No effect of copper supplementation on biochemical markers of bone metabolism in healthy adults

Aimi Baker¹, Eithne Turley², Maxine P. Bonham², Jacqueline M. O’Connor², J. J. Strain², Albert Flynn¹ and Kevin D. Cashman¹*

¹Department of Nutrition, University College, Cork, Republic of Ireland
²Northern Ireland Centre for Diet and Health (NICHE), University of Ulster, Coleraine BT52 1SA, UK

(Received 16 November 1998 – Revised 21 April 1999 – Accepted 18 May 1999)

The influence of Cu supplementation of the usual diet for 6 weeks on biochemical markers of bone turnover and on putative indices of Cu status was investigated in healthy adults (twelve male and twelve female) aged 22–46 years, who participated in a double-blind placebo-controlled repeated crossover study. The study consisted of three 6-week supplementation regimens of 3 mg CuSO₄, 3 mg Cu–glycine chelate (CuGC), and 6 mg CuGC, each separated by placebo periods of equal length. During baseline and on the last day of each dietary period, fasting morning first-void urine and fasting blood serum, plasma and erythrocytes were collected. The habitual dietary Cu intakes in males and females were approximately 1 × 4 and 1 × 1 mg/d respectively. Females had significantly higher (50 %) plasma caeruloplasmin (Cp) protein concentrations than males at baseline. Cu supplementation had no effect on erythrocyte superoxide dismutase (SOD, EC 1.15.1.1) activity or plasma Cp protein (putative indices of Cu status) in the total group. Similarly, serum osteocalcin (a marker of bone formation), urinary creatinine (Cr) concentration, urinary pyridinoline : Cr or deoxypyridinoline : Cr excretion (markers of bone resorption) were unaffected in either the total group or in males and females separately, by any Cu supplementation regimen. It is concluded that Cu supplementation of the usual diet in healthy adult males and females had no effect on biochemical markers of bone formation or bone resorption over 6-week periods.

Copper: Bone: Biochemical markers

Cu has an important role in the metabolism of the skeleton where it performs a key catalytic function as a cofactor for lysyl oxidase (EC 1.4.3.13), a Cu-dependent extracellular amine oxidase which is important in the first step of the maturation (crosslinking) of collagen to form stable fibrils (O’Dell, 1981; Tinker et al. 1988). Studies in experimental animals have shown that Cu deficiency can greatly reduce the activity of lysyl oxidase in bone (Siegel et al. 1970) and impair the crosslinking of collagen in the organic bone matrix, at least in some bones (Robins et al. 1985; Farquharson et al. 1989; Jonas et al. 1993a), leading to diminished tensile strength of bone (Jonas et al. 1993b). Cu deficiency during fetal and postnatal development has been shown to produce skeletal abnormalities and fragility in various species including the rat, chick, pig, horse and rabbit (Hurley, 1981; Fell, 1987; Dolwett & Sorenson, 1988). In human subjects, disorders of Cu deficiency with skeletal defects, such as osteopenia, cupping and flaring of metaphyses of long bones, submetaphyseal fracture, and spontaneous fractures, most frequently in the ribs, have been noted in Menke’s syndrome (Al-Rashid & Spangler, 1971; Seely et al. 1972; Ashkenazi et al. 1973), an inherited disease of Cu deficiency in young children where the gastrointestinal absorption of Cu is severely limited (Danks, 1987). Skeletal defects such as osteoporosis, multiple fractures and a variety of bone developmental defects observed in preterm infants, in whom Cu nutritional status can be impaired, have been reported to respond to oral supplementation with Cu which resulted in complete healing of fractures and improvement in the other bone defects (Allen et al. 1982; Patterson, 1990; Schmidt et al. 1991).

There is some evidence for a role for Cu deficiency in age-related osteoporosis. For example, serum Cu levels of forty-six elderly patients with fractures of the femoral neck were reported to be significantly lower than those of a group of controls matched for age and sex (Conlan et al. 1990).

Recently, we have shown that a low dietary Cu intake

Abbreviations: Cp, caeruloplasmin; Cr, creatinine; CuGC, copper–glycine chelate; Dpyr, deoxypyridinoline; Pyr, pyridinoline; SOD, superoxide dismutase.

* Corresponding author: Dr Kevin D. Cashman, fax +353 21 270244, email k.cashman@ucc.ie
(0.7 mg/d) for 6 weeks significantly increased the rate of bone resorption, as assessed by the urinary excretion of pyridinium crosslinks, in healthy adult males aged between 20 and 59 years (Baker et al. 1999). An increased rate of bone turnover in adults may be a risk factor for fracture (Riggs et al. 1996), because it exacerbates bone loss (Hansen et al. 1991). This may have consequences for bone health of many adults because while mean daily Cu intakes of adults in Europe (1–0–2.26 mg for males, 0.9–1.79 mg for females; Van Dokkum, 1995) are greater than or close to the UK reference nutrient intake (1.2 mg/d for adults; Department of Health, 1991) and the EU population reference intake (1.1 mg/d for adults; Report of the Scientific Committee for Food, 1993), there may be significant numbers of individuals with marginal Cu intakes. For example, Klevay et al. (1993) suggest that greater than 30% of diets in North America and Europe provide less than 1.0 mg/d.

Despite this evidence of marginal Cu intake and its effects on bone health, the effect of increasing dietary Cu intake above usual levels on bone mass or bone metabolism has received little attention. Eaton-Evans et al. (1996) have shown that Cu supplementation with an additional 3 mg/d for 2 years in middle-aged women (45–56 years) with a usual dietary Cu intake of approximately 1 mg/d, led to a reduced rate of loss of bone-mineral density at the lumbar spine. We have shown that increasing dietary Cu intake in healthy adult males (aged 20–59 years) from a relatively low (0–7 mg/d) to a relatively high level (6–0 mg/d) for 6 weeks significantly decreased the rate of urinary pyridinium crosslink excretion (Baker et al. 1999). However, this was a depletion–repletion type study and therefore probably not representative of increasing dietary Cu intake above usual levels.

The objective of the present study, therefore, was to investigate the effects of increasing Cu intakes, above the usual dietary intake, on biomarkers of bone metabolism in healthy adults (aged 22–46 years) over a 6-week period.

Methods

Subjects
Twenty-four healthy adults (twelve females and twelve males, mean age 31.3 (range 22–46 years) were recruited from among staff and students at University of Ulster. Males were taller (180 (SD 0–01) m) and heavier (82.2 (SD 2.76) kg) than females (162 (SD 0.01) m and 61.3 (SD 2.77) kg respectively) and their mean BMI (25.4 (SD 0.7) kg/m²) was greater than that of females (23.2 (SD 0.8) kg/m²). The subjects were apparently healthy, without any history of bone or articular disease, and with no intake of medicine that could affect bone or cartilage metabolism. Additional exclusion criteria included smoking, chronic illness or taking nutritional supplements.

Ethical considerations
Before participation in this study, all subjects signed an informed consent document approved by the Ethical Committee of the University of Ulster.

Design
The study consisted of a double-blind, placebo-controlled repeat crossover trial of the effect of Cu supplementation of the usual dietary Cu intake, using various supplementation regimens, on biochemical markers of bone turnover in healthy adult subjects.

The Cu intervention trial was designed in six periods, i.e. three separate supplementation regimens of 3 mg elemental Cu as CuSO₄, 3 mg Cu as Cu–glycine chelate (CuGC), and 6 mg Cu as CuGC, each of 6 weeks duration and separated by placebo periods of equal length. Both organic (CuGC) and inorganic (CuSO₄) forms of Cu were used in the study to determine if there would be any alteration in the effect of Cu supplementation related to the form of Cu supplement used. Subjects were randomly assigned to the unsupplemented (placebo) or Cu-supplemented diet regimens for 6 weeks followed by crossover to the alternative dietary regimen for a further 6 weeks for each of the three separate Cu supplementation regimens. During the 6 week supplementation period each subject received, in addition to their usual diet (with self-selected Cu intake approximately 1 mg/d), either 3 mg elemental Cu/d, as CuSO₄, or 3 or 6 mg elemental Cu/d as CuGC (Thompson & Joseph Ltd, Norwich, Norfolk, UK). Subjects were requested to take the active capsule or matching placebo once daily with food. Subjects were questioned at each blood collection point to ascertain whether they had taken all supplements. Overall compliance of the subjects was excellent. Subjects were instructed to collect fasting first-void urine samples between 07.00 and 09.00 hours on the last day of each treatment period and during the week immediately preceding the trial (baseline). In addition, after an overnight fast, a blood sample (10 ml) was taken at 09.00 hours on the morning of the forty-second day of each treatment period and during the week immediately preceding the trial (baseline). Habitual dietary intake was assessed for each subject by means of a diet history at the beginning and on completion of the study.

Dietary analysis
Habitual dietary information (a typical month) was collected from each subject by means of a diet history (Livingstone et al. 1992) by a trained investigator. The records were then analysed using food portion sizes and a photographic album (Crawley, 1992) and the nutrient intake calculated using the computer package COMP-EAT (Nutrition Systems, London, UK).

Collection and preparation of samples
Portions of urine collected by each individual on each day of collection were stored at −20°C from the morning of collection until required for analysis. Blood was collected by venepuncture into vacutainer tubes containing either no additive, citrate, or lithium heparin. Bloods collected in vacutainer tubes with no additive and with lithium heparin were processed to serum and plasma respectively, which were immediately stored at −80°C until required. Whole bloods from vacutainer tubes with citrate were used on the
day of collection for isolation of erythrocytes. Erythrocytes were resuspended with 0.15 M NaCl in the original blood volume and washed three times by centrifugation (2000 × g for 10 min at 25°C). A 500 µl portion of washed erythrocytes was stored at −80°C until required for determination of haemoglobin concentration and superoxide dismutase (SOD; EC 1.15.1.1) activities.

**Experimental techniques**

*Urinary pyridinoline and deoxypyridinoline.* Samples were analysed in triplicate using a three-step procedure. Urine was first hydrolysed with an equal volume of 12 M HCl at 110°C for 18 h, the crosslinks were then extracted by CFI cellulose chromatography with the use of an internal standard (acetylated pyridinoline; MetraBiosystems Ltd, Wheatley, Oxon., UK) and were measured using a reversed-phase HPLC method with fluorescence detection (Colwell et al. 1993). The acetylated pyridinoline (Pyr) was used in accordance with the method as described by Calabresi et al. (1994) and Robins et al. (1994). The crosslinks contents of urine samples were quantitated by external standardization using a commercially available Pyr/deoxypyridinoline (Dpyr) HPLC calibrator (MetraBiosystems Ltd). The intra-assay CV for Pyr and Dpyr measured as the variation between ten chromatograms obtained between column regenerations as described by Colwell et al. (1993) were 6% and 7% respectively. Inter-assay variation was avoided by analysing all samples from an individual in the same run.

*Urinary creatinine.* Fresh daily urine samples were analysed in duplicate by a colorimetric procedure using a diagnostic kit (catalogue no. 124, 192; Boehringer Mannheim GmbH, Mannheim, Germany). The intra- and inter-assay CV were 3.4% and 6.3% respectively.

*Serum osteocalcin.* Serum osteocalcin levels were measured using an ELISA (BRI-Diagnostics, Dublin 9, Republic of Ireland). The intra-assay CV was 10.2%. Inter-assay variation was avoided by analysing all samples from an individual in the same run.

*Plasma caeruloplasmin content.* Plasma caeruloplasmin (Cp) protein concentration was measured turbidimetrically using a modification of the method of Calvin & Price (1986). Plasma (pH 7.3) was diluted (1 : 41, v/v) with 0.01 M PBS (pH 7.3) and mixed with excess rabbit anti-human Cp (Dako, Glostrup, Denmark). The resulting antibody–antigen complex was stabilized with a phosphate buffer containing PEG 6000 (BDH Ltd, Poole, Dorset, UK). The absorbance was measured on the Cobas Fara autoanalyser (Roche, Basel, Switzerland), and concentration was determined from a standard curve calculated using a human serum protein calibrator (Dako). The intra-assay CV was 1.7%. Inter-assay variation was avoided by analysing all samples from an individual in the same run.

*Erythrocyte haemoglobin and superoxide dismutase.* Determination of haemoglobin concentration was performed using the cyanomethaemoglobin method. Erythrocytes (40 µl) were diluted with 20 ml diluent (Iston; Coulter Electronics Ltd, Beds., UK) in a plastic vial (Sterlin, BDH Ltd). The samples were mixed by inversion and six drops of a lysing solution (Zapoglobin; Coulter Electronics Ltd) were added. The samples were left for 5 min at room temperature, and the haemoglobin concentration was determined within 1 h, in g/l, using a haemoglobinometer (Coulter Electronics Ltd). Erythrocyte SOD activity was determined on the Cobas Fara automatic analyser (Roche), by a modification of the method of Jones & Suttle (1981), using a commercial kit (Ransod; Randox Laboratories, Co. Antrim, N. Ireland). Activity of SOD was expressed per g haemoglobin. The intra-assay CV was 2.7%. Inter-assay variation was avoided by analysing all samples from an individual in the same run.

**Statistical analysis.** Data are presented as means and standard deviations. Data for all variables were normally distributed and allowed for parametric tests of significance. Differences in age, height, weight and BMI between males and females were examined by an unpaired Student's t tests. Differences in biochemical indices of Cu status and of bone turnover between males and females at baseline were examined by unpaired Student’s t tests. Changes in the different biochemical indices (i.e. of Cu status and of bone turnover) during the placebo and Cu-supplemented periods were analysed at each crossover by the appropriate analysis for a crossover trial with continuous data as described by Jones & Kenward (1989) in which two-sample t tests are used to test hypotheses about direct treatments effects (i.e. Cu supplementation) and carry-over effects. Unavoidable absences of subjects at particular blood and urine sampling times account for differences in crossover numbers.

**Results**

Females (n 12) had significantly higher plasma Cp protein concentrations than males (n 12) at baseline (Table 1). There were no significant differences between males and females in baseline levels of urinary and serum biochemical indices of bone turnover or in erythrocyte SOD activity (a putative index of Cu status) (Table 1). The habitual dietary Cu intake in males was significantly greater than that in females, reflecting the higher energy intakes of the males (Table 1).

The effects of different Cu supplementation regimens on putative indices of Cu status and on serum and urinary biochemical indices of bone turnover are shown in Tables 2 and 3. Erythrocyte SOD, serum osteocalcin (a marker of bone formation), urinary creatinine (Cr) concentration, urinary Pyr:Cr or Dpyr:Cr excretion (markers of bone resorption) were unaffected in either the total group or in males and females separately, by any Cu supplementation regimen.

There was no significant difference in plasma Cp protein concentration between any of the unsupplemented (placebo) and Cu-supplemented dietary periods in the total group or in females. There was a significant decrease (P < 0.05) in plasma Cp protein concentration in males after supplementation with 6 mg Cu as the CuGC (Table 2).

**Discussion**

In the present study, the concentration of plasma Cp protein was higher in females than males at baseline whereas there was no difference in erythrocyte SOD activity, another putative index of Cu status, between males and females.
This is in agreement with other studies which have shown a sex-related difference in Cp concentration (Fisher et al. 1990; Johnson et al. 1992; Milne & Johnson, 1993) but not in erythrocyte SOD activity (Johnson et al. 1992; Milne & Johnson, 1993). There was no effect of Cu supplementation with either 3 (as an organic or inorganic form) or 6 mg elemental Cu/d for 6 weeks on plasma Cp levels or on erythrocyte SOD activity in the total group or in the males or females separately, except for a small decrease in Cp protein after daily supplementation with 6 mg elemental Cu as CuGC in the males, which was probably not of any physiological significance. These findings are in general agreement with the findings of other Cu intervention trials in healthy adults which showed a lack of response of circulating Cp protein levels and erythrocyte SOD activity to daily supplementation with 2–3 mg Cu (Medeiros et al. 1991; Eaton-Evans et al. 1996).

Together, these data support the contention that circulating Cp concentration or erythrocyte SOD activity, which has been proposed as being more reflective of metabolically active Cu and Cu stores than is plasma Cp concentration (Milne, 1994, 1998), are not responsive to Cu supplementation of the usual diet in healthy subjects.

The findings of the present study showed that oral Cu supplementation of the usual diet (which contained approximately 1.4 and 1.1 mg Cu/d for males and females, respectively) with either 3 or 6 mg elemental Cu/d for 6 weeks had no effect on urinary pyridinium crosslinks of collagen (Pyr and Dpyr, sensitive and specific biochemical markers of bone resorption (Eyre, 1992; Robins & New, 1997)) or serum osteocalcin (a sensitive biochemical marker of bone formation (Eyre, 1996)) in healthy adults. This is in contrast to the findings of our previous study which showed that increasing dietary Cu intake in healthy adult males from 0.7 to 6.0 mg/d over 6 weeks significantly decreased the rate of urinary excretion of pyridinium crosslinks (Baker et al. 1999). However, it should be noted that the later study was a depletion–repletion type study in which adult males were originally switched from a medium (1.6 mg/d) to low (0.7 mg/d) intake of dietary Cu, and subsequently their Cu intakes were increased from the low to a high level (6.0 mg/d), each for 6 weeks. While decreasing the Cu intakes of the males significantly increased the urinary excretion of both Pyr (30 %) and Dpyr (25 %), this increased rate of urinary pyridinium crosslink excretion was reversed during the subsequent 6-week period of dietary Cu repletion (i.e. high-Cu diet) (Baker et al. 1999).

The findings of the present study agree with those of other Cu intervention trials which demonstrated that increasing dietary Cu intake above usual levels had no effect on the rate of bone formation, as assessed by biochemical markers (Pratt et al. 1985; Eaton-Evans et al. 1996). For example, Pratt et al. (1985) studied the effect of Cu supplementation of the usual diet in healthy adults on various biochemical variables, including serum alkaline phosphatase (EC 3.1.3.1), a biochemical marker of bone formation, and found that there was no significant difference in serum alkaline phosphatase activity between subjects who received 10 mg Cu/d (as copper gluconate) or placebo over a 12-week period. Similarly, Eaton-Evans et al. (1996) found that serum total alkaline phosphatase was unaffected by Cu supplementation (3 mg elemental Cu/d as Cu–glycine chelate) for 2 years in 45–56-year-old women. However, in the former study it is unclear whether the reported values refer to the activity of total alkaline phosphatase or the bone isoform of alkaline phosphatase which is a more sensitive and specific marker of bone formation (Delmas, 1992).

When taken together, therefore, the results of our present and previous studies suggest that while low Cu intakes (i.e. 0.7 mg/d) increase the rate of bone resorption, increasing dietary Cu intakes above approximately 1 mg/d (a level close to the recommended intake (Department of Health, 1991; Report of the Scientific Committee for Food, 1993)) had no effect on the rate of bone resorption or bone formation in healthy adults. While the underlying mechanisms for the osteoporotic-like lesions observed in bone in Cu deficiency disorders in animal species and human subjects are not
Table 2. Putative indices of copper status in the total group of healthy adults, and in males and females separately during unsupplemented (placebo) and copper-supplemented dietary periods*†

(Mean values and standard deviations)

<table>
<thead>
<tr>
<th>Dietary period</th>
<th>1st crossover</th>
<th>2nd crossover</th>
<th>3rd crossover</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>3 mg Cu (as CuSO₄)</td>
<td>Placebo</td>
<td>3 mg Cu (as CuGC)</td>
</tr>
<tr>
<td>n</td>
<td></td>
<td>n Mean SD</td>
<td>n Mean SD</td>
</tr>
<tr>
<td>Total</td>
<td>22</td>
<td>0.19 0.05</td>
<td>20 0.21 0.05</td>
</tr>
<tr>
<td>Males</td>
<td>11</td>
<td>0.17 0.03</td>
<td>9 0.18 0.03</td>
</tr>
<tr>
<td>Females</td>
<td>11</td>
<td>0.21 0.07</td>
<td>12 0.23 0.07</td>
</tr>
<tr>
<td>Plasma Cp (g/l)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>23</td>
<td>1166 182</td>
<td>21 1068 151</td>
</tr>
<tr>
<td>Males</td>
<td>12</td>
<td>1107 173</td>
<td>9 1123 206</td>
</tr>
<tr>
<td>Females</td>
<td>11</td>
<td>1022 182</td>
<td>12 1028 145</td>
</tr>
<tr>
<td>Erythrocyte SOD (U/g Hb)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>23</td>
<td>1166 182</td>
<td>19 1042 170</td>
</tr>
<tr>
<td>Males</td>
<td>12</td>
<td>1107 173</td>
<td>8 1096 155</td>
</tr>
<tr>
<td>Females</td>
<td>11</td>
<td>1022 182</td>
<td>11 1003 182</td>
</tr>
</tbody>
</table>

CuGC, copper–glycine chelate; Cp, caeruloplasmin; Hb, haemoglobin.

* For details of subjects and procedures, see Table 1 and pp. 284–285.
† Direct treatment effect (i.e. Cu supplementation) was analysed for each biochemical index at each crossover by two sample t tests of within group differences after testing for carry-over effects. No significant carry-over effects were found.

Mean value was significantly different from that for the placebo period, ††P < 0.05.
Table 3. Urinary and circulating biochemical markers of bone turnover in the total group of healthy adults, and in males and females separately during unsupplemented (placebo) and copper-supplemented dietary periods*†

(Mean values and standard deviations)

<table>
<thead>
<tr>
<th>Dietary period …</th>
<th>1st crossover</th>
<th>2nd crossover</th>
<th>3rd crossover</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>3 mg Cu (as CuSO₄)</td>
<td>Placebo</td>
<td>3 mg Cu (as CuGC)</td>
</tr>
<tr>
<td></td>
<td>n</td>
<td>Mean</td>
<td>SD</td>
</tr>
<tr>
<td>Blood:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Osteocalcin (µg/l)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>23</td>
<td>10.1</td>
<td>5.8</td>
</tr>
<tr>
<td>Males</td>
<td>12</td>
<td>12.2</td>
<td>6.3</td>
</tr>
<tr>
<td>Females</td>
<td>11</td>
<td>7.7</td>
<td>4.4</td>
</tr>
<tr>
<td>Urine</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Creatinine (mmol/l)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>22</td>
<td>16.1</td>
<td>7.4</td>
</tr>
<tr>
<td>Males</td>
<td>11</td>
<td>15.7</td>
<td>7.3</td>
</tr>
<tr>
<td>Females</td>
<td>10</td>
<td>14.7</td>
<td>8.3</td>
</tr>
<tr>
<td>Pyr (nmol/nmol Cr)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>22</td>
<td>32.4</td>
<td>15.6</td>
</tr>
<tr>
<td>Males</td>
<td>11</td>
<td>36.6</td>
<td>10.6</td>
</tr>
<tr>
<td>Females</td>
<td>10</td>
<td>40.5</td>
<td>18.0</td>
</tr>
<tr>
<td>Dpyr (nmol/nmol Cr)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>22</td>
<td>10.2</td>
<td>6.2</td>
</tr>
<tr>
<td>Males</td>
<td>11</td>
<td>8.9</td>
<td>5.5</td>
</tr>
<tr>
<td>Females</td>
<td>10</td>
<td>11.4</td>
<td>6.8</td>
</tr>
</tbody>
</table>

CuGC, copper–glycine chelate; Pyr, pyridinoline; Cr, creatinine; Dpyr, deoxypyridinoline.
* For details of subjects and procedures, see Table 1 and pp. 284–285.
† Direct treatment effect (i.e. Cu supplementation) was analysed for each biochemical index at each crossover by two sample t tests of within group differences after testing for carry-over effects. No significant carry-over or direct treatment effects were found.
intake of 1.4 (SD 0.3) mg/d and twelve females (with a mean usual dietary Cu intake of 1.1 (SD 0.3) mg/d) had no effect on biochemical markers of bone formation or bone resorption over 6-week periods. However, more research is needed to examine the effects of increased Cu intake on bone metabolism and bone mass in older adults, particularly peri- and postmenopausal females, and especially in long-term studies.

Acknowledgements

This research has been part-funded by grant aid from the European Commission (Grant CT95-0813 FOODCUE) and from the Ministry of Agriculture, Fisheries and Food (Grant A181 (AN 0511)). The Cu supplements were supplied by Thompson & Joseph Ltd, Norwich, Norfolk, UK.

References


© Nutrition Society 1999