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Taurine concentrations in the diet, plasma, urine and breast milk of vegans compared with omnivores

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1. The concentration of taurine in the diets, plasma, urine and breast milk were measured in vegans and age- and sex-matched omnivore controls. Plasma and urinary amino acid concentrations were also determined.

2. Taurine was absent from the vegan diet and occurred in variable amounts in the diets of the omnivores. Urinary taurine levels were less than half those of the omnivores but plasma and breast-milk levels were only slightly lower.

3. Dietary energy intakes were similar in the vegans and omnivores, but protein intakes tended to be lower in the vegans.

Taurine occurs as a free amino acid in a wide variety of mammalian tissues (Awapara, 1956; Jacobsen & Smith, 1968; Evered *et al.* 1969; Sturman, 1973; Gaull *et al.* 1977). Besides forming conjugates with bile acids (Haslewood, 1964), it may function as an inhibitory neurotransmitter or neuromodulator (Davison & Kaczmarek, 1971; Kuriyama, 1980) and as a membrane stabilizer (Hayes, 1976; Gaull *et al.* 1982; Pasantes-Morales *et al.* 1984). Furthermore, it has been proposed that taurine may have a role in brain development (Sturman *et al.* 1977) and may act as a growth modulator (Hayes *et al.* 1980; Gaull, 1983). Although the physiological role of taurine has been intensely investigated, the ultimate source of the taurine has been relatively neglected.

Taurine can be derived from methionine or it can be obtained preformed from the consumption of food of animal origin, such as meat, offal and seafood; plant foods are devoid of taurine (Roe & Weston, 1965). The capacity for taurine biosynthesis varies between species; compared with the rat, for instance, man, primates and the cat exhibit very low activities in vitro of sulphinoalanine decarboxylase (cysteine sulphinic acid decarboxylase; *EC* 4.1.1.29), which is believed to be the rate-limiting enzyme responsible for the formation of taurine from cysteine (Hope, 1955; Jacobsen & Smith, 1968; Gaull *et al.* 1977; Sturman & Hayes, 1980). Taurine needs to be supplied in the diet of the domestic cat, since cats maintained on diets lacking taurine become blind (Hayes *et al.* 1975; Knopf *et al.* 1978). The cat, unlike man, is unable to conserve taurine by producing bile acids with glycine. The cat, therefore, has an obligatory loss of taurine in bile (Rabin *et al.* 1976). The extent to which taurine can be synthesized from precursors in man is, at present, unknown. Since the adult man, not unlike the cat, has a low activity of sulphinoalanine decarboxylase, it has been postulated that man may also require preformed dietary taurine as the rate of biosynthesis may be inadequate (Gaull *et al.* 1977; Sturman *et al.* 1977). Gaull *et al.* (1982) have suggested that breast milk supplies the newborn infant with a supply of taurine to compensate for a low capacity for taurine biosynthesis.

The present study reports the effects of a vegan diet, which is devoid of food of animal origin and presumably free of preformed taurine, and an omnivore diet on plasma, urine and breast-milk concentrations of taurine and other amino acids.

SUBJECTS AND METHODS

Vegan subjects were contacted through the Vegan Society (47 Highlands Road, Leatherhead, Surrey). Criteria for admission to the study were that the subjects had followed a vegan diet for at least 1 year and were taking no medication with the exception of oral contraceptives. The vegan subjects were matched for age and sex with omnivore controls who were recruited from the staff and student population of King's College London (KQC). Care was taken to select controls of similar height and body build. Consent for all procedures was obtained from individuals and from the College Ethical Committee. Samples of breast milk collected in a previous study (Hughes, 1981) from both vegan and omnivore mothers were also analysed for taurine.

Each subject was asked to weigh and record their food intake for seven consecutive days and to collect duplicate portions of their food for three of these days, one of which was a weekend day. Subjects were provided with dietary balances (Chantillon, accurate to 2 g), detailed instructions and large plastic bags. They were asked to collect fluids separately and to keep the food samples refrigerated and to specify in their food records which foods or drinks if any were omitted from their collected diet. Fluids such as milk or soya-milk and any foods that were omitted from the collection were added in the laboratory before homogenizing the diet. Alcoholic beverages such as beer were not added to the duplicate food portions. On the last day of the food-recording period, each subject collected a 24 h urine sample. The following day, the height and weight of each subject were recorded, using a stadiometer and beam balance respectively.

Venous blood samples were obtained between 10.00 hours and 12.00 hours from the subjects who had fasted from 22.00 hours the previous evening. Blood samples were anti-coagulated with EDTA (1 mg/ml) and chilled to 4°, and plasma was collected after centrifugation at 1500 *g* for 15 min. Plasma was deproteinized with 50 mg sulphosalicylic acid/ml and centrifuged for 30 min at 10000 rev./min. The deproteinized plasma was stored at −20° until analysed for amino acids. Portions of urine were also deproteinized and stored frozen until analysed for amino acids. Frozen mid-stream milk samples collected 4–6 weeks post-partum from fourteen vegan and fourteen omnivore mothers were deproteinized, centrifuged and stored frozen until analysed for taurine.

Amino acid analysis was carried out on a Technicon NCIIP Amino Acid AutoAnalyzer. The separation was achieved on a single column (400 mm × 9 mm) containing type C-3 chromobead resin. The column temperature was maintained at 47° and the flow rate through the column was 0.45 ml/min. For plasma and urine samples, amino acids were eluted by a sequence of lithium citrate buffers of increasing pH (2·60, 2·70, 3·30, 4·10, 5·25, 6·00 and 11·00). Amino acids were detected with absorption at 570 nm and 440 nm using EEL colorimeters after colour derivatization with ninhydrin. For analysis of amino acids in plasma and urine, norleucine was introduced as an internal standard (Sepramar; BDH Chemicals, Poole, Dorset). Milk and food samples were analysed for taurine using a shorter buffer programme with lithium citrate buffer, pH 2·70. An external taurine standard (Sigma Chemical Co., Poole, Dorset) was used for quantitative determination. Total nitrogen by the Kjeldahl method (Egan *et al.* 1981), and creatinine (Oser, 1965) were analysed in samples of urine.

The total weights of the 3-d duplicate food portions were recorded. Duplicate food portions were individually homogenized with a known volume of distilled water in a large stainless-steel Waring blender. The homogenized diet, which was a thick paste, was then transferred to a large mixing bowl and mechanically mixed for 1 h. Portions of the total diet were taken for the determination of taurine: one part diet was mixed with three parts water, deproteinized with 50 mg/ml sulphosalicylic acid, centrifuged and stored frozen. Portions of diet were also taken for estimation of dry weight and N. Energy was determined using the Gallenkamp Ballistic Bomb Calorimeter (Miller & Payne, 1959). The 7-d food record books were coded, and nutrient intakes were calculated by computer using mainly the tables of Paul & Southgate (1978) and, when necessary, additional sources (Platt, 1962; Miller & Mumford, 1972; United States Department of Agriculture, 1979) and manufacturers' information.

Statistics

Statistical analyses were carried out using a paired-sample *t* test or Wilcoxon's test for data that were not normally distributed.

RESULTS

Twenty-four vegans and a similar number of omnivore subjects took part in the study. However, complete sets of values were only obtained on eighteen vegans and twenty-four omnivore controls. Consequently only the values for these eighteen vegans (eight males and ten females) and their respective omnivore controls are reported. The heights and weights of the two groups were similar (Quetelet index (weight:height^2): male vegans 21 (SE 0.7), male omnivores 23 (SE 0.7), female vegans 21 (SE 0.7), female omnivores 21 (SE 0·5)) and the subjects were in the 18–40 year age-group. One vegan and three omnivore women were taking oral contraceptives. Only five omnivores (three female, two male) and two vegans (both males) were tobacco smokers. The vegans had followed their diet for an average of 6 years (range 1–15 years) and most had previously been vegetarians for an average of 4 years (range 0–14 years).

Calculated energy intakes were similar in both vegans and omnivores (Table 1). The vegans had lower protein intakes both in absolute terms and as a proportion of the total energy intake. Alcohol intakes were low in both groups but significantly lower in the vegans. Thiamin, nicotinic acid, carotene, vitamin C, vitamin E, pyridoxine and folate intakes were greater in the vegans but retinol, vitamin D, potential nicotinic acid (tryptophan/60) and vitamin B_{12} intakes were lower. Most of the vegan diets provided less vitamin B_{12} than the recommended daily amount (Department of Health and Social Security, 1979), and eight of the vegan diets provided less than 1 μg/d. However, four of these subjects were taking vitamin B_{12} supplements.

A N to protein conversion factor of 5·75 was applied for the calculation of the protein content of the vegan diets since the diet was predominantly cereals. A N to protein conversion factor of 6·25 was used for the omnivore diets. In both the vegans and omnivores, the values for energy measured directly were found to compare well with the values calculated from food tables (Table 2). In contrast, the values for protein obtained by direct analysis were lower by about 10 g/d compared with the calculated values. However, in agreement with the calculated values, the vegans had a significantly lower protein intake than the omnivores.

Urinary N excretion (Table 3) tended to be lower in the vegans compared with their controls. The lower urinary N excretion by the vegans probably reflects their lower protein intake. In the omnivore controls, approximately 83–92% of the dietary N was represented as urinary N. In contrast, 72–77% of the dietary N was excreted as urinary N by the vegans. These lower values may suggest incomplete urine collections by the vegans, since a marker was not used. Although the 24 h urine volumes of the male vegans were substantially lower than those of the omnivore males, this probably reflects a difference in fluid consumption, because daily creatinine excretion was similar between the two groups. The lower urinary:dietary N value in the vegans might be due to a proportionately higher faecal N excretion, but faecal N determinations were not made.

Table 1. *Daily nutrient intakes of eighteen vegan (eight male, ten female) and eighteen omnivore (eight male, ten female) subjects calculated from 7 d weighed dietary food intake values*

(Results are mean values with their standard errors)

Nutrient	Sex	Vegan Mean	Vegan SE	Omnivore Mean	Omnivore SE
Energy (MJ)	♂	10·2	0·56	10·0	1·03
	♀	8·7	0·44	9·8	0·63
	Both	9·4	0·40	9·9	0·57
Fat (% energy)	♂	40·7	1·36	39·6	3·45
	♀	34·3	2·48	37·8	1·44
	Both	37·3	1·65	38·6	1·73
Protein (% energy)	♂	11·1	0·73	13·3	0·78
	♀	11·2**	0·94	14·9	0·40
	Both	11·1**	0·58	14·1	0·46
Carbohydrate (% energy)	♂	47·0	1·75	41·4	3·92
	♀	52·4*	2·71	43·1	1·83
	Both	49·9†	1·75	42·3	2·00
Ethanol (% energy)	♂	2·0*	1·03	6·3	1·41
	♀	2·0*	0·99	5·5	1·55
	Both	2·0**	0·71	5·8	1·08
Fibre (g)	♂	46***	4·7	21	3·9
	♀	40***	5·6	17	2·8
	Both	43***	3·7	19	2·3
Thiamin (mg)	♂	1·7	0·23	1·2	0·14
	♀	1·9**	0·25	1·2	0·12
	Both	1·8**	0·17	1·2	0·09
Riboflavin (mg)	♂	1·2	0·20	1·9	0·22
	♀	2·2	0·59	1·6	0·16
	Both	1·7	0·35	1·8	0·14
Pyridoxine (mg)	♂	1·8	0·20	1·5	0·12
	♀	1·9*	0·22	1·4	0·16
	Both	1·8*	0·15	1·4	0·15
Vitamin B_{12} (μg)	♂	0·7†	0·26	9·7	2·45
	♀	2·8*	1·14	7·0	1·79
	Both	1·8**	0·66	8·3	1·48
Vitamin C (mg)	♂	119	14·3	74	12·1
	♀	154*	33·5	82	15·0
	Both	138**	19·0	79	9·5
Nicotinic acid (mg)	♂	21	2·4	22	1·7
	♀	26	3·1	19	1·9
	Both	23	2·0	20	1·3
Potential nicotinic acid (mg)	♂	9**	1·4	17	0·9
	♀	9***	0·9	15	0·7
	Both	9***	0·8	16	0·6
Biotin (μg)	♂	18†	3·0	27	2·1
	♀	19	3·2	21	1·6
	Both	19	2·1	24	1·5
Total folate (μg)	♂	281*	27·3	216	22·1
	♀	348**	46·9	151	13·0
	Both	317***	28·5	182	14·8
Vitamin A (retinol equivalent; μg)	♂	259*	54·6	1411	513·8
	♀	294	57·5	801	345·5
	Both	228†	38·7	1086	302·1
Carotene (μg)	♂	3261*	820	1573	517
	♀	1862	420	1012	75
	Both	2515†	465	1274	165

Table 1 (*cont.*)

Nutrient	Sex	Vegan Mean	Vegan SE	Omnivore Mean	Omnivore SE
Vitamin D (μg)	♂	2·3	0·49	3·9	2·11
	♀	2·6	0·52	3·4	1·37
	Both	2·4	0·35	3·7	1·18
Vitamin E (μg)	♂	16*	4·1	5·5	1·0
	♀	12**	1·6	4·9	0·5
	Both	14***	2·1	5·2	0·5
Ca (mg)	♂	700	119	1070	162
	♀	484**	48	855	64
	Both	585***	65	955	66
Fe (mg)	♂	24†	3·0	14	1·2
	♀	38†	11·4	13	0·9
	Both	31***	6·3	14	0·7

Mean values were significantly different from the mean values for omnivores (paired *t* test): * $P < 0.05$, † $P < 0.02$, ** $P < 0.01$, *** $P < 0.001$.

Table 2. *Analysed intakes of energy and protein in eighteen vegan (eight male, ten female) and eighteen omnivore (eight male, ten female) subjects*

(Results are mean values with their standard errors)

Nutrient	Sex	Vegan Mean	Vegan SE	Omnivore Mean	Omnivore SE
Energy (MJ/d)	♂	10·4	1·14	10·5	1·16
	♀	7·8	0·66	9·7	0·98
	Both	8·9	0·68	10·1	0·73
Calculated dietary protein (g/d)	♂	64·3	8·37	80·5	4·24
	♀	67·0	8·36	75·8	4·08
	Both	65·8	5·72	78·0	2·91
Analysed dietary protein (g/d)	♂	64·5	8·81	69·7	8·51
	♀	54·0	6·27	54·6	3·32
	Both	58·7	5·23	61·3	4·45
Protein (% energy)	♂	10·3	0·63	11·4	0·97
	♀	9·2	0·57	12·4	1·17
	Both	9·7*	0·42	12·0	0·77

Mean value was significantly different from the mean value for omnivores (paired *t* test): * $P < 0.05$.

No taurine could be detected in any of the vegan diets (Table 4). The omnivore diets provided widely varying amounts of preformed taurine. The male subjects in particular tended to have higher intakes of taurine than the females. The intake of preformed dietary taurine correlated with urinary taurine excretion, and the omnivore subjects excreted significantly more taurine than the vegans (Table 4). In contrast, values for the plasma taurine concentrations were only slightly lower in the vegan group. The mean taurine concentration of vegan breast milk was significantly lower than that in the omnivores (Table 5). In the interpretation of the differences in plasma and urinary taurine levels, factors such as individual intakes of alcohol, pyridoxine and vitamin A were examined. None of these factors, however, was observed to have any detectable effect on taurine levels.

Table 3. *Analysed intake of dietary nitrogen and urinary excretion of N and creatinine in eighteen vegan (eight male, ten female) and eighteen omnivore (eight male, ten female) subjects*

(Results are mean values with their standard errors)

		Vegan		Omnivore	
Urine	Sex	Mean	SE	Mean	SE
Volume (ml/d)	♂	1135*	163	1858	236
	♀	1617	175	1644	293
	Both	1403	131	1739	190
Creatinine (g/d)	♂	1·3	0·18	1·2	0·19
	♀	0·7	0·15	1·0	0·12
	Both	1·0	0·13	1·1	0·11
N (g/d)	♂	8·4	0·90	9·6	0·56
	♀	6·5	1·30	6·9	0·77
	Both	7·3	0·84	8·1	0·58
Dietary N (g/d)	♂	11·2	1·53	11·2	1·36
	♀	9·4	1·09	8·7	0·53
	Both	10·2	0·91	9·8	0·71

Mean value was significantly different from the mean value for omnivores (paired t test): * $P < 0·05$.

Table 4. *Preformed dietary taurine intake, urinary taurine excretion and plasma taurine concentration in eighteen vegan (eight male, ten female) and eighteen omnivore (eight male, ten female) subjects*

(Results are mean values with their standard errors)

		Vegan		Omnivore	
	Sex	Mean	SE	Mean	SE
Dietary taurine					
μmol/d	♂	nd		609*	348
mg/d				76	43·0
μmol/d	♀	nd		347**	75
mg/d				43	9·7
μmol/d	Both	nd		463**	156
mg/d				58	19·5
Urinary taurine (μmol/d)	♂	231	76·8	759	306·5
	♀	270	68·7	537*	113·4
	Both	253	50·0	636*	147·3
Plasma taurine (μmol/l)	♂	88	11·9	103	12·5
	♀	66	6·4	76	6·2
	Both	76	6·7	88	7·2

nd, not detected.
Mean values were significantly different from the mean values for omnivores (paired t test and Wilcoxon's test): * $P < 0·05$, ** $P < 0·01$.

The plasma and urinary amino acid levels of omnivore subjects of the present study are generally in agreement with the values reported in other studies (Soupart, 1962; Westall, 1962; Emery, 1980).

Plasma methionine concentrations tended to be lower in the vegan subjects, particularly amongst the males. However, no difference was noted in the plasma cystine+cysteic acid concentrations between the two groups (Table 6). The excretion of methionine and

Table 5. *Breast-milk taurine concentrations in vegan and omnivore subjects*
(Results are mean values with their standard errors)

	n	Mean	SE	Range
Vegan				
μmol/l	14	277**	28·4	122–529
mg/l		35**	3·6	15–66
Omnivore				
μmol/l	14	427	37·8	191–683
mg/l		54	4·7	24–85

Mean values were significantly different from omnivore mean values (*t* test): ** $P < 0.01$.

Table 6. *Plasma amino acid concentrations (μmol/l) in eighteen vegan (eight male, ten female) and eighteen omnivore (eight male, ten female) subjects*
(Results are mean values with their standard errors)

		Vegan		Omnivore	
Amino acid	Sex	Mean	SE	Mean	SE
Methionine	♂	27	3·2	40	5·7
	♀	36	5·4	39	4·4
	Both	32	3·4	40	3·4
Cystine + cysteic acid	♂	64	8·6	69	7·1
	♀	80	10·1	80	11·5
	Both	73	6·9	75	7·1
Threonine	♂	121*	11·0	153	5·4
	♀	120	7·6	131	7·0
	Both	121†	6·3	140	5·3
Valine	♂	186	14·6	227	12·0
	♀	159	10·8	192	13·2
	Both	171**	9·2	207	9·8
Leucine	♂	74	9·0	95	9·2
	♀	75	6·7	94	8·9
	Both	75*	5·3	95	6·2
Isoleucine	♂	55	7·8	60	6·4
	♀	56	8·2	54	9·8
	Both	56	5·6	56	6·0
Phenylalanine	♂	69	4·8	77	3·6
	♀	59	4·7	69	3·7
	Both	63	3·5	73	2·7
Lysine	♂	103	12·6	116	11·8
	♀	79*	9·2	115	10·1
	Both	90†	7·9	115	7·4
Serine	♂	141	10·8	140	6·1
	♀	116	9·6	138	8·3
	Both	127	7·6	139	5·2
Asparagine	♂	19	5·8	8	5·6
	♀	22	5·3	18	4·3
	Both	21	3·8	14	3·5
Glutamine + glutamic acid	♂	383	42·1	391	41·8
	♀	319	27·4	288	20·9
	Both	347	24·6	334	24·6
Glycine	♂	261	24·0	260	11·0
	♀	250	21·6	256	28·3
	Both	255	15·6	258	16·1

Table 6 (*cont.*)

Amino acid	Sex	Vegan Mean	Vegan SE	Omnivore Mean	Omnivore SE
Alanine	♂	334	39·8	277	16·7
	♀	229*	15·0	276	20·1
	Both	276	22·7	276	13·1
Proline	♂	127	31·3	166	13·6
	♀	129	19·1	147	12·7
	Both	129	16·9	155	9·3
Citrulline	♂	45†	6·9	82	12·9
	♀	42	8·0	50	4·5
	Both	43†	5·2	64	7·2
Tyrosine	♂	63†	5·8	83	5·2
	♀	56	5·9	64	4·7
	Both	59†	4·1	73	4·1
Ornithine	♂	101	13·2	97	13·9
	♀	77	8·6	69	10·9
	Both	87	7·9	81	9·0
Histidine	♂	204	30·4	231	11·5
	♀	154†	11·4	214	14·9
	Both	176**	15·6	222	9·7
Arginine	♂	45	7·5	67	6·7
	♀	35***	3·4	66	2·2
	Both	39***	3·9	67	3·1

Mean values were significantly different from omnivore mean values (paired t test): * $P < 0{\cdot}05$, † $P < 0{\cdot}02$, ** $P < 0{\cdot}01$, *** $P < 0{\cdot}001$.

Table 7. *Urinary amino acid excretion (μmol/24 h) in eighteen vegan (eight male, ten female) and eighteen omnivore (eight male, ten female) subjects*

(Results are mean values with their standard errors)

Amino acid	Sex	Vegan Mean	Vegan SE	Omnivore Mean	Omnivore SE
Methionine	♂	36	8·5	51	11·8
	♀	23	2·6	32	5·9
	Both	30	4·2	41	6·4
Cystine + cysteic acid	♂	82*	8·3	138	16·8
	♀	85	9·3	94	7·8
	Both	83*	6·2	114	9·9
Threonine	♂	118	13·7	228	54·7
	♀	144	30·5	128	15·2
	Both	133	17·8	172	27·6
Valine	♂	42*	5·6	28	12·0
	♀	45	9·0	47	12·8
	Both	44	5·4	38	8·9
Leucine	♂	44	5·4	86	23·9
	♀	46	12·1	64	7·8
	Both	45*	7·0	74	11·4
Isoleucine	♂	27	5·3	47	11·0
	♀	24	3·7	37	8·8
	Both	25*	3·1	41	6·8
Phenylalanine	♂	63	7·1	101	13·5
	♀	76	9·0	70	5·6
	Both	70	6·0	84	7·5

Table 7 (*cont.*)

Amino acid	Sex	Vegan Mean	Vegan SE	Omnivore Mean	Omnivore SE
Lysine	♂	185	21·3	629	270
	♀	240	34·0	287	63
	Both	215	21·8	439	127
Tryptophan	♂	171**	14·4	497	78·8
	♀	200	41·1	282	43·6
	Both	187**	23·4	378	48·6
Serine	♂	366*	41·4	561	105
	♀	365	74·9	330	37·1
	Both	365	44·3	433	56·7
Asparagine	♂	53	4·1	81	18·7
	♀	60	16·4	46	5·4
	Both	57	9·1	62	9·5
Glutamine + glutamic acid	♂	142	24·2	270	56·0
	♀	200	48·9	169	16·4
	Both	174	29·3	214	28·3
Glycine	♂	1461	505	1569	330
	♀	1524	302	1336	239
	Both	1496	271	1440	194
Alanine	♂	191	32·0	307	77·7
	♀	245	44·4	198	27·9
	Both	221	28·5	246	38·8
Tyrosine	♂	73*	6·7	143	21·3
	♀	86	11·4	82	5·9
	Both	80	7·0	109	12·1
3-Methylhistidine	♂	87**	9·5	226	38·5
	♀	92	15·0	133	16·6
	Both	89**	9·1	174	21·8
1-Methylhistidine	♂	23†	3·1	127	31·3
	♀	23†	6·9	63	9·8
	Both	23***	4·0	91	16·3
Histidine	♂	595†	47	1525	275
	♀	734	190	650	63
	Both	672*	107	1039	162
Arginine	♂	49	6·9	121	57·0
	♀	58	7·4	46	5·7
	Both	54	5·1	79	26·2

Mean values were significantly different from omnivore mean values (paired *t* test): * $P < 0·05$, † $P < 0·02$, ** $P < 0·01$, *** $P < 0·001$.

cystine + cysteic acid (Table 7) was lower in the vegans. The vegans excreted smaller amounts of leucine, isoleucine, tryptophan, phenylalanine and lysine. Both 3-methylhistidine and 1-methylhistidine, derivatives of the non-essential amino acid histidine which are found predominantly in muscle tissue, were present in greater quantities in the urine of the omnivores than the vegans (Table 7). Plasma concentrations of threonine, valine, lysine, leucine, asparagine, tyrosine and phenylalanine were lower in the vegans than in their omnivore controls. Of the non-essential amino acids, only histidine, citrulline and arginine were lower in the vegan subjects (Table 6).

DISCUSSION

Our results clearly show that taurine is absent from vegan diets but occurs in variable amounts in the diets of omnivores. Roe (1966) calculated from dietary food records the daily intake of preformed taurine by American subjects to be in the range of 40–400 mg. In the present study, values for taurine intake were obtained by direct analysis of the food as eaten and a range of 9–372 mg/d was found. The mean daily intake of preformed taurine in the present study was 58 mg, whereas Evered *et al.* (1969) calculated the taurine intake of English subjects to be in the order of at least 100 mg/d. Roe & Weston (1965) reported that taurine may be partly lost during cooking procedures. During boiling, taurine leaches out into the cooking fluid but may be recovered if the cooking fluid is also consumed. Also icing of fish muscle leads to a depletion of taurine, and considerable amounts of taurine may also be lost when ice-stored foods have been thawed. The methods of cooking and food processing therefore need to be taken into consideration when dietary intakes of preformed taurine are calculated rather than determined by analysis.

In the present study energy and protein intakes were both calculated and analysed. Good agreement was obtained between calculated and analysed values for dietary energy, but analysed protein values tended to be lower than calculated values. The total energy intakes of the vegans were similar to those of the omnivores but they tended to have lower intakes of protein, in agreement with other studies (Miller & Mumford, 1972; Sanders, 1978; Abdulla *et al.* 1981). Urinary N excretion tended to be lower in the vegans, but in all subjects the urinary N excretion was less than the dietary N intake. The lower plasma concentrations of citrulline and arginine are consistent with a lower rate of amino acid catabolism into urea.

Several differences were noted in the plasma and urinary free amino acid concentrations between the vegans and the omnivores. Miller & Mumford (1972) suggested that lysine or tryptophan or sulphur-containing amino acids were most likely to be the limiting amino acids in vegan diets. Indeed, plasma and urinary concentrations of lysine and the S-containing amino acids were lower in the vegans. Urinary tryptophan levels were very much lower in the vegans, and this correlated with a low tryptophan intake. However, nicotinic acid intakes were adequate in all subjects.

Methylhistidines are found in muscle tissue and have been used as indicators of protein turnover (Emery, 1980). Since the methylhistidines are found predominantly in meat, it is not surprising that low excretion values of methylhistidines were found in the vegans. The male omnivores consumed more meat and fish than the females, and this would explain their greater excretion of methylhistidines. The higher output of lysine and taurine in the male omnivores supports this argument.

Urinary taurine excretion in the vegan subjects was about half the value of that in the omnivores. Plasma taurine levels were slightly lower, but the latter difference was not statistically significant. It is evident that the intake of preformed taurine needs to be taken into consideration when interpreting values for taurine excretion.

The taurine concentration of omnivore breast milk (53 mg/l) was found to compare well with the value (48 mg/l) reported by the Department of Health and Social Security (1980), which was obtained from pooled samples of breast milk collected from different areas of Great Britain. The mean taurine concentration in the vegan breast milk (35 mg/l), although significantly lower than that found in the omnivores, was still about thirty times greater than that found in cow's-milk infant formulae (Rassin *et al.* 1977). It may be inferred that at least one-third of the taurine in omnivore milk is derived from dietary taurine if the level of taurine in vegan breast milk represents the normal level of synthesis from dietary precursors. It should be noted that the ranges of values for taurine in breast milk of vegan and omnivore mothers overlap substantially; several vegan mothers had higher taurine concentrations than did the omnivore mothers. The report of normal growth and development in children breast-fed by vegan mothers (Sanders & Purves, 1981) indicates that the absence of preformed taurine from the maternal diet has no apparent harmful effect.

It may be inferred, therefore, from the present study that adult man has a considerable capacity to synthesize taurine. A diet devoid of preformed taurine does not appear to be harmful, since clinical studies on vegans suggest that their health differs little from that of omnivores (Ellis & Montegriffo, 1970; Sanders, 1978).

REFERENCES

Abdulla, M., Anderson, I., Berthelsen, K., Birkhed, D., Dencker, I., Johansson, C. G., Jägerstad, M., Kolar, K., Nair, B. M., Nilsson-Ehle, P., Nordén, A., Rassner, S., Akesson, B. & Öckerman, P. A. (1981). *American Journal of Clinical Nutrition* **34**, 2464–2477.
Awapara, J. (1956). *Journal of Biological Chemistry* **218**, 571–576.
Davison, A. N. & Kaczmarek, L. K. (1971). *Nature* **234**, 107–108.
Department of Health and Social Security (1979). *Recommended Daily Amounts of Food, Energy and Nutrients for Groups of People in the UK, Report on Health and Social Subjects* no. 15. London: H.M. Stationery Office.
Department of Health and Social Security (1980). *Artificial Feeds for the Young Infant, Report on Health and Social Subjects* no. 18. London: H.M. Stationery Office.
Egan, H., Kirk, R. S. & Sawyer, R. (editors) (1981). *Pearson's Chemical Analysis of Foods*, 8th ed., pp. 15–18. Edinburgh: Churchill Livingstone.
Ellis, F. R. & Montegriffo, V. M. E. (1970). *American Journal of Clinical Nutrition* **23**, 249–255.
Emery, P. W. (1980). Amino acid metabolism during pregnancy. PhD Thesis, University of London.
Evered, D. F., Harvey, M. S., Luck, L. T. & Solari, M. E. (1969). *Life Sciences* **8**, 601–605.
Gaull, G. E. (1983). *Journal of Pediatric Gastroenterology and Nutrition* **2**, S266–S271.
Gaull, G. E., Rassin, D. K., Räihä, N. C. R. & Heionen, K. (1977). *Journal of Pediatrics* **90**, 348–355.
Gaull, G. E., Sturman, J. A., Wen, G. Y. & Wisniewski, H. M. (1982). In *Membranes in Growth and Development*, Progress in Clinical and Biological Research Series, vol. 91, pp. 349–355. [J. F. Hoffman and G. H. Giebisch, editors]. New York: Liss.
Haslewood, G. A. D. (1964). *Biological Reviews* **39**, 537–574.
Hayes, K. C. (1976). *Nutrition Reviews* **34**, 161–165.
Hayes, K. C., Carey, R. E. & Schmidt, S. Y. (1975). *Science* **188**, 949–951.
Hayes, K. C., Stephan, Z. F. & Sturman, J. A. (1980). *Journal of Nutrition* **110**, 2058–2064.
Hope, D. B. (1955). *Biochemistry* **59**, 497–500.
Hughes, J. (1981). The influence of maternal diet on breastmilk composition with particular regard to the water soluble vitamins. PhD Thesis, University of London.
Jacobsen, J. G. & Smith, L. H. (1968). *Physiological Reviews* **48**, 424–511.
Knopf, K., Sturman, J. A., Armstrong, M. & Hayes, K. (1978). *Journal of Nutrition* **108**, 773–778.
Kuriyama, K. (1980). *Federation Proceedings* **39**, 2680–2684.
Miller, D. S. & Mumford, P. (1972). *Plant Foods in Human Nutrition* **2**, 201–213.
Miller, D. S. & Payne, P. R. (1959). *British Journal of Nutrition* **13**, 501–508.
Oser, B. L. (editor) (1965). *Hawk's Physiological Chemistry*, 14th ed., pp. 1040–1042. New York: McGraw-Hill.
Pasantes-Morales, H., Wright, C. E. & Gaull, G. E. (1984). *Journal of Nutrition* **114**, 2256–2261.
Paul, A. A. & Southgate, D. A. T. (1978). *McCance and Widdowson's The Composition of Foods*. 4th ed. London: H.M. Stationery Office.
Platt, B. S. (1962). *Medical Research Council Special Report Series* no. 302. London: H.M. Stationery Office.
Rabin, B., Nicolosi, R. J. & Hayes, K. C. (1976). *Journal of Nutrition* **106**, 1241–1246.
Rassin, D. K., Sturman, J. A. & Gaull, G. E. (1977). *Journal of Neurochemistry* **28**, 41–50.
Roe, D. A. (1966). *Journal of Investigative Dermatology* **46**, 420–430.
Roe, D. A. & Weston, M. O. (1965). *Nature* **205**, 287–288.
Sanders, T. A. B. (1978). *Plant Foods for Man* **2**, 181–193.
Sanders, T. A. B. & Purves, R. (1981). *Journal of Human Nutrition* **35**, 349–357.
Soupart, P. (1962). In *Amino Acid Pools*, pp. 220–262 [J. T. Holden, editor]. Amsterdam: Elsevier.
Sturman, J. A. (1973). *Journal of Nutrition* **103**, 1566–1580.
Sturman, J. A. & Hayes, K. C. (1980). In *Advances in Nutritional Research*, vol. 3, pp. 231–299 [H. H. Draper, editor]. New York: Plenum.
Sturman, J. A., Rassin, D. K. & Gaull, G. E. (1977). *Life Sciences* **21**, 1–22.
United States Department of Agriculture (1979). *Agriculture Handbook* no. 8, *Composition of Foods – Raw, Processed and Prepared* [B. K. Watt and A. Merril, editors]. Washington, DC: United States Department of Agriculture.
Westall, R. G. (1962). In *Amino Acid Pools*, pp. 195–219. [J. T. Holden, editor]. Amsterdam: Elsevier.

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