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RESPONSE OF THE KITTEN TO DIETARY TAURINE DEPLETION: EFFECTS ON RENAL REABSORPTION, BILE ACID CONJUGATION AND ACTIVITIES OF ENZYMES INVOLVED IN TAURINE SYNTHESIS

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Abstract—1. Kittens were adapted to a semipurified diet and then fed either a control diet that contained 0.1% taurine or a taurine-free diet for 6 weeks; at the end of the feeding period, kittens fed the taurine-free diet had plasma and liver taurine concentrations that were 0.38 and 0.15%, respectively, of those for control kittens.

2. Hepatic cysteinesulfinate decarboxylase activity in taurine-deficient kittens was five-times the level in control kittens, but hepatic cysteine dioxygenase activity was not affected by the dietary treatment.

3. Taurine-conjugated bile acids made up 98% of the total bile acids in the gall bladder of control kittens, but they accounted for only 44% of the total bile acids in the bile of taurine-depleted kittens; both the concentrations of taurine-conjugated bile acids and total bile acids were markedly decreased in taurine-deficient kittens.

4. No effect of taurine depletion on the fractional excretion of taurine in the urine was observed.

5. The kitten may have some mechanisms for adapting to a low-taurine diet, but these are clearly not sufficient to maintain tissue taurine levels in the absence of dietary taurine.

INTRODUCTION

The importance of dietary taurine for the cat has been extensively investigated during the past decade. Hayes and coworkers (Hayes *et al.*, 1975; Berson *et al.*, 1976; Schmidt *et al.*, 1976; Wen *et al.*, 1979) demonstrated that cats fed a taurine-devoid diet are unable to maintain normal tissue levels of taurine and exhibit retinal and tapetal cell abnormalities as well as impairments in visual function. Recently, Sturman *et al.* (1985) demonstrated an adverse effect of maternal taurine depletion on the reproductive performance of cats including a substantial increase in the occurrence of stillbirth, abortion and fetal resorption. Live-born kittens had low birth weights, a poor postnatal survival rate, and exhibited a number of neurological abnormalities. Endogenous taurine biosynthesis from cysteine clearly is very limited in the cat, and this is thought to be due to their low level of hepatic cysteinesulfinate decarboxylase activity (Gaull *et al.*, 1977; Hardison *et al.*, 1977; Knopf *et al.*, 1978; De La Rosa and Stipanuk, 1985a).

The male rat has a much higher level of hepatic cysteinesulfinate decarboxylase activity and capacity for taurine synthesis than does the cat, and the rat does not require dietary taurine (Jacobsen and Smith, 1963; Worden and Stipanuk, 1985). In addition, the rat has some capacity to conserve taurine when sulfur-containing amino acid intake is low by increasing the renal reabsorption of taurine, which is apparently due to an increased uptake of taurine by the brushborder membrane of the renal epithelium (Friedman *et al.*, 1981; Chesney *et al.*, 1983; Freidman *et al.*, 1983). Also, rats depleted of taurine as a result of a vitamin B_6 deficiency or administration of guanidinoethanesulfonate are able to increase the conjugation of bile acids with glycine rather than taurine while maintaining a constant concentration of total bile salts in the bile (Doisy *et al.*, 1956; De La Rosa and Stipanuk, 1985b).

Recent measurements in our lab of cysteinesulfinate decarboxylase activity in tissues of rats and cats indicated that the difference in hepatic cysteinesulfinate decarboxylase activity between rats and cats may not be as great as previously suggested (Gaull *et al.*, 1977). Levels of activity in liver of adult female rats and of young kittens were similar (De La Rosa and Stipanuk, 1985a; Worden and Stipanuk, 1985), suggesting that their capacity for taurine synthesis may also be similar. However, despite her low level of hepatic cysteinesulfinate decarboxylase activity, the female rat is not readily depleted of taurine (Stipanuk and Kuo, 1984). These observations led us to hypothesize that the cat may not be able to conserve taurine as well as the rat. We, therefore, investigated the ability of the cat to adapt to taurine depletion. Specifically, the effects of taurine depletion on the activities of hepatic cysteine dioxygenase and cysteinesulfinate decarboxylase, on the conjugation of bile acids with taurine, and on the renal reabsorption of taurine were determined.

MATERIALS AND METHODS

Animals

Kittens that were 54–65 days of age were obtained from the specific pathogen-free colony maintained by the New York State College of Veterinary Medicine (Cornell Univer-

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sity, Ithaca, NY). For each of two separate experiments, two littermates were taken from each of four litters. Kittens were housed in suspended wire-bottom stainless steel cages provided with resting platforms in a room maintained at 23°C. In the first experiment, two kittens were housed in each cage. In the second experiment, kittens were housed individually. The room was light from 0500 to 2100 hr daily. Food and water were provided *ad libitum* and were changed each morning. Kittens were weighed weekly.

Diets

The control diet contained (by weight) 34% vitamin-free casein (ICN Nutritional Biochemicals, Cleveland, OH), 25% corn oil (Mazola, CPC International, Inc., Englewood Cliffs, NJ), 20.7% cornstarch, 15% glucose monohydrate (Cerelose, CPC International, Inc.), 4% of a mineral mix (National Research Council, 1978), 1% of a vitamin mix (Morris *et al.*, 1979), 0.3% choline chloride and 0.1% taurine (National Research Council, 1978). The taurine-free diet was identical to the control diet except that the taurine was replaced with cornstarch. The diet was made in 5–10 kg quantities and stored frozen in covered containers. Before the diet was fed, 0.5 kg of diet was mixed with an agar solution (20 g of agar dissolved in 1 l. of hot water). This mixture was poured into a tray to cool and gel, and the diet was then covered and refrigerated until it was used.

All kittens were initially adapted to the control diet over a 3-week period. At the beginning of the experimental period, the experimental group was switched to the taurine-free diet while the control group continued to receive the control diet.

Experimental protocol

In the first experiment, the effects of taurine depletion on the activities of hepatic enzymes involved in taurine synthesis and on bile acid conjugation were determined. Eight male kittens were divided between the two dietary groups (control or taurine-free) with littermates being assigned to opposite groups. Animals were fed these diets for six weeks.

At the end of the six-week experimental period, each kitten was anesthetized with CO_2 and blood was drawn from the heart into a heparinized syringe. Bile was taken with a syringe from the gall bladder. After centrifugation of the blood at 2000 *g*, plasma was removed with care so as not to disturb the buffy coat. Plasma and bile were frozen and stored at −20°C for later analysis of taurine or bile acid conjugates. Liver was removed and placed on ice. The median lobe of the liver from each animal was immediately homogenized in ice-cold 0.05 M potassium phosphate buffer, pH 6.8, for determination of cysteine dioxygenase and cysteinesulfinate decarboxylase activities. The remaining liver was frozen on dry ice and stored at −20°C for later analysis of taurine.

In the second experiment, the effect of taurine depletion on the renal clearance of taurine was investigated. Eight kittens (a male and a female from each of four litters) were assigned to either the control or taurine-deficient dietary group; littermates were assigned to opposite groups and male and female kittens were evenly distributed between the two groups. Kittens were fed the assigned diets for 23 days. On day 24, two animals in each group were switched to the other diet while the remaining two animals in each group continued to receive the same diet; these diets were fed until day 43 when the experiment was ended.

The fractional excretion of taurine was determined at three intervals during week 1, twice weekly during weeks 2–5, and again at the end of week 6. Blood and urine were collected at each time period for analysis of taurine and creatinine. For each urine-collection period, kittens were transferred to metabolic cages at 2000 hr; water but not food was available for the first 12 hr during which urine was collected. A fasting blood sample was obtained from the left or right jugular vein of each kitten at 0800 hr, the end of the first 12 hr of the urine collection period. Kittens then were returned to the metabolic cages and food was placed in the cages. Urine was collected for a second 12 hr, and then the kittens were returned to their standard cages.

Urine was collected in covered beakers that contained 6% (w/v) phenol as a preservative. Urine was filtered, and aliquots were frozen for later analysis. Blood was collected in heparinized vacutainer tubes. Hematocrits were determined in order to monitor the effect of the repeated blood collections. The remaining blood was centrifuged to obtain plasma, which was then frozen for later analysis.

Fractional excretion was calculated as follows:

$$\frac{\text{(urine taurine concentration/urine creatinine concentration)}}{\text{(plasma taurine concentration/plasma creatinine concentration)}}$$

This calculation was made separately using the taurine and creatinine values for each of the 12-hr urine collections. The fractional excretion values calculated for the two 12-hr periods were not different in any case and were, therefore, averaged to obtain the reported values.

Analytical methods

Taurine was measured by high-performance liquid chromatography of the o-phthalaldehyde/2-mercaptoethanol derivatives as described by Kuo and Stipanuk (1984). Samples were prepared for taurine analysis as described below. Liver was homogenized in 6.25% (w/v) 5-sulfosalicylic acid to prepare 20% (w/v) homogenates; 0.9 ml of plasma was mixed with 0.1 ml of 40% (w/v) 5-sulfosalicylic acid. Samples were then centrifuged to obtain the protein-free supernatant. The supernatant was neutralized with 10 M KOH. A 0.2-ml volume of each neutralized, deproteinized supernatant or of each urine sample was applied to a 2.8 × 0.6 cm column of Dowex 50 (H^+, 200–400 mesh), and taurine was eluted with 1.0 ml of 50 mM phthalate buffer, pH 4.5.

Cysteinesulfinate decarboxylase activity was measured as described previously for cat liver (De La Rosa and Stipanuk, 1985a) by measuring $^{14}CO_2$ production from L-[1-^{14}C]cysteinesulfinate. L-[1-^{14}C]Cysteinesulfinate was prepared from DL-[1-^{14}C]cysteine (Research Products International Corp., Mount Prospect, IL) by the method reported by Daniels and Stipanuk (1982). Cysteine dioxygenase activity was determined by measuring [^{35}S]cysteinesulfinate production from [^{35}S]cysteine as previously described for cat liver (De La Rosa and Stipanuk, 1985a). Liver protein content was determined by the method of Lowry *et al.* (1951) with bovine serum albumin as the standard.

Taurine-conjugated, glycine-conjugated and free bile acids in the bile were determined by the method of Bachorik and Rogers (1969). The thin-layer chromatography allowed separation of taurocholate and cholate. Taurodeoxycholate and taurochenodeoxycholate fractions were pooled for analysis as were all of the glycine-conjugated bile acids.

Creatinine in urine and plasma samples was measured by the method of Folin (1914).

Statistical analysis

Means and standard deviations were calculated. The effect of taurine-depletion on each of the parameters measured in the first study was determined by comparing the base 10 logarithms of the values for the control and taurine-depleted groups with the paired *t*-test. The fractional excretion, body weights and hematocrit values obtained for the two dietary groups in the second study were compared with the Student's *t*-test at each time point. Additionally, the slope of the least-squares linear regression equation for the plot of fractional excretion versus day of the study was determined for each kitten over the period before diets were switched, and slopes for kittens in the two

groups were compared with the Student's t-test. Pearson product moment correlation coefficients were calculated for fractional excretion values versus day of the study or plasma taurine concentration. All statistical analyses were performed using Minitab 81-1 (Pennsylvania State University, University Park, PA).

RESULTS

Kittens fed the control and the taurine-free diets grew at similar rates throughout both studies. The weights of kittens in the two groups were not significantly different ($P < 0.05$) at any time during either study. In the second experiment, in which blood samples were taken repeatedly, the hematocrits of the kittens in the control and taurine-free groups were 30 ± 4 and 29 ± 2, respectively, at the onset of the experiment. By day 22, the hematocrits had fallen to levels that were significantly lower than those observed at day 1 (21 ± 2 and 23 ± 1 for the control and taurine-free groups, respectively); hematocrits remained relatively constant for the remaining three weeks of the study. Thus, at the end of the second study, the hematocrits of kittens were slightly below the reported normal range of 23–42% for cats under 1 year of age (Bentinck-Smith, 1977). Nevertheless, the hematocrits of kittens in the two dietary groups were not different at any time point.

As shown in Table 1, consumption of a taurine-free diet for six weeks resulted in decreases in plasma and liver taurine concentrations to 0.38% and 0.15%, respectively, of those for control kittens. The plasma taurine concentrations of kittens in the second experiment are shown in Fig. 1 as a function of days of the experiment. Plasma taurine concentration decreased rapidly in kittens fed the taurine-free diet and after three weeks was 8.7% of the level in control kittens. As can be seen in Fig. 1, a slight decrease in plasma taurine concentration was observed even in the control animals. This may have been related to age, to a change in the taurine content of their diet compared to the level of taurine they received prior to weaning, or to a change in their intestinal microflora subsequent to their removal from the specific pathogen-free facility. Nevertheless, it is clear that the taurine-free diet led to a severe depletion of tissue taurine. When the diets of half of the kittens in each group were switched on day 24, plasma taurine increased or decreased as expected based on the taurine content of the diet.

The activities of hepatic cysteine dioxygenase and cysteinesulfinate decarboxylase, enzymes that catalyze the oxidation of cysteine to cysteinesulfinate and the decarboxylation of cysteinesulfinate to hypotaurine (which is then further oxidized to taurine), are reported in Table 1. Cysteine dioxygenase activity did not differ between the groups fed the control and the taurine-free diets. However, the activity of cysteinesulfinate decarboxylase, the enzyme thought to play a rate-limiting role in taurine synthesis (De La Rosa and Stipanuk, 1985a), was increased in liver of kittens fed the taurine-free diet to 5.1-times the control level.

The concentrations of bile acids in the gall bladder bile are reported in Table 2. The total concentration of bile acids in gall bladder bile of kittens fed the taurine-free diet was only 21.8 mg per ml compared to 66.5 mg per ml in the kittens fed the control diet. The concentration of taurine-conjugated bile acids in bile of taurine-depleted kittens was only 11.5% of that in bile of control kittens. The relative amount of the different bile acids and conjugates was also markedly affected by the dietary treatment of the kittens. The taurine-conjugated bile acids made up only 44% of the total bile acids in taurine-depleted kittens compared to 98% in control kittens, and the relative amount of free cholate increased to 54% compared to 1% in control kittens. The concentration of glycine-conjugated bile acids was small and not significantly affected by taurine depletion.

The fractional excretion of taurine by kittens fed the control and taurine-free diets in the second experiment is reported in Fig. 2. The fractional excretion of taurine increased over time in both the control and taurine-deficient groups, but renal clearance of taurine did not appear to be affected by the dietary treatment. Although the fractional excretion of taurine was significantly correlated both with age ($r = 0.71$ for both the control and deficient groups) and with plasma taurine concentration ($r = -0.76$ for both the control and deficient groups), the fractional excretion of taurine by kittens fed the two diets did not differ ($P < 0.05$) at any time point throughout the 6-week period. The slopes of the linear regression lines for the fractional excretion data for kittens in the two groups did not differ significantly ($P < 0.05$);

Table 1. Plasma and liver taurine concentrations and hepatic cysteine dioxygenase and cysteinesulfinate decarboxylase activities in kittens fed the control or taurine-free diet*†

	Control	Taurine-free
Plasma taurine (μmol·100 ml^{-1})	14.6 ± 10.4	0.056 ± 0.031‡ (P<0.0004)
Liver taurine (μmol·g^{-1})	16.2 ± 0.1	0.025 ± 0.013‡ (P<0.0003)
Cysteine dioxygenase (nmol cysteinesulfinate·min^{-1}·mg protein^{-1})	0.14 ± 0.02	0.17 ± 0.01
Cysteinesulfinate decarboxylase (nmol CO_2·min^{-1}·mg protein^{-1})	0.07 ± 0.05	0.36 ± 0.16‡ (P<0.034)

*Each value is the mean ± SD for four kittens.
†Values for kittens fed the taurine-free diet that are significantly different ($P < 0.05$) from corresponding values for control animals are indicated by ‡; the P value is given in parentheses.

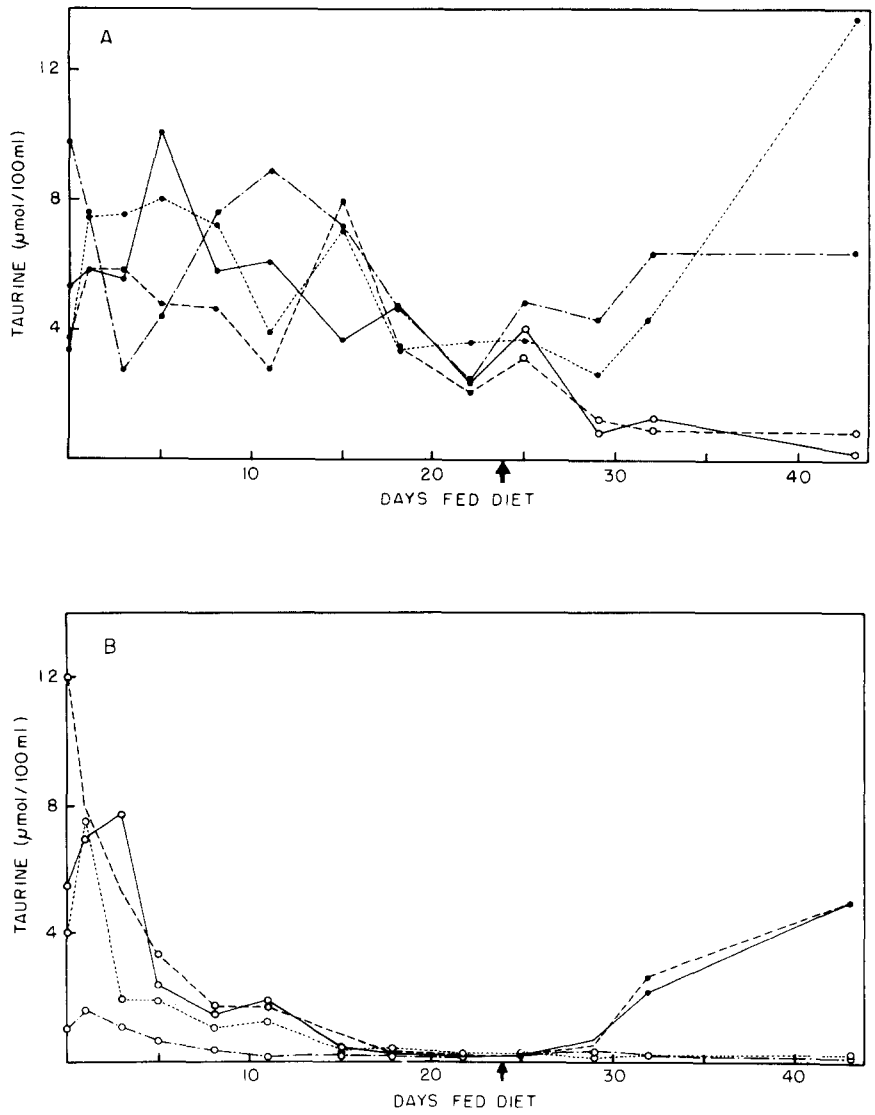

Fig. 1. Plasma taurine concentration of kittens fed the control (A) or taurine-free (B) diet. Each line represents an individual kitten. The diets of two kittens in each group were switched to the opposite diet on day 24. Closed circles indicate the control diet; open circles indicate the taurine-free diet.

Table 2. Concentrations of bile salts and bile acids in gall bladder bile of kittens fed the control or taurine-free diet*†

	Control	Taurine-free
Taurocholate	52.2 ± 5.7	8.5 ± 3.4‡ (P<0.017)
Taurodeoxycholate + taurochenodeoxycholate	2.8 ± 2.5	1.1 ± 0.2‡ (P<0.085)
Glycine-conjugates	0.9 ± 0.4	0.5 ± 0.3
Cholate	0.6 ± 0.2	11.7 ± 0.4‡ (P<0.001)
Total	66.5 ± 6.2	21.8 ± 4.9‡ (P<0.006)

*Each value is the mean ± SD for four kittens.
†Values for kittens fed the taurine-free diet that are significantly different ($P < 0.05$) from corresponding values for control animals are indicated by ‡; the P value is given in parentheses.

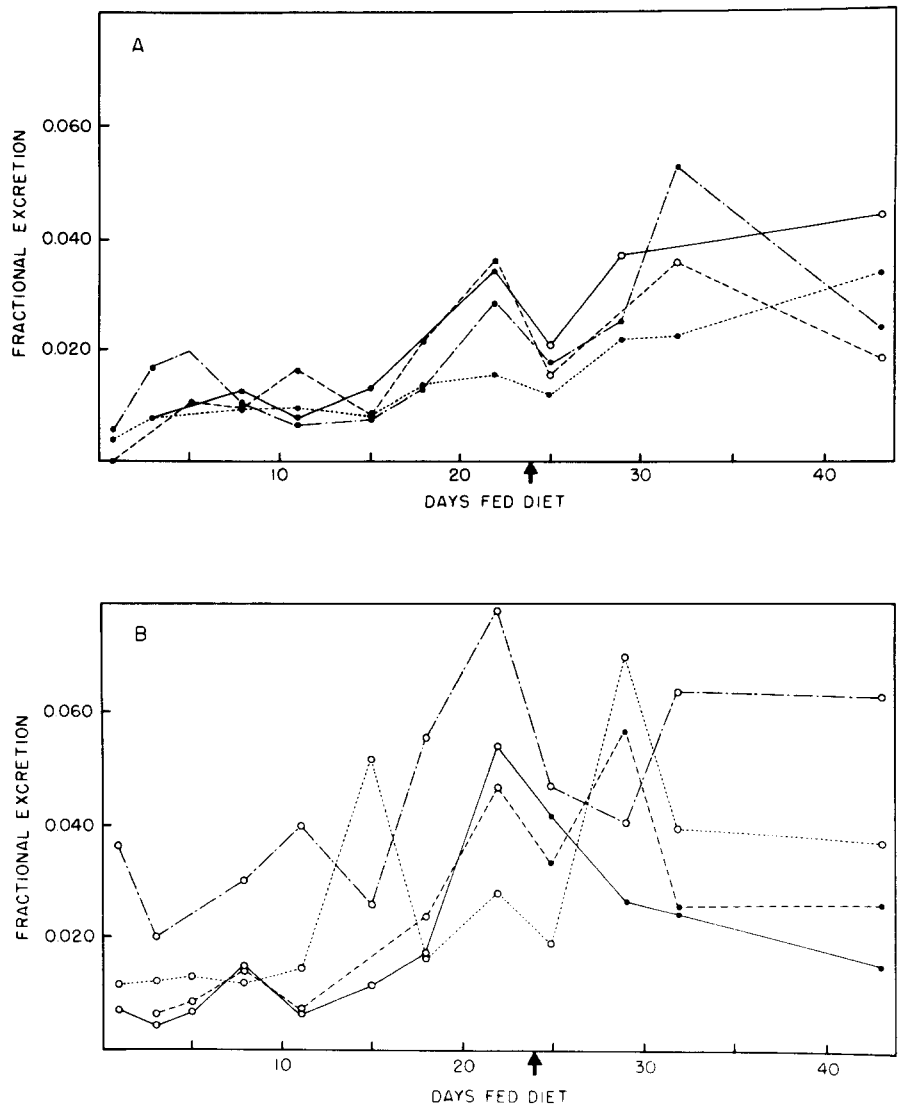

Fig. 2. Fractional excretion of taurine by kittens fed the control (A) or taurine-free (B) diet. Each line represents an individual kitten. The diets of two kittens in each group were switched to the opposite diet on day 24. Closed circles indicate the control diet; open circles indicate the taurine-free diet.

this also suggests that the observed changes in fractional excretion of taurine over time were related to age and not to the taurine content of the diet or the taurine status of the kittens.

DISCUSSION

The plasma and liver taurine concentrations observed in kittens fed the control diet with 0.1% taurine were similar to those reported by other investigators for control kittens fed semipurified diets with 0.4 or 0.15% taurine, but the values observed in our kittens fed the taurine-free diet were lower than those reported by these same investigators for taurine-depleted cats (Knopf *et al.*, 1978; Sturman *et al.*, 1978; Barnett and Burger, 1980). Our mean values for plasma and liver taurine concentrations in depleted kittens were 0.056 μmol/100 ml of plasma and 0.025 μmol/g of liver, whereas those reported by other investigators were 0.4–2.0 μmol/100 ml of plasma and 0.16–0.21 μmol/g of liver. Other investigators used longer feeding periods, which ranged from 7.5 to 15 weeks, compared to the 6-week period used in this study. The data shown in Fig. 2 indicate that taurine depletion had occurred extensively by the end of 14 days, so the higher degree of depletion obtained in this study clearly is not due to a longer depletion period. It is possible that cats from the Cornell specific pathogen-free colony are unusually sensitive to taurine depletion.

Values for both cysteine dioxygenase and cysteinesulfinate decarboxylase activities in liver of control kittens were similar to previously reported values (Gaull *et al.*, 1977; Knopf *et al.*, 1978; De La Rosa and Stipanuk, 1985a; Worden and Stipanuk, 1985). Knopf *et al.* (1978) reported that hepatic cysteinesulfinate decarboxylase activity was the same in cats fed diets with no taurine as in cats fed diets

with 0.4% taurine. Our observation of a 5-fold increase in hepatic cysteinesulfinate decarboxylase activity in taurine-depleted kittens is clearly not in agreement with their observation. It should be noted that the concentration of taurine in the liver of our taurine-depleted kittens was only 0.025 μmol/g, which is only 12% of the concentration (0.21 μmol/g) reported by Knopf *et al.* (1978) for their depleted cats. It is possible that the response of cysteinesulfinate decarboxylase activity to taurine depletion does not occur until tissue levels are extremely low. Whether or not this increase in cysteinesulfinate decarboxylase activity could result in an increase in the synthesis of taurine from cysteine in the taurine-depleted kitten was not determined, but the evidence for a rate-limiting role of cysteinesulfinate decarboxylase activity in taurine synthesis (Hardison *et al.*, 1977; Knopf *et al.*, 1978; De La Rosa and Stipanuk, 1985a) suggests that increased taurine synthesis would be likely.

The conjugation of bile acids with taurine was affected to a greater extent in this study than in previously reported studies in which taurine depletion was not as severe (Rabin *et al.*, 1976; Knopf *et al.*, 1978; Barnett and Burger, 1980). We observed an 85% decrease in the concentration of taurine-conjugated bile acids in bile of taurine-depleted kittens. In contrast, other investigators did not report a significant decrease in taurine-conjugated bile acids in taurine-depleted cats, although the mean values for taurine-depleted cats were slightly lower than those of control cats in all cases (Rabin *et al.*, 1976; Knopf *et al.*, 1978; Barnett and Burger, 1980). We also observed a much greater decrease in the concentration of total bile acids and a much greater increase in the concentration of free cholate than those previously reported (Rabin *et al.*, 1976). These greater effects of taurine depletion on bile acid conjugation in this study are probably also related to the greater degree of hepatic taurine depletion. The availability of taurine is known to influence the proportion of bile acids conjugated with taurine in other species (Hardison and Proffitt, 1977; Vessey, 1978; De La Rosa and Stipanuk, 1985b). It is clear that the cat, like the rat, loses less taurine through the biliary axis when its tissues are depleted of taurine even though it has little capacity for glycine-conjugation.

The cat's renal reabsorption of taurine was high in both control and taurine-deficient kittens and did not appear to adapt in response to the taurine status of the animal. The cat appears to differ from the rat because the fractional reabsorption of taurine has been shown to increase in rats fed diets with a low level of sulfur-containing amino acids and no taurine (Friedman *et al.*, 1981; Chesney *et al.*, 1983; Friedman *et al.*, 1983). However, because the level of sulfur-containing amino acids in the diets fed to the kittens in this study was adequate, the studies with rats fed sulfur amino acid-deficient diets may not be directly comparable to this study with kittens.

Our results suggest that the cat has a reasonable ability to conserve taurine during taurine depletion even though it does not conjugate bile acids with glycine or increase the fractional reabsorption of taurine beyond that of control animals. Additionally, the cat may have some capacity to increase its rate of taurine synthesis from cysteine. However, it is also clear that the cat is rapidly depleted of taurine when it is placed on a taurine-free diet. We conclude that the major reason the cat is susceptible to taurine-depletion is its limited capacity for taurine synthesis rather than its inability to conserve taurine. Although measurements in our lab of hepatic cysteinesulfinate decarboxylase activity in female rats and in 5- to 6-week old cats yielded similar values (De La Rosa and Stipanuk, 1985a; Worden and Stipanuk, 1985), measurements of hepatic cysteinesulfinate decarboxylase activity in 5-month old cats were an order of magnitude lower (Worden and Stipanuk, 1985). Additionally, recent studies in our lab with intact animals (De La Rosa and Stipanuk, 1985a) and with isolated hepatocytes (De La Rosa and Stipanuk, 1985c) indicated that the kitten has much less capacity for taurine synthesis from cysteine than either the male or female rat. It is possible that the lower level of cysteine dioxygenase activity found in cat tissues compared to rat tissues (De La Rosa and Stipanuk, 1985a), as well as lower cysteinesulfinate decarboxylase activity, is a factor in the cat's lower capacity for taurine synthesis.

REFERENCES

Bachorik P. S. and Rogers A. I. (1969) The direct fluorometric assay of conjugated bile acids. *J. Lab. Clin. Med.* **74,** 705–714.

Barnett K. C. and Burger I. H. (1980) Taurine deficiency retinopathy in the cat. *J. Small Anim. Pract.* **21,** 521–534.

Bentinck-Smith J. (1977) A roster of normal values. In *Current Veterinary Practice* VI. *Small Animal Practice* (Edited by Kirk R. W.), pp. 1355–1356. Saunders, Philadelpha.

Berson E. L., Hayes K. C., Rabin A. R., Schmidt S. Y. and Watson G. (1976) Retinal degeneration in cats fed casein. II. Supplementation with methionine, cysteine, or taurine. *Invest. Ophthalmol.* **15,** 52–58.

Chesney R. W., Gusowski N. and Friedman A. L. (1983) Renal adaptation to altered dietary sulfur amino acid intake occurs at luminal brushborder membrane. *Kidney Int.* **24,** 588–594.

Daniels K. M. and Stipanuk M. H. (1982) The effect of dietary cysteine level on cysteine metabolism in rats. *J. Nutr.* **112,** 2130–2141.

De La Rosa J. and Stipanuk M. H. (1985a) Evidence for a rate-limiting role of cysteinesulfinate decarboxylase activity in taurine biosynthesis *in vivo*. *Comp. Biochem. Physiol.* **81B,** 565–571.

De La Rosa J. and Stipanuk M. H. (1985b) The effect of taurine depletion with guanidinoethanesulfonate on bile acid metabolism in the rat. *Life Sci.* **36,** 1347–1351.

De La Rosa J. and Stipanuk M. H. (1985c) The oxidation of cysteine and cysteinesulfinate in rat and cat hepatocytes. *Fed. Proc.* **44,** 1591 (#6907).

Doisy E. A., Jr., Daniels M. and Zimmerman S. M. A. (1956) Nutritional influences on conjugation of bile acids by the rat. *Fed. Proc.* **15,** 243–244.

Folin O. (1914) On the determination of creatinine and creatine in urine. *J. biol. Chem.* **17,** 469–473.

Friedman A. L., Albright P. W. and Chesney R. W. (1981) Dietary adaptation of taurine transport by rat renal epithelium. *Life Sci.* **29,** 2415–2419.

Friedman A. L., Albright P. W., Gusowski N., Padilla M. and Chesney R. W. (1983) Renal adaptation to alteration in dietary amino acid intake. *Am. J. Physiol.* **245,** F159–F166.

Gaull G. E., Rassin D. K., Raiha N. C. R. and Heinonen K. (1977) Milk protein quantity and quality in low-birth-

weight infants. III. Effects on sulfur amino acids in plasma and urine. *J. Pediatr.* **90,** 348–355.

Hardison W. G. M. and Proffitt J. H. (1977) Influence of hepatic taurine concentration on bile acid conjugation with taurine. *Am. J. Physiol.* **232,** E75–E79.

Hardison W. G. M., Wood C. A. and Proffitt J. H. (1977) Quantification of taurine synthesis in the intact rat and cat liver. *Proc. Soc. exp. Biol. Med.* **155,** 55–58.

Hayes K. C., Carey R. E. and Schmidt S. Y. (1975) Retinal degeneration associated with taurine deficiency in the cat. *Science* **188,** 949–951.

Jacobsen J. G. and Smith L. H., Jr. (1963) Comparison of decarboxylation of cysteine sulphinic acid-1-^{14}C and cysteic acid-1-^{14}C by human, dog, and rat liver and brain. *Nature (Lond.)* **200,** 575–577.

Knopf K., Sturman J. A., Armstrong M. and Hayes K. C. (1978) Taurine: an essential nutrient for the cat. *J. Nutr.* **108,** 773–778.

Kuo S.-M. and Stipanuk M. H. (1984) Changes in cysteine dioxygenase and cysteinesulfinate decarboxylase activities and taurine levels in tissues of pregnant or lactating rat dams and of their fetuses or pups. *Biol. Neonate* **46,** 237–248.

Lowry O. H., Rosebrough N. J., Farr A. L. and Randall R. J. (1951) Protein measurement with the Folin phenol reagent. *J. biol. Chem.* **193,** 265–275.

Morris J. G., Rogers Q. R., Winterrowd D. L. and Kamikawa E. M. (1979) The utilization of ornithine and citrulline by the growing kitten. *J. Nutr.* **109,** 724–729.

National Research Council (1978) *Nutrient Requirements of Laboratory Animals.* National Academy of Sciences, Washington, D.C.

Rabin B., Nicolosi R. J. and Hayes K. C. (1976) Dietary influence on bile acid conjugation in the cat. *J. Nutr.* **106,** 1241–1246.

Schmidt S. Y., Berson E. L. and Hayes K. C. (1976) Retinal degeneration in cats fed casein. I. Taurine deficiency. *Invest. Ophthalmol.* **15,** 47–52.

Stipanuk M. H. and Kuo S.-M. (1984) Effect of vitamin B_6 deficiency on cysteinesulfinate decarboxylase activity and taurine concentrations in tissues of rat dams and their offspring. *Nutr. Rep. Int.* **30,** 667–680.

Sturman J. A., Rassin D. K., Hayes K. C. and Gaull G. E. (1978) Taurine deficiency in the kitten: exchange and turnover of [^{35}S]taurine in brain, retina and other tissues. *J. Nutr.* **108,** 1462–1476.

Sturman J. A., Moretz R. C., French J. H. and Wisniewski H. M. (1985) Taurine deficiency in the developing cat: Persistence of the cerebellar external granule cell layer. *J. Neurosci. Res.* **13,** 405–416.

Vessey D. A. (1978) The biochemical basis for the conjugation of bile acids with either glycine or taurine. *Biochem. J.* **174,** 621–626.

Wen G. Y., Sturman J. A., Wisniewski H. M., Lidsky A. A., Cornwell A. C. and Hayes K. C. (1979) Tapetum disorganization in taurine-depleted cats. *Invest. Ophthalmol. Vis. Sci.* **18,** 1201–1206.

Worden J. A. and Stipanuk M. H. (1985) A comparison by species, age and sex of cysteinesulfinate decarboxylase activity and taurine concentration in liver and brain of animals. *Comp. Biochem. Physiol.* **82B,** 233–240.