Dietary Taurine Content and Feline Reproduction and Outcome[1]

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ABSTRACT The reproductive performance and the outcome of the kittens was determined for female cats fed 0, 0.01, 0.02 or 0.05% taurine. Reproductive performance and outcome in the 0.02% group was substantially better than in the 0 and 0.01% groups but not as good as in the 0.05% group. Kittens in the 0.05% group had higher body weights and brain weights at birth and at 8 wk after birth than did kittens in the other groups. The concentration of taurine in milk was much higher in females fed 0.05% taurine (~1.9 mmol/L) compared with females fed 0.02% taurine (~0.55 mmol/L) or females fed 0 or 0.01% taurine (~0.2 mmol/L). The concentration of taurine in tissues and fluids of adult females, newborn kittens and 8-wk-old kittens in the 0.05% group was significantly higher than in all other groups. In general, the concentration of taurine in tissues and fluids of the 0.02% group were not significantly different than in the 0 or 0.01% groups, with the exception of 8-wk-old kittens, in which several values, including retina and five brain regions, were significantly higher than in the 0 and 0.01% groups. These results indicate that the postnatal supply of taurine in the mother's milk had a greater impact than the intrauterine environment on the taurine concentration of the offspring in the 0.02% group; this amount of dietary taurine is still insufficient for a normal reproductive performance and resulted in significantly smaller taurine concentrations in adults and offspring. J. Nutr. 121: 1195–1203, 1991.

INDEXING KEY WORDS:

• *cats* • *reproduction* • *taurine*

The last two decades have witnessed the physiological status of taurine move from that of an enigmatic end product of methionine metabolism to a widely accepted essential nutrient for cats and a conditionally essential nutrient for primates, including humans. The adverse effects of dietary taurine deficiency are now better known, starting with the landmark discovery of Hayes et al. (1) that it resulted in feline central retinal degeneration. This observation has been confirmed and extended in several laboratories, and the depletion of taurine throughout the body has been documented (2–11). Ultrastructural abnormalities were reported in a second tissue, the tapetum lucidum, the reflecting layer of cells behind the retina that maximizes retinal sensitivity in low light situations (8, 9). More recently, taurine deficiency was implicated in feline dilated cardiomyopathy, a condition that is reversed by nutritional taurine therapy if treated in time (12–14). This condition was responsible for the death of thousands of household cats every year, but it has virtually disappeared since taurine fortification of commercial cat foods was initiated. Taurine deficiency has been reported to result in profound changes in the immune system, including a decrease in total white cells, a shift in the proportional distribution of cells from polymorphonuclear to mononuclear, a decreased respiratory burst in the remaining polymorphonuclear cells and a decrease in the phagocytosis and intracellular killing of *Staphylococcoccus epidermis* (15–17). Changes in spleen and lymph nodes also were observed in taurine-deficient cats. The ramifications of these observations are presently unknown.

Over the past 5 y we reported that taurine-deficient queens have greatly increased reproductive wastage (frequently aborting or resorbing their fetuses) and have stillborn or live low-birth-weight kittens at term (11, 18). Surviving kittens exhibit a number of neurologic and morphologic abnormalities such as a persistence of cells in the cerebellar external granule cell layer (some of which are still dividing), abnormal migration and differentiation of cells in the visual cortex, and degeneration or abnormal development of the retina and tapetum lucidum (18–22).

We report here in detail the expanded data on

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pregnancy and outcome of queens fed diets containing 0 and 0.05% taurine and new data for females fed 0.01 and 0.02% taurine. Growth data and tissue taurine concentrations for kittens from all groups and milk and tissue taurine concentrations from all groups of adults are included.

MATERIALS AND METHODS

Female domestic cats raised in the colony of the Institute for Basic Research in Developmental Disabilities and vaccinated against rhinotracheitis, panleukopenia, calici virus [FVR-C-P (MLV) Pitman-Moore, Washington Crossing, NJ] were fed a completely defined, taurine-free purified diet (BioServ, Frenchtown, NJ) for at least 6 mo prior to mating. The purified diet contained (g/100 g): casein (vitamin-free), 43.0; chicken fat, 20.0; dextrin, 13.5; sucrose, 13.5; salt mix, 6.4; cellulose, 2.4; vitamin mix, 0.6; L-cystine, 0.3; choline chloride, 0.3. The salt mix contained (g/kg): potassium phosphate dibasic, 328; calcium carbonate, 290; sodium chloride, 162; magnesium sulfate, 99; calcium phosphate dibasic, 73; magnesium oxide, 32; ferric citrate, 13; manganese sulfate, 1.22; zinc chloride, 0.91; cupric sulfate, 0.29; potassium iodide, 0.077; chromium acetate, 0.044; sodium fluoride, 0.023; sodium selenite, 0.0043. The vitamin mix contained (g/kg): dextrin, 857; inositol, 100; all-*rac*-α-tocopheryl acetate (500 IU/g), 20; niacin amide, 8.0; calcium pantothenate, 5.0; retinyl acetate (500,000 IU/g), 5.0; riboflavin, 1.60; cholecalciferol (200,000 IU/g), 1.25; thiamine·HCl, 0.80; pyridoxine·HCl, 0.80; folic acid, 0.80; menadione, 0.10; biotin, 0.04; cyanocobalamin, 0.03.

Other groups of female cats were fed the same diet containing 0.01, 0.02 or 0.05% taurine. Females from all groups were bred as follows: when in estrus they were caged with a male for 1 wk; conception was defined as the middle of this period. Male cats were fed a taurine-supplemented diet, except for the interval of cohabitation with the females fed a different diet. Pregnancies were confirmed by palpation and in some instances also by X-ray 4–6 wk after conception. Gestation time did not vary among the groups. Ten to 15 female cats in each group could be maintained at any one time, although considerable replacement of individuals occurred over the many years this study was in progress.

The birth weight and semiweekly weights of all kittens were determined. Maternal samples of blood (weekly) and milk (semiweekly) were taken beginning within 48 h of birth (11). Portions of whole milk were retained for measurement of protein concentration by the method of Bradford (23).

Kittens were killed at the time of weaning (8 wk after birth) by exsanguination following an overdose of sodium pentobarbital (Nembutal, Abbott Laboratories, North Chicago, IL) or by intracardiac perfusion following an overdose of sodium pentobarbital (these kittens were used for morphological and ultrastructural studies). Blood samples were collected for measurement of routine blood chemistry parameters by a commercial laboratory (CENVET, New York, NY). Parameters measured were inorganic phosphate, total protein, albumin, globulin, albumin:globulin ratio, calcium, glucose, blood urea nitrogen, creatinine, blood urea nitrogen:creatinine ratio, total bilirubin, alkaline phosphatase (EC 3.1.3.1), lactate alanine dehydrogenase (EC 1.1.1.27), alanine aminotransferase (EC 2.6.1.2), aspartate aminotransferase (EC 2.6.1.1), sodium, potassium, chloride and cholesterol. Tissues were dissected and processed immediately or frozen on dry ice until processed by homogenizing in 0.88 mol/L trifluoroacetic acid and centrifuging to obtain a clear supernatant fluid. This fluid was stored at −80°C until derivatized with phenylisothiocyanate and separated by reverse-phase HPLC (24). The apparatus used consisted of a Spectra Physics (Piscataway, NJ) 8800 ternary HPLC pump and a 4.6 mm × 25 cm BakerBond C-18 column (Baker, Phillipsburg, NJ) maintained at 34°C. The taurine derivative was detected at 254 nm with an LDC SpectroMonitor D (Milton Roy, Riviera Beach, FL) and quantified using Nelson Analytical (Cupertino, CA) 2600 chromatography software with an IBM PC-AT (New York, NY). A Waters 712 WISP (Milford, MA) allowed the automatic analysis of up to 96 samples.

Some live kittens were killed at birth as described for the 8-wk-old kittens. When this was done, these pregnancies and any subsequent growth data on remaining kittens were not used in calculating the data presented because of possible bias caused by artificially reducing the number of kittens in a litter.

Adult female cats were killed by exsanguination following an overdose of sodium pentobarbital after they had at least four pregnancies and at least 2 wk after the last kittens were weaned. Blood samples were collected for measurement of routine blood chemistry parameters. Tissues were removed and processed as described for the kittens. These studies were approved by the Institute for Basic Research animal welfare committee.

Portions of cortex and liver were used for measurement of the activities of several enzymes involved in taurine biosynthesis. Cystathionine synthase (EC 4.2.1.22) was measured as described previously (25), except that the cystathionine formed was measured by using a Beckman 119 CL (Palo Alto, CA) automatic amino acid analyzer. Cystathionase (EC 4.4.1.1) was measured as described previously (25). Cysteine dioxygenase (EC 1.13.11.20) was measured as described by Yamaguchi et al. (26) as modified by Misra and Olney (27). Cysteinesulfinic acid decarboxylase [(EC 4.1.1.29): note that the correct name of this

TABLE 1

Blood chemistry parameters of 8-wk-old kittens and adult cats fed purified diets[1]

Parameter	Kittens (8-wk-old)	Adult cats
Inorganic phosphate, *mmol*	3.04 ± 0.45	1.78 ± 0.29
Total protein, *g*	56 ± 7	71 ± 10
Albumin, *g*	27 ± 10	25 ± 6
Globulin, *g*	30 ± 4	47 ± 10
Albumin:globulin ratio, *g/g*	0.9 ± 0.4	0.5 ± 0.1
Calcium, *mmol*	2.52 ± 1.12	2.30 ± 0.20
Glucose, *mmol*	7.3 ± 1.4	5.7 ± 2.3
Blood urea nitrogen (BUN), *mmol urea*	10.5 ± 3.2	10.8 ± 3.6
Creatinine, *μmol*	59 ± 9	98 ± 27
BUN:creatinine ratio, *mol/mol*	178 ± 57	96 ± 40
Total bilirubin, *μmol*	4.3 ± 2.9	3.4 ± 1.9
Alkaline phosphatase, *μmol/min*	37 ± 16	16 ± 8
Lactate dehydrogenase, *μmol/min*	331 ± 92	247 ± 112
Alanine aminotransferase, *μmol/min*	37 ± 18	57 ± 22
Aspartate aminotransferase, *μmol/min*	42 ± 25	57 ± 27
Sodium, *mmol*	144 ± 19	149 ± 8
Potassium, *mmol*	5.0 ± 0.5	4.6 ± 0.7
Chloride, *mmol*	111 ± 5	113 ± 8
Cholesterol, *mmol*	3.39 ± 0.83	2.38 ± 0.62

[1]Each value represents the mean ± SD of 50 kittens or of 55 adult cats. All units are expressed per liter of plasma.

enzyme is 3-sulfinoalanine decarboxylase, although we refer to it in this paper by the familiar name] was measured by collecting the $^{14}CO_2$ produced from [1-^{14}C]cysteinesulfinic acid [specific activity 1.37 TBq/mol (Research Products International, Elk Grove Village, IL)] under conditions previously described (28). Cysteinesulfinic acid decarboxylase, which decarboxylates cysteinesulfinic acid but not glutamic acid, in brain has been conclusively demonstrated to be a different protein from glutamic acid decarboxylase (EC 4.1.1.15) (29), although the latter enzyme can utilize cysteinesulfinic acid as substrate. Decarboxylation of cysteinesulfinic acid by glutamic acid decarboxylase can be prevented by saturating this enzyme with unlabeled substrate that will not contribute to the labeled CO_2 produced. Liver does not possess any glutamic acid decarboxylase activity. Therefore, measurements of cysteinesulfinic acid decarboxylase activity in brain were carried out in the presence of 100 mmol/L unlabeled L-glutamic acid. Protein concentration was measured by the method of Bradford (23). Results from all groups of animals were analyzed using one-way ANOVA ("oneway" Stata, Computing Resource Center, Los Angeles, CA); if significance was found ($P \leq 0.05$), individual groups were compared using Student's *t* test (protected *t* test).

RESULTS

Clinical description. The adult females fed the diets containing different amounts of taurine remained in apparently good condition for the duration of the study, which for some was as long as 5 y of consuming a particular diet. There were no differences in food consumption, no abnormal changes in weight, and all females came into estrus regularly. Cats fed the taurine-free and 0.01% taurine diets were noticeably poorer in grooming themselves, especially after several years of consuming the diet; this was particularly evident in longer-haired cats. These same cats rapidly developed ophthalmoscopically visible retinal degeneration by 6–8 mo, as described previously in detail (11). Most of the females fed the diet containing 0.02% taurine eventually developed retinal degeneration, but only after more than 2 y of consuming the diet. Females fed the diet containing 0.05% taurine did not develop retinal degeneration. There were no significant differences in any of the routine chemistry parameters measured between any of the groups of adults or 8-wk-old kittens (data not shown). The means of all animals tested are presented in Table 1 to provide reference data for cats and kittens raised on these purified diets. These values fall within the range of those available for "normal" cats.

The reproductive performance of the females fed 0 or 0.01% taurine was poor and essentially similar to that reported previously for taurine-deficient cats (11, 18), whereas that of the females fed 0.02% taurine was intermediate (Table 2). In the latter queens, few pregnancies were terminated prior to term, litter size was greater and contained few stillborn kittens, and survival of kittens was better than found with

TABLE 2

Outcome of pregnancies from female cats fed a purified diet (taurine-free) alone or supplemented with various amounts of taurine

Diet (% taurine)	Pregnancies		Kittens			% Pregnancies to term	No. Kittens/ term pregnancy[3]	No. Survivors/ term pregnancy
	Total	To term	Stillborn[1]	Live[1]	Survivors[2]			
0	96	49	41	84	34	51	2.5	0.69
0.01	44	22	7	46	9	50	2.4	0.41
0.02	53	36	4	98	46	68	2.8	1.28
0.05	73	64	12	218	154	88	3.6	2.41

[1]From term pregnancies.
[2]Alive at weaning at 8 wk after birth.
[3]Includes live and stillborn kittens.

mothers fed 0 or 0.01% taurine. Surviving kittens from females fed the taurine-free and 0.01% taurine diets exhibited a variety of neurologic abnormalities, including abnormal hind limb development and a peculiar gait characterized by excessive abduction and paresis; they had a grossly apparent thoracic kyphosis, as described in detail previously (11). We also have observed a number of instances of hydrocephalus in fetuses and kittens and one instance of anencephaly in a newborn kitten. These severe manifestations probably result from extreme taurine deficiency because we previously (18) noted that stillborn kittens from taurine-deficient mothers have an even smaller concentration of taurine in their brain than do live kittens. Such abnormalities probably occur frequently and remain undetected because aborted fetuses, stillborn kittens and abnormal live kittens usually are eaten by their mothers. Such abnormalities are generally not present, or present to a much lesser extent, in kittens from females fed the diet containing 0.02% taurine.

Kittens from mothers fed 0, 0.01 or 0.02% taurine had similar birth weights, and all groups were significantly smaller than kittens born to mothers fed 0.05% taurine (Table 3). In addition, kittens from mothers fed 0% taurine were significantly smaller than kittens from mothers fed 0.02% taurine. By the time of weaning at 8 wk after birth, kittens from mothers fed the 0, 0.01 or 0.02% diets were still significantly smaller than those from mothers fed the diet containing 0.05% taurine; but kittens from mothers fed the taurine-free diet were no longer significantly smaller than those from mothers fed the 0.02% diet (Table 3, Fig. 1). In addition to affecting birth weight and growth, the brain weight of kittens from mothers fed different amounts of taurine also varied (Table 3). The differences in brain weights were more pronounced at birth; all groups were significantly different from all other groups except 0 and 0.01% taurine and 0.02 and 0.05% taurine. At the time of weaning at 8 wk after birth, the brain weights were greater in proportion to the amount of taurine in the mother's diet, although the only significant difference was between 0 and 0.05% taurine.

Taurine concentrations. The concentration of taurine in the milk of the lactating females was

TABLE 3

Body and brain weights of newborn and 8-wk-old kittens from female cats fed a purified diet (taurine-free) alone or supplemented with various amounts of taurine[1]

Diet (% taurine)	Newborn			8-Wk-old		
	Body	Brain		Body	Brain	
	g					
0	76.4 ± 26.2[ab]	3.43 ± 0.83[ab]	(31)	638 ± 228[d]	19.8 ± 2.1[c]	(23)
0.01	77.7 ± 14.8[a]	3.67 ± 0.34[bc]	(7)	624 ± 101[d]	20.0 ± 1.3	(7)
0.02	83.2 ± 20.3[a]	4.24 ± 0.69	(14)	692 ± 118[c]	20.6 ± 2.1	(16)
0.05	105.6 ± 30.3	4.86 ± 1.14	(23)	749 ± 142	21.7 ± 1.8	(28)

[1]Each value represents the mean ± SD of the body weight of all kittens used in this study and of the brain weights of the number of brain samples given in parentheses. Significance was determined using Student's *t* test. [a]Significantly lower than 0.05% group ($P < 0.0001$). [b]Significantly lower than 0.02% group ($P < 0.05$). [c]Significantly lower than 0.05% group ($P < 0.05$). [d]Significantly lower than 0.05% group ($P < 0.001$).

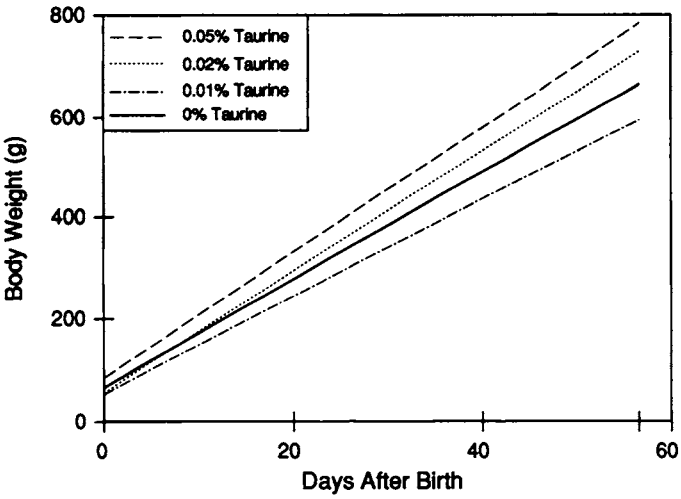

FIGURE 1 Body weight of kittens from birth to weaning at 8 wk after birth from mothers fed 0, 0.01, 0.02 or 0.05% taurine. These data are derived from the semiweekly weights of all surviving kittens (34, 9, 46 and 154, respectively) in this study using a standard computer program for linear regression. Correlation coefficients are 0.75, 0.93, 0.90 and 0.87, respectively.

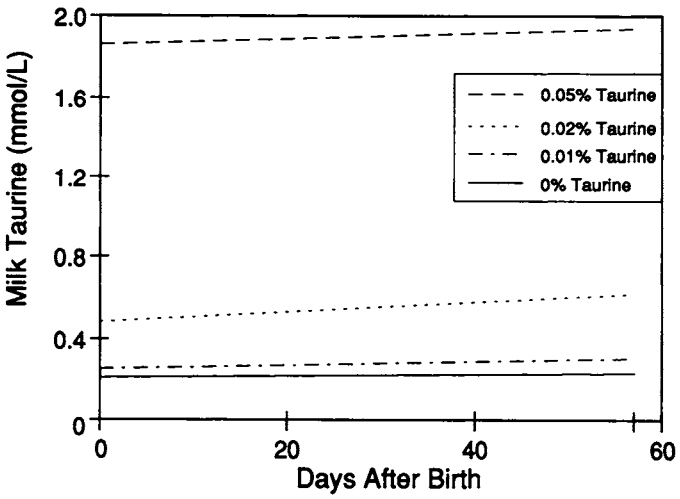

FIGURE 2 Concentration of taurine in milk of lactating female cats fed 0, 0.01, 0.02 or 0.05% taurine. These data are derived from the semiweekly determinations from all females (34, 9, 36 and 64, respectively) in this study using a standard computer program for linear regression. Correlation coefficients are 0.05, 0.07, 0.02 and 0.03, respectively.

greatest in those fed the diet containing 0.05% taurine, substantially smaller in those fed 0.02% taurine and smallest in those fed 0.01 or 0% taurine (Fig. 2). The concentration of protein in milk did not vary much among the groups or during lactation. Mean values (± SD) were 57.9 ± 15.6, 61.2 ± 23.6, 63.7 ± 18.0 and 56.8 ± 17.0 g/L for mothers fed 0, 0.01, 0.02 and 0.05% taurine, respectively. The value for the 0.05% group was significantly smaller ($P < 0.05$) than the value for the 0.02% group.

The concentration of taurine in tissues and fluids of adult female cats generally was higher when the proportion of taurine in the diet was higher (Table 4). The concentration of taurine in all tissues and fluids from the 0.05% group was significantly higher than in all other groups, whereas few tissues from the 0.02% group had higher concentrations than the 0 and 0.01% groups, and only retina from the 0.01% group was significantly higher than the 0% group. All brain regions from the 0, 0.01 and 0.02% groups had significantly smaller taurine concentrations than the 0.05% group, yet the values did not vary significantly between the 0, 0.01 and 0.02% groups.

Tissues and fluids of newborn kittens from mothers fed 0.05% taurine had significantly higher taurine concentrations than all other groups (Table 5). Only plasma and the occipital lobe of newborn kittens from mothers fed 0.02% taurine were significantly greater than those of the 0 or 0.01% groups. No concentrations in the 0.01% group were significantly higher than those in the 0% group.

At weaning (8 wk after birth) the concentration of taurine in all tissues and fluids of the 0.05% group was significantly higher than all other groups (Table 6). Several values of the 0.02% group were significantly higher than those of the 0% group, including five brain regions. None of the values of the 0.01% group were significantly higher than those of the 0% group.

The activities of the enzymes involved in taurine biosynthesis in liver and brain of 8-wk-old kittens from mothers fed 0.01% or 0.02% taurine were not significantly different from those previously published (11) for kittens of mothers fed 0 and 0.05% taurine (data not shown).

DISCUSSION

The present results confirm that the dietary content of taurine directly influences the outcome of pregnancy in cats and the subsequent growth and development of their offspring. The magnitude of the effects resulting from diets deficient in taurine was generally greater when the amount of taurine in the diet was smaller, but the effects were by no means proportional. Thus, there was no discernible difference in reproductive performance and outcome between females fed 0% taurine and those fed 0.01% taurine (Table 2). Increasing the maternal dietary taurine content by a similar increment to a total of 0.02% had a profound, beneficial effect on reproductive performance and outcome. These mothers had fewer pregnancies terminated prior to term, frequently had multiple live births and often had more than one live kitten survive to weaning at 8 wk after birth. We have never observed this latter fact for offspring from mothers fed 0 or 0.01% taurine. The

TABLE 4

Concentration of taurine in tissues and fluids of adult cats fed a purified diet (taurine-free) alone or supplemented with various amounts of taurine[1]

Tissue	Dietary taurine			
	0%	0.01%	0.02%	0.05%
	μmol/g wet weight			
Retina	15.9 ± 5.5	23.8 ± 6.8[2]	31.9 ± 6.8[3]	42.4 ± 4.4
Tapetum	5.78 ± 2.94	4.54 ± 1.26	4.92 ± 0.86	11.1 ± 3.6
Lens	1.68 ± 0.88	2.31 ± 1.30	1.97 ± 0.84	6.64 ± 2.30
Liver	0.60 ± 0.48	0.98 ± 1.02	1.59 ± 1.41	8.50 ± 3.33
Kidney	0.92 ± 0.45	1.10 ± 0.46	1.51 ± 0.95	5.15 ± 1.91
Lung	2.11 ± 1.63	2.42 ± 1.00	3.36 ± 1.53	8.28 ± 2.60
Spleen	1.46 ± 0.70	1.80 ± 1.25	2.01 ± 0.99	7.34 ± 2.44
Adrenal	3.63 ± 1.87	4.31 ± 2.02	5.00 ± 2.15	12.5 ± 3.6
Heart	1.67 ± 1.04	2.86 ± 1.57	3.40 ± 2.52[2]	12.0 ± 2.7
Gastrocnemius	0.82 ± 0.38	0.92 ± 0.45	1.48 ± 1.09	5.84 ± 1.02
Biceps	1.26 ± 0.94	1.40 ± 1.06	3.03 ± 1.61[3]	6.35 ± 1.62
Triceps	1.47 ± 1.41	1.26 ± 0.89	1.51 ± 1.35	7.83 ± 2.96
Diaphragm	0.67 ± 0.57	0.60 ± 0.51	2.80 ± 1.42[2]	5.49 ± 2.33
Plasma, *μmol/L*	7.6 ± 6.1	9.3 ± 7.7	70.0 ± 27.5[3]	127 ± 53
Occipital lobe	0.56 ± 0.48	0.50 ± 0.37	0.44 ± 0.19	2.28 ± 0.88
Frontal lobe	0.50 ± 0.37	0.57 ± 0.25	0.55 ± 0.23	2.19 ± 0.49
Temporal lobe	0.43 ± 0.35	0.43 ± 0.11	0.38 ± 0.12	1.92 ± 0.88
Parietal lobe	0.57 ± 0.48	0.34 ± 0.19	0.36 ± 0.14	2.32 ± 0.76
Cerebellum	0.45 ± 0.24	0.56 ± 0.30	0.56 ± 0.27	3.14 ± 0.80
Superior colliculus	0.27 ± 0.13	0.25 ± 0.15	0.29 ± 0.10	1.65 ± 0.44
Inferior colliculus	0.36 ± 0.28	0.21 ± 0.10	0.35 ± 0.18	1.56 ± 0.47
Hippocampus	0.42 ± 0.22	0.50 ± 0.25	0.48 ± 0.15	2.19 ± 0.64
Corpus callosum	0.40 ± 0.29	0.38 ± 0.18	0.46 ± 0.20	2.67 ± 0.57
Thalamus	0.38 ± 0.44	0.24 ± 0.11	0.32 ± 0.11	1.55 ± 0.29
Pons	0.25 ± 0.25	0.19 ± 0.10	0.25 ± 0.12	1.48 ± 0.38
Medulla	0.36 ± 0.35	0.25 ± 0.15	0.45 ± 0.49	1.47 ± 0.47
Olfactory bulb	3.19 ± 1.57	4.43 ± 2.36	3.90 ± 1.94	7.43 ± 1.89
Lateral geniculate nucleus	0.39 ± 0.30	0.25 ± 0.17	0.36 ± 0.19	1.95 ± 0.71
Optic tract	1.07 ± 0.48	0.87 ± 0.25	0.97 ± 0.30	2.25 ± 0.84
Optic nerve	1.37 ± 0.58	1.65 ± 0.92	1.23 ± 0.26	3.29 ± 1.08
Spinal Cord	0.39 ± 0.44	0.25 ± 0.20	0.26 ± 0.28	1.03 ± 0.41
Sciatic nerve	0.27 ± 0.29	0.32 ± 0.25	0.42 ± 0.38	1.14 ± 0.40

[1]Each value represents the mean ± SD of 10 to 30 cats. The 0.05% group is significantly greater than all other groups (at least $P < 0.05$, in most instances $P < 0.001$). Significance was determined by Student's t test.

[2]Significantly greater than 0% group ($P < 0.05$).

[3]Significantly greater than 0 and 0.01% groups ($P < 0.05$).

reproductive performance and outcome of females fed 0.05% taurine was not different from that reported for cats fed various proprietary cat foods (30–32). The taurine content of proprietary cat foods is approximately the same (0.05%) on a dry weight basis, although we have analyzed brands that range from 0.02 to 0.2%. Recently a number of proprietary cat foods, including some that contain at least 0.05% taurine, were reported as a possible cause of feline dilated cardiomyopathy associated with low plasma taurine concentrations (12–14). This condition, which responds to nutritional taurine therapy, has been virtually eliminated by the recent taurine fortification of commercial cat foods, which now contain 0.2% or more of taurine. However, there is increasing evidence that the root cause of this condition is not insufficient taurine in the diet but rather the presence of some other factor, such as an inhibitor of taurine uptake, which may have been produced during cooking (ref. 33; and Wright, C. E., Sturman, J. A. & Pion, P. D., unpublished data).

The maternal dietary taurine content significantly affected the body weight of the offspring, both at birth and at weaning; kittens from the 0, 0.01 and 0.02% groups were significantly smaller than kittens from the 0.05% group at both ages (Table 3, Fig. 1). These weight and growth differences were minimized because the number of kittens suckling the mothers fed 0.05% taurine was greater than the number suckling the mothers fed 0.02% taurine, which in turn was greater than the number suckling the mothers fed 0.01 or 0% taurine. The total protein content of the

TABLE 5

Concentration of taurine in tissues and fluids of newborn kittens from mothers fed a purified diet (taurine-free) alone or supplemented with various amounts of taurine[1]

Tissue	Dietary taurine			
	0%	0.01%	0.02%	0.05%
	μmol/g wet weight			
Retina	8.51 ± 4.36	6.41 ± 2.46	9.98 ± 1.07	19.6 ± 5.9
Lens	5.65 ± 2.09	6.06 ± 2.79	6.02 ± 1.55	15.2 ± 2.0
Liver	4.28 ± 2.93	5.22 ± 1.07	4.40 ± 2.68	9.37 ± 3.95
Kidney	3.68 ± 2.16	2.66 ± 0.96	3.74 ± 1.23	6.58 ± 1.97
Lung	4.06 ± 2.50	2.91 ± 1.38	4.59 ± 2.66	8.54 ± 2.31
Spleen	2.51 ± 2.10	2.59 ± 1.34	2.79 ± 1.55	5.81 ± 1.61
Heart	5.77 ± 4.12	3.79 ± 1.24	6.30 ± 2.61	12.9 ± 4.7
Gastrocnemius	2.78 ± 1.97	2.76 ± 1.10	4.08 ± 2.97	9.36 ± 3.45
Biceps	3.39 ± 2.00	3.26 ± 1.96	3.01 ± 0.62	9.58 ± 2.51
Triceps	3.53 ± 2.05	3.17 ± 1.14	3.27 ± 1.90	9.35 ± 2.15
Diaphragm	2.73 ± 2.20	2.60 ± 0.93	3.09 ± 1.98	6.54 ± 2.03
Stomach contents	0.25 ± 0.16	—	—	0.87 ± 0.73
Plasma, *μmol/L*	24.6 ± 10.7	32.9 ± 21.9	125 ± 65[2]	155 ± 71
Occipital lobe	3.67 ± 1.85	2.98 ± 0.66	5.38 ± 2.56[2]	7.77 ± 2.15
Frontal lobe	3.44 ± 1.71	3.66 ± 1.80	3.89 ± 1.43	8.84 ± 0.83
Cerebellum	3.60 ± 2.39	2.64 ± 1.03	3.32 ± 1.35	7.17 ± 1.71
Olfactory bulb	5.95 ± 3.03	5.61 ± 2.46	7.22 ± 2.02	11.7 ± 2.9
Spinal cord	0.61 ± 0.21	1.43 ± 0.44	1.07 ± 0.22	3.88 ± 0.76

[1]Each value represents the means ± SD from 10 to 24 kittens. The 0.05% group is significantly greater than all other groups (at least $P < 0.05$, in most instances $P < 0.001$). Significance was determined by Student's t test.

[2]Significantly greater than 0 and 0.01% groups ($P < 0.05$).

milk of the various groups was not substantially different. We previously demonstrated that the amino acid composition of milk proteins from lactating mothers fed 0 or 0.05% taurine is not different (11). The only free amino acid in milk from the various groups that is different is taurine. Of course, there could be differences in other milk constituents (such as growth hormones) that have not been measured, but part (if not all) of the growth differences can be attributed to the differences in the taurine content of the milk, because we have demonstrated that oral taurine supplementation of kittens suckling taurine-deficient mothers largely restored their growth rate (34). Brain weights of newborn kittens from the 0 and 0.01% groups and of 8-wk-old kittens from the 0% group were significantly lower than those from the 0.05% group (Table 3).

An important observation from this study is that, although the reproductive performance and outcome of females fed 0.02% taurine were significantly better than those of females fed 0 or 0.01% taurine, the concentration of taurine in the tissues and fluids, with a few exceptions, was little different (Table 4). The higher plasma taurine concentration may have been sufficient to supply the growing fetuses with enough taurine to make the difference during this critical period and to increase the milk taurine concentration during lactation (Fig. 2). The greater taurine concentrations in all tissues and fluids of the females fed the 0.05% taurine diet vs. other groups is evident (Table 4, Fig. 2).

The differences noted in the taurine concentrations of tissues and fluids between the 0.05% groups and all other groups persisted in the tissues and fluids of newborn kittens (Table 5). With the exceptions of plasma and the occipital lobe of the 0.02% group, there were no significant differences between the 0, 0.01 and 0.02% groups. At weaning at 8 wk after birth, the significantly higher taurine concentrations in tissues and fluids of the 0.05% group persisted (Table 6). At this time, however, the concentrations of a number of tissues and fluids of the 0.02% group were significantly higher than those of the 0 and 0.01% groups. These included retina and five brain regions and indicate that the postnatal supply of taurine in the mother's milk had a greater impact on the taurine concentrations of the offspring in the 0.02% group than did the slightly higher intra-uterine taurine supply.

These results further demonstrate that the biosynthetic capacity for taurine of cats and kittens is low, and they do not adapt to a taurine deficiency state. A dietary amount of 0.02% taurine is insufficient for a normal reproductive performance and outcome and results in profoundly lower taurine concentrations in adults and their offspring.

TABLE 6

Concentration of taurine in tissues and fluids of kittens from mothers fed a purified diet (taurine-free) alone or supplemented with various amounts of taurine[1]

Tissue	Dietary taurine			
	0%	0.01%	0.02%	0.05%
	μmol/g wet weight			
Retina	23.1 ± 5.3	24.3 ± 4.5	35.6 ± 5.7[3]	45.6 ± 10.8
Tapetum	4.07 ± 1.55	5.64 ± 2.20	4.18 ± 2.87	8.22 ± 2.34
Lens	5.85 ± 2.34	6.20 ± 1.54	8.21 ± 1.94	16.0 ± 4.21
Liver	2.85 ± 2.33	2.60 ± 1.53	2.96 ± 1.49	13.1 ± 4.4
Kidney	1.90 ± 0.94	1.62 ± 0.31	2.35 ± 1.05	5.45 ± 2.06
Lung	3.48 ± 2.11	4.18 ± 1.43	4.37 ± 1.25	9.73 ± 3.58
Spleen	1.51 ± 0.77	1.60 ± 0.43	2.40 ± 1.45	7.18 ± 3.17
Adrenal	2.68 ± 1.83	2.28 ± 0.80	2.39 ± 1.18	9.55 ± 1.38
Heart	3.07 ± 1.98	4.95 ± 2.66	6.97 ± 2.19[2]	15.1 ± 1.1
Gastrocnemius	1.81 ± 0.93	1.64 ± 0.61	2.52 ± 1.24	8.63 ± 2.50
Biceps	1.34 ± 0.79	1.85 ± 0.64	2.85 ± 1.05[2]	10.6 ± 4.8
Triceps	1.75 ± 0.88	1.99 ± 0.51	2.65 ± 1.26	9.47 ± 3.51
Diaphragm	1.57 ± 0.98	1.33 ± 0.40	2.01 ± 1.02	8.02 ± 2.68
Plasma, *μmol/L*	13.9 ± 8.1	25.2 ± 19.4	36.0 ± 32.7[2]	72.4 ± 37.0
Urine, *μmol/L*	78.2 ± 38.4	125 ± 39	187 ± 62[3]	288 ± 83
Occipital lobe	1.23 ± 0.61	1.62 ± 0.72	2.49 ± 0.46[2]	5.60 ± 1.82
Frontal lobe	1.03 ± 0.55	1.40 ± 0.29	1.81 ± 0.32	4.79 ± 0.91
Temporal lobe	1.22 ± 0.42	2.10 ± 1.25	2.13 ± 0.58	5.23 ± 0.97
Parietal lobe	1.38 ± 0.66	1.64 ± 0.68	2.28 ± 0.49	4.67 ± 1.22
Cerebellum	1.70 ± 0.73	2.35 ± 1.04	2.42 ± 0.83	5.55 ± 1.49
Superior colliculus	0.77 ± 0.33	1.15 ± 0.33	1.70 ± 0.95[2]	4.24 ± 1.34
Inferior colliculus	0.83 ± 0.47	1.39 ± 0.83	0.91 ± 0.23	3.14 ± 0.70
Hippocampus	0.93 ± 0.29	1.69 ± 0.64	1.92 ± 0.64[2]	5.03 ± 1.31
Corpus callosum	1.06 ± 0.49	1.69 ± 0.54	1.76 ± 0.67	4.87 ± 1.11
Thalamus	0.75 ± 0.28	1.66 ± 1.16	1.19 ± 0.32	3.71 ± 1.10
Pons	0.67 ± 0.29	0.72 ± 0.19	0.76 ± 0.24	3.03 ± 0.95
Medulla	0.65 ± 0.34	0.76 ± 0.18	0.87 ± 0.44	2.65 ± 0.37
Olfactory bulb	4.53 ± 1.14	6.09 ± 1.63	6.64 ± 1.50	8.37 ± 1.06
Lateral geniculate nucleus	0.78 ± 0.43	1.29 ± 0.37	1.58 ± 0.55[2]	4.44 ± 1.26
Optic tract	1.29 ± 0.51	1.99 ± 1.10	1.81 ± 0.56	4.49 ± 1.48
Optic nerve	2.78 ± 0.63	2.26 ± 0.86	3.52 ± 1.32	6.40 ± 1.18
Spinal cord	0.41 ± 0.13	0.76 ± 0.12	0.89 ± 0.30[2]	3.29 ± 0.91
Sciatic nerve	0.92 ± 0.43	1.67 ± 0.66	1.53 ± 0.43	3.26 ± 0.81

[1]Each value represents the means ± SD from 10 to 30 kittens, 8 wk old. The 0.05% group is significantly greater than all other groups (at least $P < 0.05$, in most instances $P < 0.001$). Significance was determined by Student's t test.

[2]Significantly greater than 0 and 0.01% groups ($P < 0.05$).

[3]Significantly greater than 0% group ($P < 0.05$).

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