has been placed on the study of institutionalized, and often chronically ill, elderly subjects rather than the non-institutionalized elderly who form the majority of this population. The present study presents information on the dietary intake and biochemical status of non-institutionalized elderly subjects (68–73 and 74–90 years) and compares such data with those obtained for adult (20–64 years) and adolescent (13–14 years) populations living within the same community. Nutrient intakes and appropriate biochemical measurements of nutrient status, performed on fasting blood samples, were statistically examined and have been discussed in relation to potential age-related influences. The nutrient intake of elderly subjects was on a par with adolescents of corresponding sex but generally lower than that of adult counterparts. There were several significant differences in biochemical measurements of nutrient status between age groups. In general these did not suggest progressive age-related trends. However, there were significant suggestions of age-related increases in whole-blood glutathione peroxidase (*EC* 1.11.1.9) activity, serum ferritin, plasma cholesterol, LDL and triacylglycerol concentrations and decreases in plasma HDL and ascorbic acid concentrations. The significance of these differences is discussed. An age-related difference (suggestive of a decline) in vitamin C status together with a difference (suggestive of an increase) in glutathione peroxidase activity may indicate an imbalance in the regulation of O_2-derived free-radicals with ageing. These observations are worthy of a further study in the light of current thinking which relates the induction of a number of diseases to oxidative damage.

Nutrient intake: Elderly

As recommended by the Committee on Medical Aspects of Food Policy panel (Department of Health, 1992), the majority of people aged 65 years or more ideally should adopt similar eating and lifestyle patterns to those advised for younger adults. The Dietary and Nutritional Survey of British Adults (Gregory *et al.* 1990) reported on the diet and nutritional status of a nationally representative sample of 16–64-year-olds during 1986/1987, and in doing so also provided a basis for nutrition education and health promotion programmes. From smaller studies of older individuals, performed in the late 1960s and early 1970s, it was concluded that the dietary patterns and food intakes of non-institutionalized, generally healthy elderly were similar to those of younger adults (Department of Health and Social Security, 1972, 1979). Thus, nutritional advice aimed at promoting and maintaining good health in younger individuals was also deemed

appropriate for older subjects. However, this premise may no longer be valid; even if new studies confirm that nutrient intakes remain similar with advancing age, it does not necessarily mean that blood biochemical indices of nutritional status would remain at levels encountered during younger adulthood. As stated in the recent Department of Health report *The Nutrition of Elderly People*, 'Nutritional reviews concerning elderly people are especially constrained by lack of data' (Department of Health, 1992); this is particularly so in the case of elderly people living in their own homes and eating self-selected diets, since much of the emphasis in the nutritional literature has been placed on the study of the dietary intake and biochemical status of institutionalized, and often chronically ill, elderly.

A new diet and nutrition survey of British elderly, commissioned by the Ministry of Agriculture, Fisheries and Food and the Department of Health, is currently in progress collecting both dietary and biochemical information. This will provide more up-to-date information on dietary trends in the elderly and allow comparison not only of current dietary habits but also of biochemical status between younger and older adults. However, for practical reasons, studies of representative samples of the British population involve the recruitment of only a few individuals from any one specific area of the country. Data obtained from national studies need to be complemented by more detailed investigations at a local level, where environment, availability of food items and nutritional or health support programmes are relatively more uniform, and where any age-related differences in dietary habits, nutritional status and nutrient utilization may become more apparent.

The present paper presents information, as judged by a range of biochemical measurements, on the dietary intake and nutritional status of elderly (68+ years), adult (20–64 years) and adolescent (13–14 years) populations living within the same general community, the city of Norwich. Nutrient intakes and biochemical measurements of micronutrient and lipid status have been statistically examined and are discussed in relation to potential age-related influences.

MATERIALS AND METHODS

Subjects

The studies were approved by the Institute of Food Research's Ethics Committee before recruitment of subjects.

Three separate studies investigating dietary intake and the micronutrient and lipid status in elderly, younger adult and adolescent populations were performed in Norwich between 1989 and 1991. There was considerable overlap in the areas of Norwich from which subjects were recruited and the same fieldworkers and dietary/biochemical analysts performed all three studies. This provided an opportunity to identify possible age-related differences in dietary habits and biochemical status of subjects living in the same general community.

Elderly subjects (68–73 years, n 74; 74+ years, n 71). These were randomly selected from the age–sex register of two General Practices in Norwich, after the exclusion of those addresses known to be institutions for the care of the elderly, and were invited by letter to take part in the study. Response rates dropped with increasing age from 67% of those aged under 70 years to 20% of these aged over 85 years. Recruitment took place in two phases, the first consisting of a group aged 68–73 years ('younger elderly') and the second consisting of subjects aged 74 years and over ('older elderly'). Due to the poor response rate of people in the older age groups the second phase was extended, another random selection being made from the GP registers and more invitations sent out. Response rates and the final age–sex distribution compared with Office of Population Censuses and Surveys (OPCS) media estimates for Norwich Health District 1990 are shown elsewhere (Maisey *et al.* 1995). Only one subject received meals-on-wheels. The age, sex, height,

weight, smoking behaviour and percentage of subjects taking prescribed medicines are shown in Table 1. The socio-economic class distribution of subjects is shown in Fig. 1. The subjects were seen initially either in their local GP surgery or at home according to preference. After explanation of the study and the signing of a consent form by the subject, demographic, social and medical information was elicited and anthropometric measurements were made.

Adult subjects (*20–64 years*, n *83*). These were also recruited from the General Practitioners' list of a central Norwich health centre. A random sample of names and addresses of 18–64-year-olds were drawn from the list and these individuals were sent a letter explaining the purpose of the study and inviting them to participate by returning a form in a prepaid envelope. A second letter was sent out to non-responders at 3 weeks. Those people who responded positively (45%) were visited by a field worker who described the study in detail and provided training in dietary recording. The age, sex, height, weight, smoking behaviour and percentage of subjects taking prescribed medicines (excluding oral contraceptives) are shown in Table 1. The socio-economic class distribution of subjects is shown in Fig. 1.

Adolescent subjects (*13–14 years*, n *54*). These were recruited from two local-authority schools with a response rate of 30%. The sex, height and weight of subjects are shown in Table 1. None of the subjects was on prescribed medication during the study period and none admitted to being a habitual smoker. The socio-economic class of subjects was not specifically ascertained at the request of the Ethics Committee, but the majority of their families would probably be assigned to socio-economic classes I–III on the basis of parental occupation and housing conditions in the catchment area.

All subjects. The characteristics of non-responders were not ascertained.

Measurement of dietary intake

Elderly subjects, *68–73 years*. These subjects completed 7 d of weighed record and/or estimated record (household measures). This was usually over consecutive days but, if not, always included each day of the week. Of this age group, 31% directly weighed all their food, 57% used household measures and 12% used a combination of methods. Subjects were visited three times during the period of dietary recording by a fieldworker. Dietary records, scales and types of household measures used were checked, any additional or missing information obtained, records annotated and completed records collected. In addition, in this and the other studies described below each subject was given a telephone number which would put them in contact with someone who could assist with queries on the days when a visit from the fieldworker was not planned. Dietary information from this group of subjects was collected between mid-May and mid-August 1990.

Elderly subjects, *74+ years*. These subjects completed 5 d of weighed record and/or estimated record (household measures), similar to the 'younger' elderly group. Three weekdays and two weekend days of the same week were included. Subjects were visited three or four times over the period of dietary recording. In addition to checks mentioned above, subjects were asked to recall their activities and what they had eaten over the past 24–48 h. Considerably more interviewer prompting and extensive annotation of the weighed records was required for this age group. Also, interview time tended to be longer, as many lived alone and valued the fieldworker as a social caller. Only 7% of this group directly weighed all their food, 90% used household measures and the remaining 3% used a combination of methods. Dietary information from this groups of subjects was collected between November 1990 and June 1991.

Adult subjects. These subjects kept a written weighed record of everything consumed over 7 consecutive days. Where subjects were not able to weigh an item, for example when eating away from home, they were asked to record their intake using household measures,

Table 1. *Description of study populations: age, sex, height, weight, smoking behaviour (Smo), use of prescribed medicines (Med) and period of nutritional assessment*

(Mean values with their standard errors and ranges in parentheses)

	Male					Female					
		Height (m)	Weight (kg)				Height (m)	Weight (kg)			
Group and age	*n*	Mean SE (range)	Mean SE (range)	Smo* (%)	Med† (%)	*n*	Mean SE (range)	Mean SE (range)	Smo* (%)	Med† (%)	Period
Adolescents 13–14 years	19	1·61 0·02 (1·42–1·87)	47·5 2·3 (33·1–68·0)	0	0	35	1·60 0·01 (1·50–1·74)	51·1 1·1 (38·5–62·5)	0	0	Nov–Dec 1989
Adults (total) 20–64 years	41	1·74 0·01 (1·59–1·85)	77·0 1·1 (56·2–100·6)	37	32	42	1·63 0·01 (1·46–1·77)	63·4 2·0 (48·9–100·6)	26	26	May–Nov 1990
Adults (sub-group) 20–39 years	15	1·78 0·02 (1·67–1·85)	75·6 2·2 (65·2–85·6)	47	20	21	1·63 0·02 (1·46–1·77)	60·6 2·4 (48·9–94·7)	29	14	May–Nov 1990
Adults (sub-group) 40–64 years	26	1·72 0·02 (1·59–1·84)	78·1 2·7 (56·2–100·6)	31	38	21	1·63 0·01 (1·54–1·75)	67·1 3·2 (53·9–100·6)	19	38	May–Nov 1990
Younger elderly 68–73 years	32	1·67 0·01 (1·50–1·78)	72·4 2·0 (46·0–92·0)	25	75	42	1·57 0·01 (1·41–1·71)	63·5 1·6 (45·0–84·0)	12	79	May–Aug 1990
Older elderly 74–90 years	28	1·67 0·01 (1·52–1·84)	70·5 2·0 (47·5–92·0)	18	82	43	1·55 0·01 (1·41–1·72)	61·1 1·5 (41·0–82·0)	9	78	Nov 1990/June 1991

* Habitual smokers.

† Prescription medication, excluding oral contraceptives.

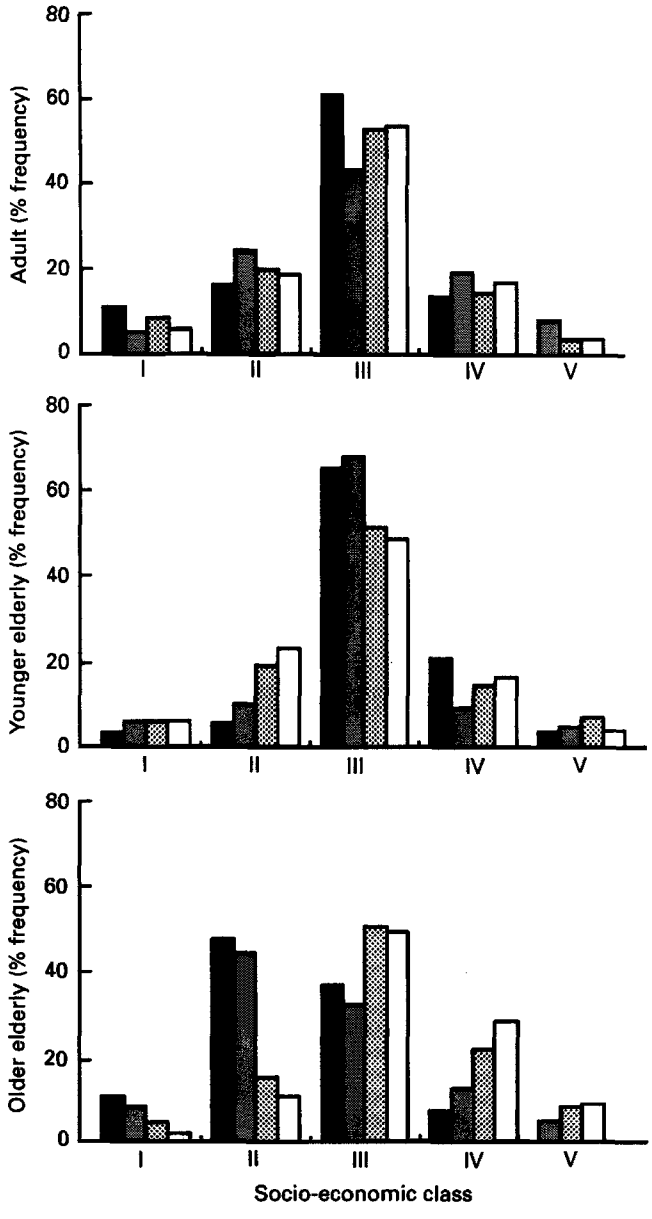

Fig. 1. Socio-economic class distribution of male (■) and female (▩) subjects within each age group in the present study, compared with 1990 data on males (▨) and females (□) from the General Household Survey (Office of Population Censuses and Surveys, 1992). Socio-economic class I, 'Higher Managerial and Professional'; class II, 'Intermediate Managerial and Professional'; class III, 'Supervisory, Clerical, Junior Managerial Administrator or Professional (III N), Skilled Manual Worker (III M)'; class IV, 'Semi-skilled/Unskilled Manual Worker'; class V, 'Casual or Low-Grade Worker'. The majority of families of adolescent subjects would probably be assigned to socio-economic classes I–III.

standard measures or average portion sizes, with the aid of diagrams provided at the back of the diary. An initial home visit by the fieldworker involved a full explanation of the procedure of keeping a weighed diary, and a demonstration of the use of the scales (model no. 2001; Salter Homewares Ltd., Tonbridge, Kent; maximum capacity 2 kg and accurate

to 2 g) and recording information. Thereafter, the subject was visited after 2 d and after completion of the 7th d when diaries were checked, annotated and collected. Dietary information for this group of subjects was collected between May and November 1990.

Adolescent subjects. These subjects kept a written, weighed record of everything consumed every sixth day for 7 weeks in the months of November and December 1989. A full description of the methods used to collect the weighed records of food intake in this study is presented elsewhere (Finglas *et al.* 1993; Southon *et al.* 1994).

Dietary records were coded using *McCance and Widdowson's The Composition of Foods* (Paul & Southgate, 1978), together with *Immigrant Food Supplement* (Tan *et al.* 1985), *Additional Foods* (Wiles *et al.* 1980), *Cereals and Cereal Products* (Holland *et al.* 1988) and *Milk Products and Eggs* (Holland *et al.* 1989). Where household measures were used, weights of the actual measure used were recorded in the subject's own home. Portion weights were obtained using *Food Portion Sizes* (Crawley, 1988) and our own data (J. M. Loughridge and A. D. Walker, Institute of Food Research) collected during these and previous dietary intake studies. Mean daily nutrient intakes were calculated using the Institute of Food Research's food composition database.

All subjects. Subjects were asked to record details of any nutritional supplements consumed.

Blood collection and preparation

Adolescents. Fasting (12 h) venous blood samples were collected during the period of dietary assessment but not on, or immediately following, a day of dietary recording.

Adults. Fasting blood samples were collected within 1–4 weeks of the end of dietary assessment.

Elderly. Fasting blood samples were collected 1–3 weeks before dietary assessment.

All subjects. In cases of subject immobility a phlebotomist and a research worker travelled to the subject's home. Adult and elderly blood samples were taken at a General Practitioners surgery near to the subject's home, and adolescents' blood taken in a medical room at the Institute of Food Research.

Adolescent and adult subjects. Blood was collected by venepuncture and divided as follows: (a) serum was separated from 1·5 ml unheparinized whole blood by centrifugation at 8800 ***g*** for 4 min within 2 h of collection and the serum stored at −40° until analysed for serum ferritin; (b) 1·5 ml fresh (within 1–2 h of collection), whole, heparinized blood was centrifuged at 8800 ***g*** for 4 min, the plasma separated, placed on ice for 10 min and then analysed for ascorbic acid; (c) 100 μl well mixed, heparinized whole blood was taken for haemoglobin (Hb), packed cell volume (PCV), erythrocyte count (RBC), mean cell volume (MCV) and leucocyte count (WBC) determinations, which were performed within 4 h of collection; (d) 100 μl heparinized whole blood was taken for glutathione peroxidase (*EC* 1.11.1.9) assay; (e) blood was centrifuged at 2500 ***g*** for 10 min at 4°, the plasma removed and subsamples taken for measurement of alkaline phosphatase (*EC* 3.1.3.1) activity (200 μl) and measurement of Zn and Cu (2 ml), vitamin B_6 (500 μl), vitamin B_{12} and pteroylglutamate (500 μl), vitamin D (100 μl), cholesterol, HDL, LDL and triacylglycerols (1 ml) concentration. Remaining packed erythrocytes were thoroughly washed with an equal volume of cold (4°), isotonic saline (9 g NaCl/l) and centrifuged at 2500 ***g*** for 10 min at 4°. The washing procedure and centrifugation were repeated once more and resulting packed cells resuspended in isotonic saline. Subsamples (1 ml) were taken for determination of erythrocyte superoxide dismutase (*EC* 1.15.1.1) and glutathione reductase (*EC* 1.6.4.1) activity, and total thiamin concentration. Samples were centrifuged at 8800 ***g*** for 4 min and the supernatant fraction removed. Packed cells were resuspended in about 1 ml distilled water for measurement of erythrocyte glutathione reductase (EGR) activity.

All subsamples, with the exception of that for alkaline phosphatase analysis, were placed immediately on dry ice and stored at −196° (samples for EGR) or −40° (all other samples) until analysed. Plasma used for the determination of alkaline phosphatase activity was placed at 4° and analysed within 4 h of collection.

Elderly subjects. Blood sampling and preparation were similar to that described above except that haematological measurements were performed by the Haematology Department of the Norfolk and Norwich Hospital.

Blood analysis: indices of micronutrient status

Iron. Hb, PCV, RBC, MCV and WBC were measured using a semi-automated Coulter counter (model CBC-5; Coulter Electronics, Luton, Beds) using Coulter's '4C-normal cell control' as quality control (QC). It was noted that 'in-house' Hb values were correlated to, but 8% higher than, Haematology Department Hb values in the elderly groups. The Hb values given for adolescents and adults (see Table 4) are 'values corrected to the Haematology Department Hb analysis' (i.e. values 8% lower than those actually obtained 'in-house') thus enabling an accurate cross-sectional statistical comparison to be made between all four subject age groups.

Serum ferritin was determined using an ELISA procedure (Enzymum-Test Ferritin kit; Boehringer Mannheim Immunodiagnostics, Mannheim, Germany) using QC sera supplied with the ELISA kit.

Zinc and copper. Samples (2 ml) of plasma were deproteinized with 4 ml trichloroacetic acid (50 g/l), centrifuged (600 *g*, 10 min) and the supernatant fraction diluted with distilled water and analysed for Zn and Cu using a Pye Unicam PU 9000 atomic absorption spectrometer (Pye Unicam, Cambridge, Cambs) calibrated with either $Zn(NO_3)_2$ or $Cu(NO_3)_2$ 'Spectrosol®' standard solutions for atomic spectroscopy (BDH Chemicals Ltd., Poole, Dorset). QC was provided by the use of either an in-house plasma pool held under liquid N_2 or Seronorm® (Nycomed Pharma AS, Oslo, Norway).

Plasma alkaline phosphatase activity was determined colorimetrically at 25° using a kit assay (Test-Combination Alkaline Phosphatase kit; Boehringer Mannheim Diagnostica, Mannheim, Germany) and Precinorm® (Boehringer) as QC. Tabulated values can be multiplied by 1·6 to convert to assay units at 37°.

Erythrocyte superoxide dismutase activity was measured using a kit assay (RANSOD; Randox Laboratories Ltd, Crumlin, County Antrim). QC was provided by an in-house washed-erythrocyte pool held under liquid N_2.

Selenium. Whole-blood glutathione peroxidase activity was measured using the modified method of Paglia & Valentine (1967), as described by Whanger *et al.* (1988), with QC provided by an in-house whole-blood pool held under liquid N_2.

Ascorbic acid. Plasma ascorbic acid (PAA) concentration was determined using a HPLC technique. Details of the analysis are presented elsewhere (Finglas *et al.* 1993). QC was provided by an in-house pool of plasma stabilized with metaphosphoric acid and held under liquid N_2.

Cholecalciferol. Plasma 25-hydroxycholecalciferol was measured using a radio-immunoassay (RIA) procedure (25-OH D ^{3}H RIA kit; INCSTAR Corp., Stillwater, MN, USA), QC samples being supplied with each assay kit.

Thiamin. Total erythrocyte thiamin was measured using the method of Bailey & Finglas (1990) with the modifications described by Bailey *et al.* (1994).

Riboflavin. Basal and stimulated (with added coenzyme; flavine adenine dinucleotide) erythrocyte glutathione reductase activity was determined (Powers *et al.* 1983) and used to calculate the activity coefficient (EGRAC). QC was provided by repeat analysis of a batch

of blood samples held under liquid N_2, having a wide span (about 1·0–1·5) of EGRAC values.

Vitamin B_{12}/pteroylglutamate. Plasma vitamin B_{12} and pteroylglutamate were measured using a radioassay kit (Quantaphase B_{12}/Folate radioassay; Bio-Rad Lab. Ltd., Watford, Herts) together with QC of Lyphocheck (levels 1, 2 and 3; Bio-Rad Limited).

Pyridoxine. Plasma pyridoxal-5-phosphate was measured by the method of Naoi *et al.* (1988) with the modifications described by Southon *et al.* 1994. QC was provided by an in-house pool of plasma held under liquid N_2.

Lipids. Plasma cholesterol was analysed using the Boehringer-Mannheim enzymic, colorimetric, 'Cholesterol C-System (CHOD-PAP)'. HDL was assayed using the same cholesterol kit after LDL and VLDL precipitation using Boehringer-Mannheim's 'HDL Cholesterol' solution of phosphotungstic acid and Mg ions. Triacylglycerols were analysed using the Boehringer-Mannheim 'Triglyceride fully enzymatic UV method'. Precinorm-L (Boehringer-Mannheim) was used as a QC for cholesterol, HDL and triacylglycerols. LDL was calculated in mmol/l using the equation:

$$\text{LDL} = \text{total cholesterol} - (\text{TG}/2{\cdot}2) - \text{HDL cholesterol},$$

as described by Friedewald *et al.* (1972).

Statistical treatment of results

Mean values for each measurement tabulated for the adolescent (13–14 years), adult (20–64 years), younger elderly (68–73 years) and older elderly (74–90 years) subject groups were analysed separately for each sex, since it could be reasonably expected that many results (especially average daily nutrient intakes) would be sex-dependent to varying degrees.

Mean values (within each sex stratum) for each of the four subject groups were compared by one-way ANOVA after testing for normality of data distribution and variance homogeneity: data not normally distributed or with heterogeneous variances were mathematically transformed ($\log_{10}$) before statistical analysis. Means were compared using the standard error of the difference of means (SED); $t = (\bar{x}_1 - \bar{x}_2)/\text{SED}$ with residual degrees of freedom, where SED is calculated from the residual mean square (RMS); $\text{SED} = \sqrt{((\text{RMS}(1/n_1 + 1/n_2))}$.

Means with large variance heterogeneity even after $\log_{10}$ transformation were compared using a 'modified t test' designed for use with means having unequal variances (Snedecor & Cochran, 1967). Data for regression analysis were inspected for normality of distribution and, if necessary, $\log_{10}$ transformed.

RESULTS

A description of subjects' height, weight, smoking habits and the proportion of subjects taking regular, prescribed medication is given in Table 1, together with the period of study of each subgroup. The socio-economic class distribution of each subject group is displayed in Fig. 1.

Calculated average daily nutrient intake

Calculated average daily intakes of energy, macronutrients and minerals, and vitamins are given in Tables 2 and 3 respectively. Data were analysed separately for each sex and, hence, all comparisons are within a sex.

The mean energy intake of elderly people was significantly lower than that for adult counterparts. The average daily intakes of most other nutrients were also lower in the elderly with the exception of fibre, Cu, thiamin, riboflavin, vitamin D and biotin, which were similar to the adults. Vitamin C intake for males was also similar in adult and elderly groups, but older elderly females had a significantly lower intake than both the younger elderly and adult females.

Table 2. *Calculated average daily intakes of energy, macronutrients and minerals for male (M) and female (F) adolescent (Adol), adult and elderly study populations**

(Values are means with their standard errors, and ranges in parentheses)

Sex/group	M/Adol	M/Adult	M/Elderly	M/Elderly	F/Adol	F/Adult	F/Elderly	F/Elderly
Age (years)...	13–14	20–64	68–73	74–90	13–14	20–64	68–73	74–90
n...	19	41	32	28	35	42	42	43
Nutrient	Mean SE (range)	Mean SE (range)	Mean SE (range)	Mean SE (range)	Mean SE (range)	Mean SE (range)	Mean SE (range)	Mean SE (range)
Energy (MJ)	$8{\cdot}8^{ab}$ 0·4 (5·8–12·2)	$9{\cdot}9^{a}$ 0·4 (3·2–14·0)	$8{\cdot}6^{b}$ 0·3 (5·2–11·2)	$8{\cdot}5^{b}$ 0·4 (3·5–14·7)	$7{\cdot}2^{xy}$ 0·2 (4·3–11·1)	$7{\cdot}9^{x}$ 0·3 (2·9–14·5)	$6{\cdot}8^{y}$ 0·2 (3·7–9·6)	$6{\cdot}7^{y}$ 0·3 (4·3–10·7)
Protein (g)	67^{a} 3 (48–95)	87^{c} 3 (33–125)	79^{b} 2 (54–106)	77^{ab} 3 (46–136)	54^{x} 2 (33–86)	67^{y} 2 (37–101)	64^{y} 2 (36–90)	62^{y} 2 (36–93)
Fat (g)	82^{a} 4 (53–120)	94^{a} 4 (38–142)	84^{a} 3 (54–122)	84^{a} 5 (40–146)	70^{x} 3 (36–126)	76^{x} 4 (24–149)	67^{x} 3 (29–115)	67^{x} 3 (42–112)
Carbohydrate (g)	294^{a} 15 (185–428)	278^{ab} 12 (78–434)	250^{bc} 11 (114–362)	243^{c} 14 (88–286)	233^{x} 7 (151–319)	231^{x} 10 (87–366)	195^{y} 7 (69–456)	190^{y} 8 (109–328)
Fibre (g)	23^{a} 2 (14–45)	21^{a} 1 (9–37)	21^{a} 2 (10–42)	21^{a} 2 (10–49)	18^{x} 1 (8–28)	20x 1 (6–42)	18^{x} 1 (8–35)	17^{x} 1 (6–29)
Calcium (mg)	899^{a} 60 (130–1315)	1168^{b} 53 (456–1833)	992^{a} 43 (577–1445)	939^{a} 66 (451–1457)	754^{x} 39 (326–1242)	998^{y} 48 (377–1754)	864^{x} 43 (220–1701)	868^{x} 35 (405–1465)
Iron (mg)†	$14{\cdot}9^{a}$ 2·4 (7·5–55·5)	$13{\cdot}2^{a}$ 0·6 (5·4–25·1)	$12{\cdot}2^{a}$ 0·6 (7·2–17·4)	$12{\cdot}5^{a}$ 1·2 (6·7–37)	$9{\cdot}7^{x}$ 0·4 (5·7–16·4)	$13{\cdot}3^{y}$ 1·0 (4·3–30·9)	$11{\cdot}9^{xy}$ 1·1 (6·2–38·1)	$10{\cdot}1^{x}$ 0·7 (5·3–31·6)
Zinc (mg)	$9{\cdot}3^{a}$ 0·6 (6·5–14·5)	$10{\cdot}8^{a}$ 0·4 (3·2–16·2)	$9{\cdot}7^{a}$ 0·4 (5·6–14·7)	$9{\cdot}9^{a}$ 0·6 (4·1–18·1)	$6{\cdot}7^{x}$ 0·4 (1·1–14·1)	$8{\cdot}4^{y}$ 0·4 (3·6–13·7)	$8{\cdot}2^{y}$ 0·3 (4·2–13·7)	$8{\cdot}1^{y}$ 0·4 (3·9–14·1)
Copper (mg)†	$1{\cdot}6^{a}$ 0·1 (1·0–2·5)	$1{\cdot}9^{a}$ 0·1 (0·7–6·7)	$2{\cdot}0^{a}$ 0·3 (1·0–7·3)	$1{\cdot}7^{a}$ 0·1 (0·7–6·7)	$1{\cdot}2^{x}$ 0·1 (0·8–2·2)	$1{\cdot}4^{xy}$ 0·1 (0·6–2·9)	$1{\cdot}6^{y}$ 0·1 (0·7–4·9)	$1{\cdot}3^{x}$ 0·1 (0·5–5·2)

^{a,b,c} Mean values for males, within a row, not sharing a common superscript letter were significantly different, $P < 0{\cdot}05$ (one-way ANOVA).
^{x,y} Mean values for females, within a row, not sharing a common superscript letter were significantly different, $P < 0{\cdot}05$ (one-way ANOVA).
* For details of subjects and procedures, see Table 1 and pp. 454–458.
† Data $\log_{10}$ transformed before ANOVA because of unequal variances.

Table 3. *Calculated average daily intakes of vitamins for male (M) and female (F) adolescent (Adol), adult and elderly study populations**

(Values are means with their standard errors, and ranges in parentheses)

Sex/group	M/Adol	M/Adult	M/Elderly	M/Elderly	F/Adol	F/Adult	F/Elderly	F/Elderly
Age (years)...	13–14	20–64	68–73	74–90	13–14	20–64	68–73	74–90
n...	19	41	32	28	35	42	42	43
Nutrient	Mean SE (range)	Mean SE (range)	Mean SE (range)	Mean SE (range)	Mean SE (range)	Mean SE (range)	Mean SE (range)	Mean SE (range)
Thiamin (mg)	$1{\cdot}5^{a}$ 0·2 (0·8–3·6)	$1{\cdot}3^{a}$ 0·1 (0·5–2·0)	$1{\cdot}3^{a}$ 0·1 (0·7–2·6)	$1{\cdot}4^{a}$ 0·1 (0·8–2·3)	$1{\cdot}1^{x}$ 0·1 (0·6–1·8)	$1{\cdot}2^{x}$ 0·1 (0·4–2·1)	$1{\cdot}2^{x}$ 0·1 (0·6–2·2)	$1{\cdot}1^{x}$ 0·1 (0·5–2·7)
Riboflavin (mg)	$2{\cdot}0^{a}$ 0·2 (0·9–3·7)	$2{\cdot}0^{a}$ 0·1 (0·8–3·5)	$1{\cdot}8^{a}$ 0·1 (1·0–3·6)	$2{\cdot}0^{a}$ 0·2 (0·8–3·8)	$1{\cdot}3^{x}$ 0·1 (0·4–2·7)	$1{\cdot}7^{y}$ 0·1 (0·5–3·1)	$1{\cdot}7^{y}$ 0·1 (0·9–3·1)	$1{\cdot}7^{y}$ 0·1 (0·7–3·3)
Nicotinic acid equivalents (mg)	32^{a} 2 (19–51)	39^{a} 1 (14–55)	20^{a} 1 (9–40)	21^{a} 1 (7–35)	25^{x} 1 (15–44)	31^{z} 1 (14–49)	16^{y} 1 (10–47)	17^{y} 1 (7–36)
Vitamin B_6 (mg)†	$1{\cdot}3^{a}$ 0·1 (0·8–1·9)	$1{\cdot}5^{b}$ 0·06 (0·8–2·4)	$1{\cdot}3^{a}$ 0·1 (0·7–2·0)	$1{\cdot}3^{a}$ 0·1 (0·7–2·1)	$1{\cdot}1^{xy}$ 0·03 (0·7–1·6)	$1{\cdot}3^{x}$ 0·04 (0·5–2·4)	$1{\cdot}2^{x}$ 0·1 (0·6–2·0)	$1{\cdot}0^{y}$ 0·1 (0·5–1·8)
Vitamin C (mg)†	121^{a} 22 (24–428)	66^{b} 5 (16–134)	81^{b} 8 (33–169)	58^{b} 5 (25–136)	75^{x} 7 (19–182)	72^{x} 5 (26–151)	81^{x} 8 (20–246)	52^{y} 5 (14–142)
Vitamin E (mg)†	$5{\cdot}4^{a}$ 0·3 (2·9–8·2)	$5{\cdot}6^{a}$ 0·5 (1·7–20·5)	$5{\cdot}1^{a}$ 0·4 (2·2–11·9)	$4{\cdot}7^{a}$ 0·4 (1·8–12·2)	$4{\cdot}9^{x}$ 0·3 (1·2–9·1)	$5{\cdot}1^{x}$ 0·3 (1·4–12·5)	$4{\cdot}3^{x}$ 0·2 (2·4–8·2)	$3{\cdot}6^{y}$ 0·2 (1·4–7·1)
Vitamin B_{12} (μg)†	$4{\cdot}0^{a}$ 0·7 (1·8–12·5)	$6{\cdot}2^{b}$ 0·7 (2·4–28·7)	$5{\cdot}0^{a}$ 0·8 (1·9–23·3)	$4{\cdot}9^{a}$ 0·6 (2·4–13·1)	$2{\cdot}6^{x}$ 0·3 (0·8–9·5)	$4{\cdot}7^{yz}$ 0·8 (1·2–29·9)	$5{\cdot}9^{z}$ 1·1 (0·9–38·4)	$3{\cdot}9^{y}$ 0·5 (1·0–16·8)
Pteroylglutamic acid (μg)	174^{a} 14 (91–318)	208^{a} 11 (87–443)	175^{a} 11 (79–319)	173^{a} 11 (69–267)	143^{x} 7 (61–278)	175^{y} 9 (65–310)	154^{xy} 8 (92–283)	145^{x} 7 (65–219)
Vitamin D (μg)†	$1{\cdot}6^{a}$ 0·2 (0·7–3·5)	$3{\cdot}0^{b}$ 0·3 (0·8–7·9)	$3{\cdot}6^{b}$ 0·4 (1·0–8·8)	$3{\cdot}4^{b}$ 0·5 (0·4–11·7)	$2{\cdot}1^{x}$ 0·2 (0·2–7·2)	$2{\cdot}9^{x}$ 0·3 (0·4–9·0)	$2{\cdot}7^{x}$ 0·2 (0·1–6·1)	$2{\cdot}9^{x}$ 0·3 (0·8–10·7)
Retinol equivalents (μg)†	952^{a} 172 (306–2882)	1027^{a} 152 (240–5695)	816^{a} 218 (301–3354)	733^{a} 138 (248–11828)	685^{xz} 72 (130–2315)	1026^{xy} 175 (228–6396)	925^{y} 203 (269–7422)	575^{yz} 108 (101–4968)
Biotin (μg)†	17^{a} 1 (2–28)	25^{b} 1 (7–37)	23^{b} 1 (13–39)	24^{b} 2 (10–59)	13^{x} 1 (5–25)	21^{y} 1 (6–41)	20^{y} 1 (9–32)	19^{y} 1 (8–37)

[a,b,c] Mean values for males, within the same row, not sharing a common superscript letter were significantly different, $P < 0{\cdot}05$ (one-way ANOVA).
[x,y,z] Mean values for females, within the same row, not sharing a common superscript letter were significantly different, $P < 0{\cdot}05$ (one-way ANOVA).
* For details of subjects and procedures, see Table 1 and pp. 454–458.
† Data $\log_{10}$ transformed before ANOVA because of unequal variances.

Average daily energy intakes for both younger and older elderly groups were similar to the adolescents. Not surprisingly, the mean intakes of most of the other nutrients listed in Tables 2 and 3 were also similar, with the exception of carbohydrate, vitamin C and nicotinic acid equivalents which were lower in the elderly, and protein, vitamin D, biotin, riboflavin (females only) and vitamin B_{12} (females only) which were higher.

There was a significant trend towards lower absolute carbohydrate intake with increasing age. However, if expressed as a percentage of energy intake, carbohydrate intake was 53% in adolescents and a consistent 46% for adults and elderly. Protein intake, when expressed as a percentage of energy intake, increased with age from 13% for adolescents through to 15% for adults and 17% for elderly subjects. The general pattern was a higher energy and nutrient intake in the adult group compared with elderly and adolescent counterparts.

Biochemical indices of status

Values for biochemical measurements of mineral, vitamin and lipid status are given in Tables 4, 5 and 6 respectively. Once more, comparisons are within a sex.

Erythrocyte superoxide dismutase activities, and erythrocyte thiamin and plasma B_{12} concentrations were similar between age groups. Plasma pyridoxal-5′-phosphate (PLP) concentrations were also generally similar; however, there appeared to be a slight tendency towards a higher mean concentration with age but only in the case of the older elderly males did this reach significance. Using a criterion of $< 34{\cdot}4$ nmol/l as indicative of inadequate B_6 status (Rose *et al.* 1976), 50% (male) and 27% (female) of the adolescents, 59% (male) and 49% (female) of adults, 50% (male) and 60% (female) of the younger elderly, 25% (male) and 28% (female) of the older elderly could be classified as deficient. Adult and elderly mean plasma pteroylglutamate and Zn concentrations were similar, but lower than those of adolescents. Adult and elderly EGRAC (an indicator of riboflavin status) values were also similar, but higher (indicative of lower status) than those of adolescents. Using a cut-off value for EGRAC of $> 1{\cdot}4$ to indicate deficient riboflavin status (Gibson, 1990), 15% (male) and 11% (female) of the adolescents, 18% (male) and 30% (female) of adults, 28% (male) and 14% (female) of the younger elderly, 39% (male) and 32% (female) of the older elderly could be classified as deficient. Plasma 25-hydroxycholecalciferol concentrations were significantly higher in the adult and elderly groups, with the exception of the older elderly females, compared with adolescents, whilst mean alkaline phosphatase activity showed the expected decrease in adults compared with younger and older subjects.

The most noticeable, potentially age-related trends in the biochemical measurements undertaken related to serum ferritin, plasma Cu, plasma ascorbic acid and plasma cholesterol concentrations, and whole-blood glutathione peroxidase activity.

Mean serum ferritin concentration increased from 24 μl/l in adolescent males to 75 and 154 μg/l in the adult and older elderly males respectively. The mean concentration for younger elderly males was not significantly different from adults. In the females the ferritin concentration increased from a mean of 21 μg/l in adolescent girls to 36, 71 and 69 μg/l in adult, younger elderly and older elderly females respectively. Approximately 11 and 29% of adolescent males and females respectively had no body Fe stores (Fe deficient) on the basis of ferritin concentrations of < 12 μg/l (Cook *et al.* 1992), with an additional 37 and 41% respectively having poor Fe stores (12–24 μg ferritin/l). In the adult group none of the males and 20% of the females had a ferritin concentration < 12 μg/l, with an additional 3% of males and 34% of females having values between 12 and 24 μg/l. The incidence of subjects with either no Fe stores or poor Fe stores was slightly higher in the younger elderly males compared with adult counterparts (6% < 12 μg/l; 22% 12–24 μg/l) but in younger elderly females and the older elderly groups there was a further decrease in the incidence of poor ferritin values. There was also a potential trend for increased Hb concentration with age; mean values increased from the adolescent group through to the

Table 4. *Selected biochemical indices of mineral status for male (M) and female (F) adolescent (Adol), adult and elderly study populations**

(Values are means with their standard errors, and ranges in parentheses)

Sex/group	M/Adol	M/Adult	M/Elderly	M/Elderly	F/Adol	F/Adult	F/Elderly	F/Elderly
Age (years)...	13–14	20–64	68–73	74–90	13–14	20–64	68–73	74–90
n...	19	41	32	28	35	42	42	43
Index	Mean SE (range)	Mean SE (range)	Mean SE (range)	Mean SE (range)	Mean SE (range)	Mean SE (range)	Mean SE (range)	Mean SE (range)
Haemoglobin (Hb) (g/l)†	129^{a} 2 (117–138)	140^{b} 1 (128–148)	144^{b} 2 (127–159)	143^{b} 2 (101–160)	128^{x} 1 (123–138)	130^{xy} 2 (119–143)	134^{y} 1 (116–154)	134^{y} 1 (113–157)
Packed cell volume (%)†	$40{\cdot}8^{a}$ 0·6 (35·2–44·3)	$48{\cdot}1^{b}$ 0·5 (41·2–52·5)	$42{\cdot}6^{a}$ 0·5 (37·0–46·6)	$42{\cdot}7^{a}$ 0·6 (31·9–47·7)	$40{\cdot}2^{x}$ 0·3 (37·2–44·7)	$43{\cdot}1^{y}$ 0·5 (38·3–49·6)	$39{\cdot}6^{x}$ 0·4 (35·4–46·6)	$40{\cdot}1^{x}$ 0·4 (34·2–46·8)
Mean cell volume (fl)†	83^{a} 0·8 (77–90)	90^{b} 0·6 (84–98)	90^{b} 1·0 (76–100)	90^{b} 0·9 (76–100)	84^{x} 0·5 (77–90)	91^{y} 0·7 (76–101)	89^{y} 0·5 (82–96)	90^{y} 0·7 (81–103)
Serum ferritin (μg/l)†	24^{a} 2 (8–40)	75^{b} 9 (22–276)	65^{b} 9 (9–186)	154^{c} 21 (26–480)	21^{x} 2 (2–56)	36^{y} 6 (6–170)	71^{z} 9 (7–250)	69^{z} 7 (13–260)
Plasma zinc (μmol/l)†	17^{a} 0·6 (14–24)	15^{b} 0·3 (11–19)	15^{b} 0·4 (10–19)	15^{b} 0·3 (12–18)	18^{x} 0·5 (12–26)	15^{z} 0·3 (10–19)	15^{z} 0·3 (12–23)	16^{y} 0·6 (12–37)
Plasma copper (μmol/l)†	13^{a} 0·7 (9–18)	15^{b} 0·4 (12–19)	20^{c} 0·4 (15–36)	18^{d} 0·7 (14–27)	12^{x} 0·5 (8–20)	19^{y} 0·8 (13–35)	22^{z} 0·5 (16–30)	22^{z} 0·8 (14–49)
Plasma alkaline phosphatase (*EC* 3.1.3.1; U/l) at 25°†	75^{a} 7 (43–146)	20^{e} 2 (12–69)	58^{b} 3 (31–106)	51^{b} 3 (24–102)	43^{x} 3 (15–97)	17^{y} 1 (8–33)	57^{z} 2 (33–101)	59^{z} 3 (31–123)
Erythrocyte superoxide dismutase (*EC* 1.15.1.1; U/g Hb)†	861^{a} 31 (673–1132)	981^{a} 49 (427–1715)	895^{a} 35 (536–1452)	920^{a} 37 (493–1251)	847^{x} 24 (608–1313)	908^{x} 41 (548–1354)	894^{x} 45 (480–1378)	889^{x} 28 (511–1282)
Whole-blood glutathione peroxidase (*EC* 1.11.1.9; U/mg Hb)†	89^{a} 5 (56–126)	101^{a} 5 (38–181)	102^{a} 4 (64–133)	119^{b} 3 (93–157)	89^{x} 5 (57–118)	100^{xy} 4 (49–181)	104^{y} 3 (57–147)	114^{z} 3 (58–161)

^{a,b,c} Mean values for males, within the same row, not sharing a common superscript letter were significantly different, $P < 0{\cdot}05$ (one-way ANOVA).
^{x,y,z} Mean values for females, within the same row, not sharing a common superscript letter were significantly different, $P < 0{\cdot}05$ (one-way ANOVA).
* For details of subjects and procedures, see Table 1 and pp. 454–459.
† Data $\log_{10}$ transformed before ANOVA because of unequal variances.

Table 5. *Selected biochemical indices of vitamin status for male (M) and female (F) adolescent (Adol), adult and elderly study populations**

(Values are means with their standard errors, and ranges in parentheses)

Sex/group	M/Adol	M/Adult	M/Elderly	M/Elderly	F/Adol	F/Adult	F/Elderly	F/Elderly
Age (years)...	13–14	20–64	68–73	74–90	13–14	20–64	68–73	74–90
n...	19	41	32	28	35	42	42	43
Index	Mean SE (range)	Mean SE (range)	Mean SE (range)	Mean SE (range)	Mean SE (range)	Mean SE (range)	Mean SE (range)	Mean SE (range)
Plasma ascorbic acid (μmol/l)†	81^{a} 9 (39–207)	49^{b} 4 (1–126)	33^{c} 4 (4–83)	43^{bc} 4 (10–80)	77^{x} 4 (37–143)	62^{y} 5 (3–110)	48^{z} 4 (9–93)	46^{z} 4 (6–90)
Plasma pyridoxal-5′-phosphate (nmol/l)†	38^{a} 3 (24–78)	40^{a} 3 (16–85)	40^{a} 5 (14–165)	64^{b} 8 (25–128)	47^{x} 3 (25–106)	45^{x} 4 (15–126)	47^{x} 8 (15–269)	55^{x} 5 (21–133)
Plasma 25-hydroxycholecalciferol (nmol/l)†	65^{a} 5 (35–107)	131^{bc} 22 (14–484)	180^{c} 17 (26–355)	105^{b} 12 (14–314)	71^{x} 5 (26–120)	149^{y} 17 (18–362)	171^{y} 14 (40–303)	69^{x} 7 (18–242)
Plasma B_{12} (pmol/l)	329^{a} 26 (178–592)	332^{a} 22 (142–645)	414^{a} 32 (192–777)	359^{a} 29 (130–761)	359^{x} 22 (152–681)	368^{x} 30 (132–787)	431^{x} 27 (244–1073)	420^{x} 24 (122–847)
Plasma pteroylglutamate (nmol/l)‡	26^{a} 2 (16–47)	13^{b} 1 (4–20)	16^{b} 1 (6–31)	16^{b} 2 (4–31)	21^{x} 1 (10–33)	15^{y} 1 (5–27)	18^{y} 2 (7–64)	19^{xy} 2 (4–62)
Erythrocyte thiamin (nmol/l)‡	206^{a} 18 (120–446)	212^{a} 9 (92–324)	204^{a} 8 (125–289)	239^{a} 19 (124–652)	227^{x} 24 (101–950)	344^{x} 78 (137–2366)	241^{x} 11 (94–488)	252^{x} 12 (55–579)
EGRAC‡	$1{\cdot}24^{a}$ 0·06 (1·00–1·78)	$1{\cdot}29^{b}$ 0·02 (1·08–1·54)	$1{\cdot}30^{b}$ 0·03 (1·05–1·69)	$1{\cdot}37^{b}$ 0·03 (1·07–1·80)	$1{\cdot}18^{x}$ 0·02 (1·00–1·52)	$1{\cdot}34^{z}$ 0·02 (1·03–1·67)	$1{\cdot}29^{y}$ 0·02 (1·00–1·52)	$1{\cdot}35^{z}$ 0·02 (1·14–1·69)

[a, b, c] Mean values for males, within the same row, not sharing a common superscript letter were significantly different, $P < 0{\cdot}05$ (one-way ANOVA).
[x, y, z] Mean values for females, within the same row, not sharing a common superscript letter were significantly different, $P < 0{\cdot}05$ (one-way ANOVA).
* For details of subjects and procedures, see Table 1 and pp. 454–460.
† Data $\log_{10}$ transformed before ANOVA because of unequal variances.
‡ Means with large variance heterogeneity after $\log_{10}$ transformation were compared with a statistical programme designed for means with unequal variance.

Table 6. *Lipid status of male (M) and female (F) adolescent (Adol), adult and elderly study populations**

(Mean values with their standard errors, and ranges in parentheses)

Sex/group	M/Adol	M/Adult	M/Elderly	M/Elderly	F/Adol	F/Adult	F/Elderly	F/Elderly
Age (years)...	13–14	20–64	68–73	74–90	13–14	20–64	68–73	74–90
n...	19	41	32	28	35	41	42	43
Index	Mean SE (range)	Mean SE (range)	Mean SE (range)	Mean SE (range)	Mean SE (range)	Mean SE (range)	Mean SE (range)	Mean SE (range)
Plasma cholesterol (mmol/l)†	4·46[a] 0·16 (3·38–5·68)	5·54[b] 0·20 (3·37–8·45)	5·81[b] 0·15 (3·72–7·55)	5·73[b] 0·20 (4·07–8·07)	4·15[x] 0·11 (2·78–5·58)	5·37[y] 0·20 (2·94–8·66)	6·63[z] 0·17 (4·37–10·56)	6·38[z] 0·22 (3·98–10·65)
Plasma triacylglycerols (mmol/l)†	0·66[a] 0·046 (0·35–0·93)	0·85[b] 0·07 (0·28–2·13)	0·85[b] 0·067 (0·09–1·66)	1·01[b] 0·079 (0·33–2·01)	0·68[x] 0·045 (0·34–1·62)	0·61[x] 0·05 (0·14–1·50)	0·98[y] 0·063 (0·46–2·06)	1·18[y] 0·081 (0·52–2·87)
Plasma HDL (mmol/l)†	1·62[a] 0·100 (1·06–2·77)	1·08[b] 0·05 (0·57–1·89)	1·10[b] 0·047 (0·69–1·79)	1·20[b] 0·070 (0·73–2·20)	1·59[x] 0·068 (0·99–3·35)	1·54[xy] 0·08 (0·89–3·33)	1·36[y] 0·054 (0·86–2·30)	1·35[y] 0·056 (0·74–2·29)
Plasma LDL (mmol/l)†	2·54[a] 0·171 (0·97–3·64)	4·06[b] 0·20 (1·82–6·90)	4·31[b] 0·153 (2·24–5·56)	4·07[b] 0·193 (2·42–6·11)	2·20[x] 0·107 (1·01–3·47)	3·55[y] 0·21 (0·93–6·64)	4·83[z] 0·157 (2·66–8·46)	4·49[z] 0·216 (1·97–8·91)
Chol:HDL ratio†	2·90[a] 0·172 (1·41–4·34)	5·54[b] 0·35 (2·45–10·64)	5·59[b] 0·336 (2·96–9·62)	5·17[b] 0·335 (2·52–9·64)	2·73[x] 0·127 (1·67–5·26)	3·73[y] 0·21 (1·33–6·50)	5·15[z] 0·235 (3·08–10·08)	5·12[z] 0·271 (2·25–8·70)

[a,b,c] Mean values for males, within a row, not sharing a common superscript letter were significantly different, $P < 0·05$ (one-way ANOVA).

[x,y,z] Mean values for females, within a row, not sharing a common superscript letter were significantly different, $P < 0·05$ (one-way ANOVA).

* For details of subjects and procedures, see Table 1 and pp. 454–460.

† Data $\log_{10}$ transformed before ANOVA because of unequal variances.

elderly groups by approximately 6–15 g/l, but the difference between adults and elderly did not reach significance. Only one male adolescent, one female adult, one female younger elderly and two male older elderly subjects could be classified as anaemic on the basis of Hb values < 110 (female) or 120 (male) g/l.

Mean plasma Cu concentration increased from 12–13 μmol/l in adolescents to approximately 20 μmol/l in the elderly, the concentration in the elderly being significantly higher than values for both adolescent and adult groups.

Whole-blood glutathione peroxidase activity per unit Hb also showed a steady rise with age group, suggesting a rise with age from 89 U/mg Hb in adolescents to 119 and 114 U/mg Hb in older elderly males and females respectively.

On the other hand, PAA concentration decreased with age of group from approximately 80 μmol/l in adolescents to 49–62 μmol/l in adults and 33–48 μmol/l in elderly groups. Using the cut-off value for PAA of < 20 μmol/l (Gibson, 1990), none of the adolescents, 9% (male) and 3% (female) of adults, 25% (male) and 14% (female) of younger elderly, and 29% (male) and 28% (female) of older elderly could be classified as having a 'low' vitamin C status. Within all male groups there was a significant correlation between the calculated ($\log_{10}$ normalized) daily vitamin C intake and PAA (r 0·63, $P < 0·005$; r 0·45, $P < 0·001$; r 0·63, $P < 0·001$; and r 0·63, $P < 0·001$ for adolescents, adults, younger elderly and older elderly respectively). Intake and PAA were also significantly correlated in adult and older elderly females (r 0·52, $P < 0·001$; and r 0·58, $P < 0·001$ respectively) but not adolescent and younger elderly females (r 0·18, $P = 0·315$; and r 0·22, $P = 0·17$ respectively). There was no significant relationship between intake and subject age within either sex stratum. However, PAA was potentially related to age (PAA = 70·3 − 0·476 age, r 0·40, $P < 0·001$ for males; PAA = 74·6 − 0·391 age, r 0·38, $P < 0·001$ for females). An overall expression of the combined effect of both intake and age on PAA was calculated for both males and females, male PAA = −37·6 + 56·5 $\log_{10}$ mean vitamin C intake − 0·357 age in years, r 0·62, $P < 0·001$; female PAA = 5·8 + 37·7 $\log_{10}$ mean vitamin C intake − 0·348 age in years, r 0·52, $P < 0·001$.

The adolescent group had the lowest plasma cholesterol, triacylglycerol and LDL concentrations, and highest HDL concentration, compared with adult and elderly groups. Values for adult, younger elderly and older elderly males were not significantly different. However, the elderly female group had significantly higher concentrations of cholesterol, triacylglycerols and LDL, and a lower mean HDL concentration, compared with both adult and adolescent female groups.

DISCUSSION

The proportion of the UK population surviving into old age is increasing steadily. The elderly population, that is anyone aged 65 years or over, now represents nearly 20% of the total population and is expected to continue increasing, at least over the next 20 years (Department of Health, 1992). It is likely that the population in the age range 60–64 years will increase by 40%, those of 85+ years by more than 50%, and by the year 2020 it is predicted that at least one in four of the adult population will be aged 65 years or more (Samuels, 1989). This has profound implications for the National Health Service since the elderly population utilize a disproportionate amount of health-care services.

It is well recognized that with advancing age there is a higher incidence of chronic disease and many of the diseases and conditions to which elderly people are prone will have a nutritional component, either as a possible cause or as a result of the presence of the condition (Havlik, 1992). The general consensus at present is that the 'healthy' elderly probably differ little in relation to nutrient requirements from other healthy adults in the population (Bidlack, 1990). However, data are limited regarding the nutritional needs of

the elderly and the effects of ageing on nutrient requirements in both healthy and chronically ill individuals.

The elderly population is extremely diverse in relation to age span, lifestyle and health status (Clayton, 1992) and much of the emphasis in the nutritional literature has been placed on study of the dietary intake and biochemical status of institutionalized, and often chronically ill, elderly. It is obviously important to determine the role of nutrition in supporting chronically ill subjects (Department of Health, 1992); however, non-institutionalized elderly, living unsupported in their own homes and eating self-selected diets, constitute the majority of 65+-year-olds. The present paper is, therefore, concerned with this relatively understudied group and how they compare with adults (20–64 years) and adolescents (13–14 years) living within the same stable community. Data for the elderly subjects were divided into young (68–73 years) and older (74–90 years) elderly.

The socio-economic class distribution of adult subjects who took part in the studies closely matched the Office of Population Censuses and Surveys' (OPCS 1992) General Household Survey 1990 (Fig. 1). The class distribution of the younger elderly also matched OPCS figures, except for a slight over-representation of group III at the expense of group II. Quite clearly, from the comparison with the OPCS (1992) distribution in Fig. 1, there was a shift in the class distribution of the older elderly subjects towards a significant over-representation of class II at the expense of classes III, IV and V. The socio-economic status of adolescent subjects was not ascertained specifically but, as with adult and elderly groups, most subjects could probably be assigned to classes I to III on the basis of parental occupation. The three study groups were therefore comparable to national statistics in terms of their socio-economic background.

None of the adolescents admitted to being a habitual smoker. Smoking was most prevalent in adults aged 20–39 years with a decrease in the proportion of both male and female smokers with increasing age. Conversely, the use of prescribed medication increased with age with four out of every five of the elderly subjects taking regular medication. It is well known that drugs can influence nutrient absorption, metabolism and excretion. However, the frequency of adverse effects arising from nutrient and medication incompatibilities in the elderly has not been well documented (Smith, 1990) and such interactions have not been taken into account in the present study.

Dietary intake

Estimates of food intake for each group were obtained on either 5 d (older elderly) or 7 d (adolescents, adults and younger elderly) weighed records/estimated records (household measures). Adolescents recorded and weighed food intake for a total of 7 d, every sixth day for 7 weeks. This procedure was chosen to overcome possible recording fatigue since subjects also collected duplicate portions of all foods and beverages consumed on the days of dietary recording. Details of this study are presented elsewhere (Southon *et al.* 1994). Adult subjects also weighed foods consumed over a 7 d period but in this instance consecutive days were recorded. By and large the younger elderly subjects recorded their diet in a similar manner to the adults, but in some cases circumstances dictated that amounts eaten had to be recorded in terms of household measures or portion sizes. In general, with advancing age there was increased disability and more interviewer involvement was required to collect useful dietary information, hence the recording period was limited to 5 d with the older elderly subjects. However, in all studies, both weekend days and at least 3 weekdays were included in the dietary record.

A further consideration in relation to comparison of nutrient intakes between the study groups is the time at which data were collected. As outlined on pp. 455–458, a considerable amount of time was spent by fieldworkers with each subject to ensure the quality of

information obtained. Thus, dietary interviews for the four age groups were spread over a 20 month period. Although there was overlap in periods of data collection, all of the information for adolescents, and some of that for the older elderly, was collected during the winter period, the remaining data for the older elderly were collected during the spring, and data for adults and younger elderly were collected in the spring and summer.

Few seasonal effects have been demonstrated for nutrient intakes. In industrial societies seasonal variations in food supply are minimized and seasonal fluctuations in nutrient intake are very small compared with those observed for daily intakes (Bingham, 1987; Gibson, 1990). Seasonal variation in vitamin C intake might be one possible exception and the slightly lower intake of this vitamin in the older elderly men could be associated with the season in which data for this group were collected. On the other hand, vitamin C intake in older elderly females was not significantly different from younger elderly and adult counterparts indicating that any seasonal effect was minimal. In any event, measurement of habitual dietary intake is a notoriously difficult procedure and the most we could hope for when comparing the data obtained in the present study was some gross indication of possible differences in dietary habits between the study groups.

Energy intake was higher in the adults compared with other groups, with the elderly having a similar average daily energy intake to the adolescents. The mean dietary energy intakes of adult and elderly men (9·9 and 8·6 MJ/d respectively) and women (7·9 and 6·8 MJ/d respectively) in the present study were similar to values reported in other larger studies (10·3 and 9·0 MJ/d for adult and elderly men respectively, and 7·0 and 6·8 MJ/d for adult and elderly women respectively; Department of Health, 1992).

In order to assess whether reported energy intakes (EI) were sufficient to maintain body weights, estimates of BMR (BMR_{est}) were derived from Schofield's equations, which utilize sex- and age-dependent multiplication factors of weight and height measurements (Schofield, 1985; Food and Agriculture Organization/World Health Organization/United Nations University, 1985), and EI:BMR_{est} ratios for each age–sex group were calculated. Goldberg *et al.* (1991) have published tables, adjusted for sample size and study duration, indicating what they consider to be minimum EI:BMR_{est} ratios compatible with reported EI being plausible measures of actual dietary intakes during measurement periods. A comparison of ratios calculated for our subject groups was made with these minimum expected ratios; EI:BMR_{est} ratios calculated for our male adolescent, adult, younger elderly and older elderly groups were 1·40 (98% of cut-off ratio of 1·43), 1·36 (93% of cut-off ratio 1·47), 1·42 (97% of cut-off ratio 1·46) and 1·42 (98% of cut-off ratio 1·45) respectively. EI:BMR_{est} ratios calculated for our female adolescent, adult, younger elderly and older elderly groups were 1·26 (89% of cut-off ratio of 1·41), 1·39 (97% of cut-off ratio 1·43), 1·31 (92% of cut-off ratio 1·43) and 1·32 (93% of cut-off ratio 1·42) respectively.

All dietary assessment methods ultimately depend on the full cooperation of the subjects and our calculated EI:BMR_{est} ratios, lower for women than for men, do imply dietary under-reporting. However, this is not unusual, being in common with 64% of the studies employing weighed records studied by Black *et al.* (1991), and does not compromise our comparisons because EI:BMR_{est} ratios were consistent enough, within each sex stratum, to justify reporting dietary comparisons.

Not surprisingly, the average daily intake of most macro- and micronutrients followed the same trend as energy intake. Bearing in mind the likely errors associated with dietary assessment (Bingham, 1987) and the calculation of nutrient intake using tables of food composition (Southon *et al.* 1992), it would appear that, on average, the diet of the elderly and other study groups was adequate in comparison with current recommendations (Department of Health, 1991). Mean fat intake was higher (34–37% total energy) than the recommended maximum of 33% total energy but the intake of most other nutrients

comfortably exceeded the estimated average requirement (EAR), and often the reference nutrient intake (RNI). Average daily pteroylglutamate intake in the adolescent and older elderly females fell below the recommended EAR of 150 μg/d. However, values for pteroylglutamate intake, calculated using *McCance and Widdowson's The Composition of Foods*, 4th edition (Paul & Southgate, 1978) need to be interpreted with care. Some foods have been assigned 'zero' pteroylglutamate values when they should have been more accurately assigned 'missing data' or 'unanalysed' codings. When added to various historical problems of pteroylglutamate analysis, pteroylglutamate intake calculated from Paul & Southgate (1978) may underestimate actual intake by as much as 50% (Southon *et al.* 1992). The nutrient intake data for the adolescent group are discussed in detail elsewhere (Southon *et al.* 1992, 1993, 1994).

Biochemical indices of status

Apart from the many problems, both random and systematic (Bingham, 1987; Nelson *et al.* 1989; Borrelli, 1990), relating to the estimation of habitual dietary intake, including potential discrepancies between calculated nutrient intakes from weighed records and analysed duplicate portions (Southon *et al.* 1992), there is also the questionable usefulness of using such data for the assessment of biochemical status, and hence nutritional adequacy, particularly in situations where especially low nutrient intakes are not encountered, and this has been discussed at length elsewhere (Southon *et al.* 1994). In the present studies a range of biochemical measurements were also performed in addition to dietary assessment. Relationships between calculated dietary intake of nutrients and appropriate biochemical indices of status have been examined for each of the study groups. Where there is no mention of any such relationship in the following discussion it should be assumed that there was no consistent significant relationship within the range of intakes measured.

Serum ferritin concentration (an index of body Fe stores) increased, and the incidence of Fe deficiency decreased, with age group. It should be noted, however, that the estimation of Fe status in older adults is confounded by the increased possibility of inflammatory disease with concomitant elevation of circulating ferritin. Nevertheless, the progressive increase in serum ferritin in females is also undoubtedly linked to the cessation of blood loss post-menopause (Mertz, 1992). We found no relationship, within older adults, between serum ferritin and other potential 'acute-phase indicators' such as plasma Zn (depressed in inflammatory states) and plasma Cu (raised in inflammatory states), nor between any of these 'acute-phase indicators' and any age-associated differences that we have found (i.e. plasma vitamin C and glutathione peroxidase).

The mean plasma Zn concentrations of both male and female adolescent groups were significantly higher than those of the other groups. A peak in serum Zn concentration in adolescence and early adulthood has been documented previously (Pilch & Senti, 1984). However, in the present study no further decline in Zn concentration was observed with increasing age of group as has been found in some other studies (Gibson, 1990). Conversely, plasma Cu concentration increased progressively with age group, reaching a plateau in the younger elderly group and, as in other studies, adult females tended to have higher levels than males. Again this potential age–sex effect is well documented (Gibson, 1990). These differences probably have little significance since most individuals had plasma concentrations of both Zn and Cu well in excess of suggested cut-off levels for deficiency.

The activities of several enzymes were also measured in addition to plasma mineral concentration. Plasma (Zn-) alkaline phosphatase activities were generally within the normal range and showed the expected fall in adult compared with adolescent and elderly groups (Lentner, 1984*b*). Activity of the bone enzyme tends to peak in adolescents between

10 and 12 years in girls, and 12 and 15 years in boys (Lentner, 1984*b*), which was reflected in the significantly higher value obtained for the 13-year-old boys in the present study compared with their female counterparts. There was no evidence from this study to support the view that significantly higher alkaline phosphatase activity occurs in females than males (Gibson, 1990), and no evidence that alkaline phosphatase activity was associated with variation in Zn intake, or vitamin D status, within the ranges measured.

Differences in plasma Cu concentration were not reflected in the activity of the Cu-dependent enzyme superoxide dismutase (SOD). Mean SOD activity was similar, within a sex, across age groups and tended to be lower in females than males, although not significantly so. Whole blood (Se-) glutathione peroxidase (GSH-Px) activity suggested that there was no evidence of Se deficiency in the study groups. Blood GSH-Px activity is only related to blood Se concentrations when these are low, GSH-Px activities above 40 U/mg Hb (by the assay method used in the present paper) indicating Se sufficiency (Whanger *et al.* 1988). It was noticeable, however, that in both sexes whole-blood GSH-Px activity significantly increased with the age of the group, suggesting an age effect. At the level of GSH-Px activity observed (> 40 U/mg Hb), these differences between groups would not have resulted from differences in Se intake. The activity of this enzyme can only be used to assess Se status in persons living in countries where dietary intakes are habitually low (Gibson, 1990; Department of Health, 1991). Both SOD and GSH-Px contribute to the antioxidant defence system and, if the free-radical theory of ageing is correct, it might be expected that longevity would be associated with higher activity of such enzymes. However, SOD activity did not increase with age of subject, and although there is an excellent positive correlation between SOD activity and maximum life span in primate and rodent species, this is not true for GSH-Px (Halliwell & Gutteridge, 1989). This increase in GSH-Px activity with advancing age is in accord with the observation of Ceballos-Picot *et al.* 1992*c*) but this response and its biological significance still requires more detailed consideration. One possible theory is that increased Se-GSH-Px activity may occur in response to increased production of H_2O_2. This is observed in animals with high expression of Cu-Zn-SOD which leads to excessive production of H_2O_2 (Ceballos-Picot *et al.* 1992*b*). Since modifications of Cu-Zn-SOD and GSH-Px appear to be independent (Ceballos-Picot *et al.* 1992*a*), the fact that we did not see any difference in SOD activity in the elderly groups does not exclude the possibility that increased Se-GSH-Px may be an indicator of imbalance in the regulation of O_2-derived free radicals with ageing.

There were also significant group differences, suggestive of age-related trends, in PAA concentration, with lower values and an increasing incidence of marginal deficiency being associated with the elderly groups. In the females PAA concentration decreased from a mean value of 77 μmol/l in adolescents to 62 μmol/l in adults, 48 μmol/l in younger elderly and 46 μmol/l in the older elderly, although vitamin C intake was not significantly related to female age groups. Male PAA also decreased significantly with increasing age group though vitamin C intake, like that of females, was statistically unrelated to age group. Both male and female PAA were positively correlated with mean vitamin C intake, but the results indicated that age was also potentially a significant independent (negative) factor. The negative effect of age in both sexes raises the possibility of higher vitamin C requirements with increasing age. At present the RNI (40 mg/d) is the same for all groups above 15 years of age. Vitamin C is an important water-soluble antioxidant which has been proposed to be effective against free-radical-mediated damage to tissues, a process implicated in the ageing process, and several specific disease processes common in later life (Department of Health, 1992; Davies *et al.* 1991). A knowledge of vitamin C metabolism and the consequences of chronic marginal vitamin deficiency in elderly people is therefore deemed to be an important research area (Department of Health, 1992); this is especially

so if the results of the present study indicating a potential decline in vitamin C status with age, independent of intake, is confirmed in future work.

There was very little evidence for progressive age-related changes in the other biochemical measurements undertaken. Mean values for plasma PLP concentration increased slightly with age group but this was significant for males only, and goes against the findings of other workers who report declining values with age in both males and females (Rose *et al.* 1976; Lentner, 1984*a*). The seemingly high incidence of inadequate B_6 status in all age groups may be, to some degree, an artifact of arbitrarily placed cut-off points (Rose *et al.* 1976). However, PLP levels are now known to be affected by protein intake and physical exercise (Leklem, 1990) and such factors may need to be taken into consideration when attempting to assess vitamin B_6 status.

Plasma pteroylglutamate levels were similar in adult, younger elderly and older elderly groups. There were very few individuals with low plasma pteroylglutamate levels and no evidence of an increase in poorer status between adulthood and old age. The significantly higher mean plasma pteroylglutamate concentration in both adolescent males and females was not associated with a higher average daily intake of the vitamin. A similar pattern was observed with regard to riboflavin status, with adolescents having the lowest values for EGRAC (i.e. better status) but in this instance there was some evidence for an increase in the incidence of 'low' status with advancing age. In other studies, between 4 and 42% of the elderly populations studied have been described as biochemically deficient in riboflavin (Bidlack, 1990) and, as in the present study, more abnormal EGRAC results have been found in elderly populations compared with younger adults (Department of Health, 1991). In the present study the relatively high proportion of subjects with EGRAC values $> 1{\cdot}4$, the cut-off value for deficiency, would not have been predicted from their calculated dietary intake of the vitamin, and perhaps the usefulness of this cut-off should be considered in relation to other measures of riboflavin status. When using erythrocyte transketolase activation coefficients to assess thiamin status in adolescents we found a higher incidence of so-called 'deficient' values compared with measurements of erythrocyte thiamin concentration within the same individuals (Bailey *et al.* 1994). Only erythrocyte thiamin concentration was measured in adult and elderly subjects taking part in the present studies. Comparison of values obtained for all age groups showed no significant differences in either thiamin intake or erythrocyte thiamin concentration between age groups, suggesting the absence of an age-related response. Plasma cyanocobalamin levels did not differ between age groups and all subjects had levels above 110 pmol/l which is considered to be the depletion threshold (Gibson, 1990).

Several factors have been shown to affect the vitamin D status of the elderly: lack of exposure to the sun, possible decreased absorption, and a possible age-related decline in 25-hydroxylation of cholecalciferol in the liver (Bidlack, 1990). It was not possible to compare vitamin D status between all age groups because blood samples were not necessarily obtained in the same season. However, the adult and younger elderly data are comparable and there was no evidence of impaired vitamin D status in the elderly group (as judged by circulating plasma 25-hydroxycholecalciferol concentration). Even in the older elderly subjects, who were assessed over the winter and spring period, only two males and two females had a 25-hydroxycholecalciferol concentration of < 25 nmol/l.

The plasma cholesterol, triacylglycerol and LDL concentrations increased, and HDL concentration decreased, with age of group. In the present study adolescent males had significantly lower concentrations of total cholesterol, LDL and triacylglycerols than adult and elderly subjects who had similar mean values. In females, however, cholesterol and LDL concentrations increased progressively from the adolescent to the elderly groups. For the best overall mortality target, it has been suggested that levels of circulating total

cholesterol should probably be below 5·2 to 5·72 mmol/l for adults and < 6·5 mmol/l in older adults (Aronow *et al.* 1989). In the present studies, about 45% of adult, younger elderly and older elderly males exceeded suggested plasma cholesterol thresholds as did about 25% of adult females and about 60% of both younger and older elderly females. These age and sex differences are already well documented (Morley, 1990) but there is a great deal of controversy as to the significance of the age effect, the association between high cholesterol levels and risk of heart disease in older adults, and whether or not it is feasible, or even desirable, to attempt to alter cholesterol levels in the population over 70 years of age (Morley, 1990).

In conclusion, the dietary needs of the 'healthy' elderly may prove to be generally similar to those of younger adults as implied by current dietary recommendations (Department of Health, 1991). However, the studies described here indicate that for some nutrients there may be differences in metabolism and utilization, not just between adults and elderly, but also between younger and older elderly subjects, vitamin C being an important example. It is accepted that good nutrition contributes to the health of elderly people and to their ability to recover from illness (Department of Health, 1992) and, as recently stated by Whitehead (1992), it is also quite obvious that more specific nutritional studies urgently need to be carried out in older people to identify where critical differences do occur and to plan confidently for optimal nutritional health.

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