HIGH DIETARY TAURINE AND FELINE REPRODUCTION

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INTRODUCTION

Taurine is now well established as an essential nutrient for cats and may also be a conditionally essential nutrient for some other species, especially during development (Sturman, 1988). There is now a large body of literature dealing with the effects of taurine deficiency (Hayes, 1988; Sturman, 1988; Hayes and Trautwein, 1989; Sturman, 1990). Little attention has been paid to potential effects of taurine supplementation, however. In humans and cynamolgus monkeys which conjugate bile acids with taurine and glycine, the proportion of bile acids conjugated with taurine increases as the amount of taurine in the diet is increased (Sjovall, 1960; Haslewood, 1967; Hofmann and Small, 1967; Schersten, 1971; Sturman et al., 1975; Hayes et al., 1980). Such changes influence absorption from the gut, and beneficial effects of dietary taurine supplementation have been reported in chronic and acute hepatitis (Matsuyama et al., 1983; Nakashima et al., 1983), drug-induced liver disease (Attili et al., 1984), cirrhosis (Kroll and Lund, 1966), myotonia (Durelli et al., 1983), cystic fibrosis (Darling et al., 1985; Belli et al., 1987; Colombo et al., 1988; Thompson, 1988) and epilepsy (Barbeau and Donaldson, 1973; Barbeau and Donaldson, 1974; Bergamini et al., 1974; Fukuyama and Ochiai, 1982) although not in retinitis pigmentosa (Reccia et al., 1980). In addition, taurine has been added to commercial infant formulas and pediatric parenteral solutions in recent years because of mounting evidence of subtle abnormalities in visual function resulting from its absence (Sturman, 1986). A recent study reported adverse effects in the guinea pig comprising of fatty changes in the liver accompanied by changes in the lipid content after 14 days of oral administration of taurine (Cantafora et al., 1986). Sudden death syndrome in broiler chickens is reduced by supplementing their diet with taurine (Campbell and Classen, 1989). Other recent reports implicated taurine deficiency in feline dilated cardiomyopathy, and demonstrated its reversal by nutritional taurine therapy if treated in time (Pion et al., 1987; Pion et al., 1988; Pion et al., 1990; Novotny et al., 1991; Fox and Sturman, 1992). This successful treatment led to the fortification of commercial cat foods, which already contained taurine, with additional taurine. Although this has resulted in the virtual disappearance of this condition, no systematic studies have been reported on the long term effects of a high taurine diet. The results of such a study are reported here.

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Female cats were fed completely defined purified diets containing 0.05%, 0.2%, or 1% taurine for at least 6 months prior to breeding as described in detail elsewhere (Sturman and Messing, 1992). Breeding performance was evaluated and taurine concentrations in tissues and fluids of adults and offspring measured.

The high taurine diet had no effect on appetite, food consumption, weight gain, or estrus cycle of the adult females. The reproductive performance, if anything, was slightly better in the females fed the high taurine diet; the proportion of pregnancies reaching term, and the number of kittens surviving to weaning per term pregnancy was slightly greater for the cats fed 1% taurine than those fed 0.05% or 0.2% taurine although none of these trends was statistically significant (Table 1). The growth rates of the kittens from females fed the different amounts of taurine were not significantly different although the greatest was achieved by the kittens from females fed the 0.05% taurine diet (Figure 1). This observation is supported by examination of the birth weights and 8-week-old weights of all kittens in this study (Table 2). The kittens at birth weigh more from females fed the greatest amount of taurine, whereas the reverse is true at 8 weeks of age. The brain weights of kittens from mothers fed 1% taurine were significantly greater than those of the other diet groups, both at birth and at 8 weeks of age. The concentration of taurine in the milk of the lactating females was greater in those fed the highest amounts of dietary taurine and generally increased during lactation (Figure 2).

Table 1. Outcome of pregnancies from females fed a purified diet supplemented with various amounts of taurine.

Diet (% taurine)	0.05	0.2	1.0
Pregnancies	73	24	38
To term	64	20	37
Kittens stillborn[1]	12	9	4
Kittens live[1]	218	65	125
Survivors[2]	154	44	99
% Pregnancies to term	88	83	97
# Kittens/ term pregnancy[3]	3.6	3.7	3.5
# Survivors/ term pregnancy	2.41	2.20	2.68

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

Tissue taurine concentrations in adult cats fed the high taurine diet over an extended period of time (average 2.5 years) were greater in soft tissues and some muscles than controls, but not in retina or brain. Despite spending the entire gestation period in a taurine-enriched environment, newborn kittens from mothers fed 1% taurine had few tissues with significantly higher taurine concentrations. By weaning at 8 weeks after birth, such kittens had many tissues with greater taurine concentrations, including most brain regions. By 12 and 20 weeks after birth, most tissues had significantly greater taurine concentrations. Some representative values for tissues at different ages are provided in Table 3.

Taken together, these results indicate that the fully mature cat brain is largely resistant to significant increases in taurine concentration by consuming a high taurine

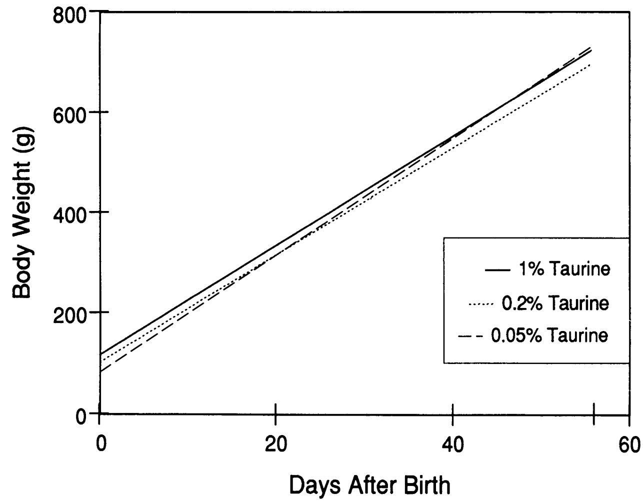

Figure 1. Growth curves of kittens from females fed 0.05%, 0.2%, or 1.0% taurine. The curves are derived from the twice-weekly weights of all kittens included in this study using a standard computer program for linear regression. Correlation coefficients are 0.87, 0.85 and 0.86, respectively.

Table 2. Body and brain weight of newborn and 8-week-old kittens from females fed a purified diet supplemented with various amounts of taurine.

Diet (% taurine)	0.05	0.2	1.0
Newborn			
Body	105.6 ± 30.3	111.6 ± 23.8	113.4 ± 20.8 [1]
Brain	4.86 ± 1.14(23)	4.44 ± 1.10(11)	5.41 ± 0.90[2](9)
8-Week-old			
Body	749 ± 142	722 ± 141	699 ± 147 [3]
Brain	21.7 ± 1.8(28)	22.1 ± 0.9(13)	23.0 ± 1.0[4](10)

Each value represents the mean (in g) ± SD of the body weights of all kittens used in this study and of the number of brain samples in parentheses.
Significance was determined using Student's t test.
1 Significantly greater than 0.05% ($P < 0.01$).
2 Significantly greater than 0.2% ($P < 0.05$).
3 Significantly smaller than 0.05% ($P < 0.05$).
4 Significantly greater than 0.05% ($P < 0.05$).

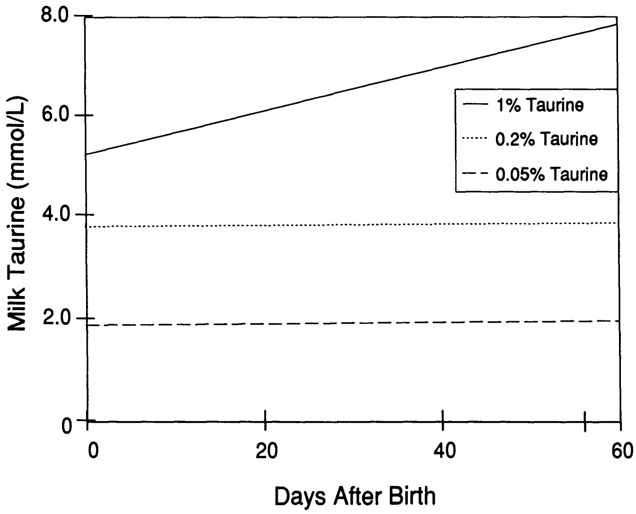

Figure 2. Concentration of taurine in milk of lactating females fed 0.05%, 0.2%, or 1% taurine. The curves are derived from the twice-weekly milk samples from all females included in this study using a standard computer program for linear regression. Correlation coefficients are 0.03, 0.03 and 0.05, respectively.

Table 3. Tissue taurine concentrations in kittens of different ages.

Age and diet	Liver	Lung	Biceps
	μmol/g wet weight		
Newborn 0.05%	9.37 ± 3.95*	8.54 ± 2.31	9.58 ± 2.51
1%	12.9 ± 3.0	9.35 ± 2.19	9.41 ± 4.52
8 Weeks 0.05%	13.1 ± 4.4	9.73 ± 3.58	10.6 ± 4.8
1%	13.1 ± 3.0	10.5 ± 1.6	13.7 ± 3.7
12 Weeks 0.05%	12.5 ± 4.1 *	11.1 ± 2.2 *	10.1 ± 3.7 *
1%	20.1 ± 3.4	14.9 ± 2.3	19.3 ± 3.2
20 Weeks 0.05%	9.16 ± 2.92*	14.9 ± 10.3	9.38 ± 1.35*
1%	18.2 ± 0.8	15.2 ± 2.0	14.4 ± 2.8
Adult 0.05%	8.50 ± 3.33*	8.28 ± 2.6*	6.35 ± 1.62*
1%	17.2 ± 6.3	11.8 ± 2.1	11.4 ± 3.1

* Significantly different, P < 0.05.

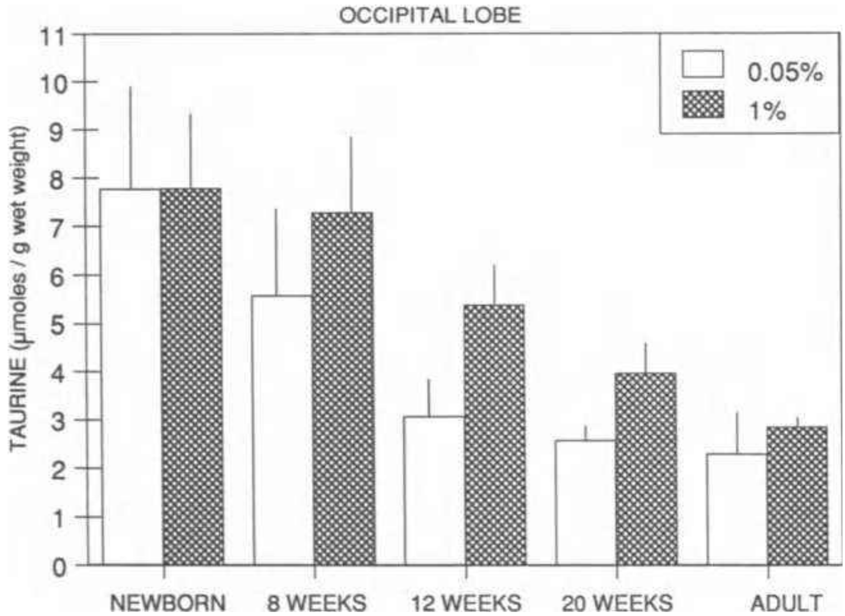

Figure 3. Taurine concentration in occipital lobe as a function of diet and age.

diet over a long period of time, as might be expected. Less expected was the observation that the fetal cat brain was also resistant to increases in taurine concentration, despite the immaturity of the blood brain barrier during gestation. Even more surprising in light of this observation was the apparent decrease in resistance to increases in brain taurine concentrations in young juveniles at 8 wk, 12 wk, and 20 wk after birth, when brain development has been largely completed and the blood brain barrier is fully mature. The high dietary intake provided to the kittens during lactation had a greater impact than the in utero environment of the mothers consuming the high taurine diet. Perhaps the explanation of these results is that the higher taurine concentrations in the blood prevent the normal decrease in brain taurine concentrations during development, illustrated for occipital lobe and cerebellum (Figures 3 and 4). Olfactory bulb, which has a much greater taurine concentration than other regions is not affected (Figure 5), nor is the retina which has an extremely high taurine content. It would be of interest to know when the adult property of resistance to increases in brain taurine concentrations is reached, and whether other compounds besides taurine can increase in juvenile kitten brain.

A number of reports in the literature have linked dietary taurine metabolism to dietary protein content. Mature rhesus monkeys do not appear to be dependent on dietary taurine to maintain their body taurine pools (although rhesus monkey infants do, Sturman et al., 1988) unless their diet is deficient in protein (Neuringer et al., 1979; Neuringer et al., 1985). Supplementary dietary taurine given to lactating mice fed a protein-deficient diet increased the neonatal survival, but had no effect on lactating mice fed a protein-sufficient diet (van Gelder and Parent, 1981). Further data obtained from this same animal model showed that a limited period of undernutrition had a permanent effect on the levels of certain amino acids, including taurine, in the adult cerebellum, and that these changes were modified by taurine supplementation (van Gelder and Parent, 1982). Weanling rats fed a low-protein diet have reduced taurine concentrations in plasma and retina and abnormal retinal function (depressed a and b waves in the electroretinogram) (Bankson and Russell, 1988). Dietary taurine supplementation normalized the taurine concentrations but resulted in further impairment of visual function. Injection of taurine, but not of sodium chloride or valine, into fertilized chicken eggs resulted in increased taurine concentrations in heart and brain, and hatchlings with severe ataxia, reduced muscle strength and impaired motor coordination (van Gelder and Belanger, 1988). There are some significant differences in the lipid composition of liver from adults fed

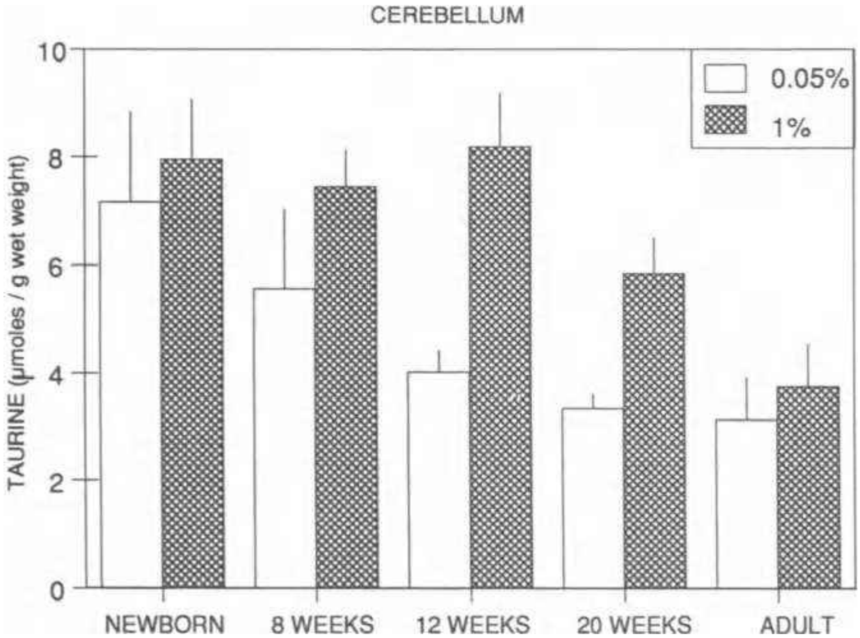

Figure 4. Taurine concentration in cerebellum as a function of diet and age.

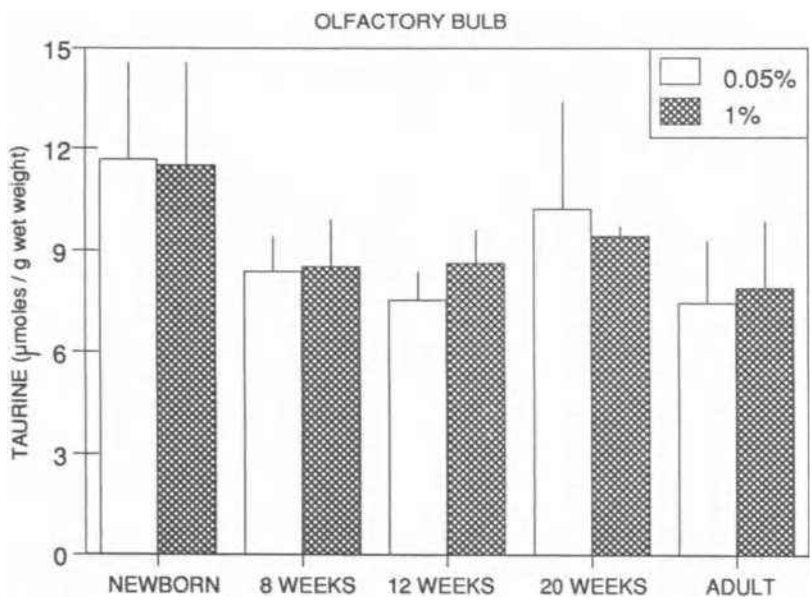

Figure 5. Taurine concentration in olfactory bulb as a function of diet and age.

Table 4. Lipid composition in liver of adult cats fed 0.05% or 1% taurine.

Diet (% taurine)	0.05	1
	mol/g wet weight	
Cholesteryl esters	3.44 ± 1.51	2.69 ± 1.75
Triglycerides	1.78 ± 1.34	6.45 ± 1.46[1]
Free fatty acids	19.57 ± 8.29	6.18 ± 2.18[1]
Cholesterol	5.25 ± 1.62	7.11 ± 1.53[2]
Phosphatidylethanolamine	4.89 ± 1.1	3.90 ± 0.86[3]
Phosphatidylcholine	7.85 ± 2.48	6.36 ± 2.53
Sphingomyelin	1.85 ± 0.42	1.76 ± 0.38
Total lipid	44.6 ± 7.9	34.5 ± 4.8 [3]

[1] Significantly different ($P < 0.001$).
[2] Significantly different ($P < 0.01$).
[3] Significantly different ($P < 0.05$).

0.05% and 1% taurine (Table 4) and in the fatty acid distribution within the lipid classes (Cantafora et al., 1991). The consequences of these differences, if any, are not obvious, and at this stage our studies provide no evidence of ill effects produced by prolonged feeding of high taurine diets to adult cats or on their offspring.

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