Hypokalaemic episodic polymyopathy in cats fed a vegetarian diet

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SUMMARY: A previously undocumented hypokalaemic condition with a cyclical nature, comprising acute bouts of polymyopathy followed by spontaneous recoveries, is described in the cat. Cats being fed a high protein vegetarian diet developed recurrent episodes of polymyopathy, characterised by ventroflexion of the head and neck, stiff forelimb gait, lateral head-resting and generalised muscle weakness. Plasma potassium concentrations (mean ± standard deviation) were reduced from 3.28 ± 0.33 mmol/l at the beginning of the experiment to 2.45 ± 0.24 mmol/l during bouts of myopathy. This hypokalaemia was associated with increased creatine kinase activities indicative of muscle damage, and decreased urinary potassium concentrations, and was caused by insufficient dietary potassium. Cats that received the same diet supplemented with potassium did not develop hypokalaemic polymyopathy. Spontaneous recoveries of affected cats were not associated consistently with increases in plasma potassium concentrations. Plasma taurine concentrations decreased and glutamic acid increased markedly in all cats fed the experimental diet. There was no evidence of thiamin deficiency associated with the high glutamic acid intake. Veterinarians should be aware that hypokalaemic cats, and in particular those on potassium-deficient diets, may show cyclical disease with episodes of polymyopathy recurring after periods of spontaneous clinical recovery. This condition in cats may be a useful animal model for familial hypokalaemic periodic paralysis in humans.

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Introduction

Hypokalaemia in cats causes a well-recognised polymyopathy, which is characterised clinically by generalised muscular weakness and persistent ventroflexion of the head and neck, and which is usually accompanied by increased activities of serum (or plasma) creatine kinase (CK; Hills *et al* 1982; Dow *et al* 1987a, b, 1989). In veterinary practice the condition is associated with certain diseases, in particular chronic renal failure, and there is a good response to potassium supplementation (Dow *et al* 1989; Dow and Fettman 1990). Hypokalaemia may also occur in cats fed potassium-deficient diets or diets that are marginally adequate in potassium and also contain urinary acidifiers (Ching *et al* 1989; Dow *et al* 1990). Hypokalaemia associated with episodic bouts of polymyopathy has been reported as an apparently breed-related condition in Burmese kittens (Blaxter *et al* 1986), and it also occurs in dogs fed potassium-deficient diets (Smith *et al* 1950) and in humans with familial hypokalaemic periodic paralysis (Mrak 1985). Previous reports of the disease in potassium-depleted cats have not described the condition as being cyclical in nature with affected animals showing spontaneous clinical recoveries between bouts of myopathy. This paper records such an episodic polymyopathy in hypokalaemic cats fed an experimental diet.

Attention was first drawn to the clinical condition by observations on 3 adult cats (2 to 2.5 years of age) that were being fed a human commercial vegetarian diet as part of an experiment to induce taurine deficiency retinopathy (Leon *et al*, unpublished data). All 3 cats developed marked ventroflexion of the head and neck, and generalised weakness, beginning 5.5 to 8.5 wk after commencement of the experimental diet. Other signs noted included lateral head-resting, stiff forelimb gait, occasional unsteadiness, and slight tremor of the head and pinnae. These manifestations were initially attributed to thiamin deficiency and the affected cats were immediately treated with daily intramuscular (IM) or subcutaneous (SC) injections of 35 mg thiamin disulphide nitrate*. One of the cats was also removed from the vegetarian diet. All 3 animals recovered rapidly and appeared clinically normal after 2 to 4 d. In one cat the same clinical signs recurred twice at intervals of 10 and 5 d after apparent recovery, despite dietary supplementation with thiamin hydrochloride†. Tests on the vegetarian diet and affected cats' faeces revealed no evidence for thiaminase activity. However, plasma amino acid profiles of the 3 cats showed increases in glutamic acid concentrations in addition to the expected reduction in taurine concentrations. This undoubtedly reflected the high glutamic acid content of the vegetarian diet. In this context Deady *et al* (1981) have reported that kittens with high concentrations of dietary glutamic acid develop signs of thiamin deficiency, which include ventroflexion of the head and ataxia. A clue to the nature of the condition came from biochemical tests of blood of the 3 affected adult cats. These tests revealed hypokalaemia and increased CK activity and prompted the present nutritional trial to determine the relationship between the vegetarian diet, any possible thiamin deficiency, and the potassium status of affected cats.

Materials and Methods

Animals

Ten conventionally-bred domestic short-haired cats (5 male, 5 female), all aged 5 months and produced by Animal Services of the John Curtin School of Medical Research, were used as experimental animals. Body weights at the commencement of the experiment ranged between 2.0 and 2.4 kg. Before the study the cats had been fed a standard commercial canned cat food at an

* B-Calm®, Troy Laboratories Pty Ltd, Smithfield, New South Wales
† Sigma Chemical Co, St. Louis, Missouri, USA

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average level of 400 g/d and a commercial dry cat food *ad libitum*. The animals were divided into two groups of 5 with 3 males in one group and 2 males in the other. The groups were weight-matched as evenly as possible. They were housed in 4 pens with segregation of males and females. Four adult cats (2 male, 2 female) fed commercial cat food were used to obtain control urinary potassium concentrations.

Dietary Regimens

Cats in both study groups were fed one of 2 high protein human vegetarian diets (diets 1[‡] and 2[§]) on alternate days, at 330 g/d. Table 1 shows the composition of the 2 diets as analysed by the manufacturer and amino acid analysis profiles. Elemental potassium concentrations in these diets were 17 mg/100 g (diet 1) and 26 mg/100g (diet 2). (A conversion factor of about x5 may be used to transform these figures to a dry matter basis). One group of cats was fed the 2 experimental diets only, and the other group received the same diets supplemented with potassium at the National Research Council (1986) recommended rate for high protein diets of 5 g/kg diet (dry matter basis). The potassium salt of D-gluconic acid was added at a rate of 0.61 g/100 g diet (that is 2 g per cat daily). Water was available *ad libitum*. Uneaten food was removed and water changed on a daily basis.

Experimental Protocol

Blood samples were taken from all 10 cats, and body weights recorded, at the start of the experiment before initiation of the test diets, and at fortnightly intervals thereafter. The cats were observed daily to detect the onset of any clinical signs. Heparinised blood samples were collected from the jugular vein of cats at the onset of definite clinical signs (usually ventroflexion of the head and neck) and again upon clinical recovery. Food had been withheld for 16 h and the cats lightly anaesthetised with 35 mg ketamine hydrochloride[¶] IM, before each sample was collected. When possible, at the time blood samples were obtained, urine specimens were collected by transabdominal manual expression of the bladder and immediately frozen. Two cats that showed clinical signs were treated with daily injections (IM or SC) of 35 mg thiamin disulphide nitrate until recovery. Thiamin was not given to any of the other cats. The experiment lasted for 6 wk. The experimental programme conformed with NH&MRC guidelines for the conduct of experiments as overseen by the Australian National University Animal Experimentation Ethics Committee.

TABLE 1
Composition of vegetarian diets*

Component	Diet 1 g/100g (DM)	Diet 2 g/100g (DM)
Protein[†] (N x 6.25)	62.0	61.0
Fat	2.5	4.8
Starch	21.0	20.0
Total sugars	5.5	3.4
Dietary fibre	1.5	3.3
Ash	7.5	7.5

* Analysis performed by Sanitarium Research Laboratories.
† Amino acid analysis performed at John Curtin School of Medical Research with Beckman 120 amino acid analyser.
Diet 1: Aspartic acid, 5.1%; Threonine, 3.9%; Serine, 5.2%; Glutamic acid, 23.5%; Proline, 14.3%; Glycine, 3.7%; Alanine, 3.7%; Cysteine[‡], 2.2%; Valine, 5.2%; Methionine, 1.5%; Isoleucine, 4.1%; Leucine, 6.2%; Tyrosine, 5.3%; Phenylalanine, 6.9%; Histidine, 2.6%; Lysine, 2.2%; Arginine, 4.7%.
Diet 2: Aspartic acid, 5.2%; Threonine, 0.0%; Serine, 8.3%; Glutamic acid, 23.1%; Proline, 13.9%; Glycine, 3.5%; Alanine, 3.8%; Cysteine[‡], 2.4%; Valine, 5.4%; Methionine, 2.1%; Isoleucine, 4.1%; Leucine, 5.9%; Tyrosine, 5.5%; Phenylalanine, 7.1%; Histidine, 2.7%; Lysine, 2.3%; Arginine, 5.0%. All the above are assumed to be L-isomeric, but analysis could not determine this.
‡ Eluted as cystine and calculated as ½(cystine).

‡ Casserole Mince®, Sanitarium Health Food Co, Wahroonga, New South Wales
§ Tenderbits®, Sanitarium Health Food Co, Wahroonga, New South Wales
¶ Ketamil®, Troy Laboratories Pty Ltd, Smithfield, New South Wales

Analytical Procedures

Blood samples were immediately placed on ice, then centrifuged and the plasma separated, avoiding contamination with the buffy coat. A sample of plasma was frozen at –20°C for biochemical analysis. Another 1 ml of plasma was mixed with 40 µl of a 1.5 mmol/l solution of DL-norleucine[†] (Nle) in normal saline (to give an amino acid standard), deproteinised with 30 mg of sulphosalicylic acid, centrifuged, and the supernatant used for analysis of plasma amino acids.

The remaining erythrocytes were washed twice in normal saline and stored frozen in liquid nitrogen. These samples were used for estimation of erythrocyte transketolase activity within one week of collection.

Plasma biochemistry entailed measurement of potassium, creatinine and urea concentrations, and CK activities. Plasma and urinary potassium concentrations were determined with a flame photometer and standard curve following a 1:200 dilution of samples. Plasma creatinine and urea concentrations and CK activities were measured with a dry chemistry machine[#] using the methods of Frey *et al* (1985), Munan *et al* (1978), and Braun *et al* (1987), respectively.

For amino acid analysis the deproteinised plasma samples were hydrolysed with 6 mol/l hydrochloric acid in an evacuated, sealed tube at 110°C for 22 h. The hydrochloric acid was then removed on a rotary evaporator and the samples dissolved in sodium citrate buffer (Na-S Beckman amino acid sample dilution buffer). The equivalent of 10 µl of sample was analysed on a high performance amino acid analyser**.

Erythrocyte transketolase activities were determined with a Unicam SP800 spectrophotometer, after thawing the frozen samples, using the method of Bayoumi and Rosalki (1976). Activities were assayed both with and without thiamin pyrophosphate (TPP) to assess the increase in activity with added vitamin B_1 (TPP effect).

Statistics

Student's *t*-test was used to determine the statistical significance of differences between the means of the two diet groups. All measurements quoted are means ± standard deviations (SD).

Results

Clinical Signs

None of the cats in the potassium-supplemented group showed detectable clinical signs of myopathy during the experiment. However, all cats in the unsupplemented group developed clinical signs within 2 wk of initiation of the experimental diet (range:

Reflotron®, Boehringer Mannheim, Castle Hill, New South Wales
** Beckman System 6300, Beckman Instruments, Palo Alto, California, USA

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5 to 13 d). The first sign observed was always ventroflexion of the head and neck, which often developed rapidly and became more marked over a period of a few hours. This reflected profound weakness of the nuchal musculature since, in several cases, manual elevation of the cat's head followed by its release would result in the head falling back to the sternal position. Other signs noted were lateral head-resting, stiff forelimb gait (without spasticity), generalised muscular weakness and, occasionally, mild unsteadiness and slight tremor of the head and pinnae. Two affected cats sometimes assumed an unusual posture — squatting on the hindquarters with the forequarters raised off the ground. It is possible that this may have been an attempt by these cats to raise their heads in the absence of nuchal muscle tone. Muscular hypersensitivity on palpation usually was not obvious in the affected animals during the initial myopathic episodes. Most cats responded affectionately to stroking and maintained a bright demeanour and a good appetite. Reflexes appeared to be unaffected and no abnormalities were detected on auscultation or ophthalmoscopic examination. The duration of these bouts of polymyopathy ranged from 2 to 10 d (mean: 4.5 d). All affected cats recovered spontaneously. Recovery was associated with a gradual reduction in the severity of clinical signs, with ventroflexion of the head and neck tending to be the last sign to disappear.

The clinical signs of polymyopathy recurred two to three times in all cats in the unsupplemented group over the 6 wk period of the experiment. The interval between recovery from one clinical episode and the onset of the next ranged from 8 to 21 d (first to second episode) and 7 to 11 d (second to third episode). Two cats manifested muscular hypersensitivity during their third (cat 2744) and second (cat 2762) myopathic episodes. This was evident as a marked reluctance to be stroked or palpated. These 2 animals also developed a stiff hindlimb gait, with tucked up hindquarters, which persisted for 3 days after all other signs, including ventroflexion of the head and neck, had disappeared. Cat 2744 was removed from the unsupplemented group and placed on potassium supplementation during its third bout of myopathy because of marked generalised muscular weakness. Thiamin treatment of 2 cats (2744 and 2762) during their first episode of myopathy did not improve the recovery rate or prevent recurrence compared with untreated animals.

All cats that were fed the experimental diet showed weight loss and poor coat condition, although the latter was thought to be less noticeable in the potassium-supplemented group. Over the 6 wk duration of the experiment the mean weight loss in the unsupplemented group of cats was 0.48 ± 0.13 kg while that of the potassium-supplemented group was 0.40 ± 0.28 kg. This difference was not statistically significant ($p > 0.05$). Emesis was occasionally observed, but was not considered a feature of cats being fed either diet.

Plasma Potassium Concentrations

Table 2 shows the plasma potassium concentrations of all cats in both experimental groups at fortnightly intervals. The plasma potassium concentrations in clinically affected cats in the unsupplemented group during episodes of polymyopathy are shown in Table 3.

Urinary Potassium Concentrations

Urinary potassium concentration of 4 animals fed normal cat food was 159.5 ± 13.0 mmol/l (range: 153 – 179 mmol/l). The urinary potassium concentration of 5 cats being fed the potassium-supplemented diet was 43.8 ± 20.4 mmol/l (range: 26 – 72 mmol/l). This was significantly reduced compared with the control cats ($p < 0.005$). The 5 cats being fed the experimental diet with no supplementation showed markedly reduced urinary concentrations of potassium. During 5 clinical episodes of polymyopathy in this group of cats their urinary potassium concentration was 11.2 ± 4.9 mmol/l (range: 6 – 19 mmol/l). This concentration was significantly decreased even when compared with the potassium-supplemented group ($p < 0.01$). Between bouts of myopathy, when these animals appeared clinically normal, their urinary potassium remained low at 7.5 ± 4.7 mmol/l ($n = 8$).

TABLE 2
Plasma potassium concentrations in unsupplemented and potassium-supplemented groups of experimental cats*

Group	Before diet	Period on experimental diet		
		2 wk	4 wk	6 wk
Unsupplemented	3.28 ± 0.33	3.16 ± 0.43†	2.64 ± 0.18†	2.63 ± 0.29†
Potassium-supplemented	3.68 ± 0.36	4.30 ± 0.19	3.92 ± 0.41	4.40 ± 0.31

* Values are means ± SD (mmol/l) for 5 cats
† Significantly decreased ($p < 0.005$)

TABLE 3
Plasma potassium concentrations in unsupplemented cats during episodes of polymyopathy*

Cat No.	E. 1	R. 1	E. 2	R. 2	E. 3
2733	2.4	2.7	2.5	2.4	2.4
2737	2.2	2.4	3.1	2.5	2.3
2744	2.5	3.0	2.5	2.2	2.4
2756	2.2	3.1	2.7	–	–†
2762	2.2	2.8	2.5	–	–†
Mean± SD	2.30 ± 0.14	2.80 ± 0.27	2.66 ± 0.26		

Where E. = episode and R. = recovery
* Values in mmol/l
† Cats 2756 and 2762 did not recover from their second bout of polymyopathy before the experiment concluded.

TABLE 4
Plasma creatine kinase activities in unsupplemented and potassium-supplemented groups of experimental cats*†

Group	Cat No.	Period on experimental diet			
		0 wk	2 wk	4 wk	6 wk
Unsupplemented	2733	86	106	>1000	>1000
	2737	71	89	>1000	>1000
	2744	88	61	>1000	–‡
	2756	58	241	91	224
	2762	71	41	36	883
Potassium-supplemented	2720	110	83	37	25
	2730	249	30	100	38
	2739	135	316	44	69
	2759	52	43	54	38
	2760	49	20	22	19

* Values in U/l
† ACT Veterinary Laboratory's normal range of values for feline creatine kinase is < 60 U/l
‡ Cat 2744 was placed on potassium supplementation after 5 wk due to marked muscle weakness.

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TABLE 5
Plasma creatine kinase activities in unsupplemented cats during episodes of polymyopathy*

Cat No.	Myopathic episodes				
	E. 1	R. 1	E. 2	R. 2	E.3
2733	106	>1000	>1000	713	>1000
2737	145	108	>1000	>1000	>1000
2744	499	513	970	>1000	>1000
2756	74	279	>1000	–	–†
2762	923	68	216	–	–†

Where E. = episode and R. = recovery
* Values in U/l
† Cats 2756 and 2762 did not recover from their second bout of polymyopathy before the experiment concluded.

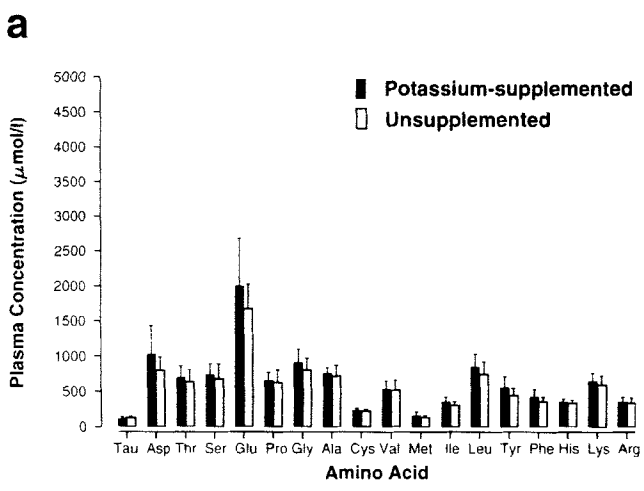

Figure 1. Plasma amino acid concentrations in cats fed a vegetarian diet. Values are mean ± SD, n = 5. Norleucine (600 μmol/l) was used as an internal standard. (a) Values at beginning of experiment. (b) Values after 6 wk on the vegetarian diet. Plasma taurine (Tau) was undetectable and glutamic acid (Glu) was markedly increased in both potassium-supplemented and unsupplemented groups.

Plasma Creatine Kinase Activities

The plasma CK activities of cats in both experimental groups are shown in Table 4. Table 5 shows the plasma CK values of cats in the unsupplemented group during episodes of polymyopathy.

Plasma Urea and Creatinine Concentrations

At the beginning of the experiment the urea concentrations were 11.1 ± 0.9 mmol/l in the potassium-supplemented group of cats and 10.6 ± 2.7 mmol/l in the unsupplemented group (the ACT Veterinary Laboratory's normal range of values for feline plasma urea is 7.2 – 10.7 mmol/l). These values showed no significant change ($p > 0.05$) during the 6 wk period of the experiment in either group of cats.

The plasma creatinine concentration at the start of the experiment was 94 ± 5 μmol/l in the potassium-supplemented group and 90 ± 8 μmol/l in the unsupplemented group (the ACT Veterinary Laboratory's normal range of values for feline plasma creatinine is 50 – 180 μmol/l). There were no significant increases in these values ($p > 0.05$), but instead both groups of cats demonstrated a slight decrease in plasma creatinine concentrations. During episodes of polymyopathy in animals in the unsupplemented group there were no consistent alterations in the concentrations of plasma urea or creatinine.

Plasma Amino Acids

The most notable changes in plasma amino acid concentrations in the 2 groups of cats related to taurine and glutamic acid (Figure 1). The plasma amino acid concentrations of one cat in the potassium-supplemented group at the beginning of the experiment consisted of disproportionately high values (about two-fold higher) in comparison with those from the other animals and there was reason to suspect an aberration in sample processing. The data from the first sampling of this individual have therefore been omitted from statistical analyses. The taurine concentrations at the beginning of the experiment were 122 ± 16 μmol/l (potassium-supplemented group) and 122 ± 23 μmol/l (unsupplemented group). After 2 wk on the vegetarian diet these taurine concentrations had decreased to 16 ± 18 μmol/l (potassium-supplemented group) and 30 ± 19 μmol/l (unsupplemented group). After 4 wk these concentrations had decreased even further and by 6 wk no plasma taurine could be detected in any cat in either group. There were no significant differences in the plasma taurine concentrations between the two groups ($p > 0.05$).

The plasma glutamic acid concentrations before initiation of the experimental diet were 2000 ± 681 μmol/l (potassium-supplemented group) and 1673 ± 349 μmol/l (unsupplemented group). After 2 wk on the diet the glutamic acid concentrations had increased markedly and stabilised so that after 4 wk the plasma concentrations were 3180 ± 156 μmol/l (potassium-supplemented group) and 3431 ± 432 μmol/l (unsupplemented group). This increase was statistically significant for both groups of cats ($p < 0.01$). There were no statistically significant changes in the other plasma amino acids in either group of cats during the experiment.

Erythrocyte Transketolase Activities

The aim of performing erythrocyte transketolase assays was to determine if thiamin deficiency was a factor in the development of clinical signs, independent of potassium status. For this reason the results of erythrocyte transketolase activities from both the potassium-supplemented and unsupplemented groups at the start of the experiment have been pooled, and compared with activities of those animals showing clinical signs. The erythrocyte transketolase activity of all 10 cats at the beginning of the experiment was 2.24 ± 0.53 units (range: 1.64 – 3.22 units) with a mean TPP effect of 9.5 ± 3.8 %. At the onset of clinical signs of polymyopathy in the 5 cats in the unsupplemented group their erythrocyte transketolase activity was 2.33 ± 0.55 units with a reduced mean TPP effect of 2.0 ± 1.2 %. This difference was not statistically significant ($p > 0.05$).

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Discussion

The clinical signs of polymyopathy observed in this study in 5 cats that were being fed an unsupplemented high protein vegetarian diet were clearly associated with hypokalaemia. This was confirmed both by the reduced plasma potassium concentrations of this group of animals, and also because cats being fed the same food, supplemented with potassium, did not exhibit clinical signs and maintained normal plasma potassium concentrations. Cats affected with hypokalaemic polymyopathy demonstrated clinical signs that were characterised by the acute onset of ventroflexion of the head and neck, stiff forelimb gait, and lateral head-resting with generalised muscular weakness. These clinical signs are consistent with those observed in hypokalaemic cats by other workers both in clinical veterinary practice (Dow *et al* 1987a, b, 1989) and in experimentally induced potassium depletion (Hills *et al* 1982). Weight loss and unkempt hair coats were observed in all animals on the vegetarian diet. Muscular hypersensitivity on palpation was not a prominent feature in the present study, although 2 cats did show muscle hypersensitivity and stiff hindquarters during subsequent bouts of polymyopathy.

The similarity of clinical signs in the early stages of hypokalaemic polymyopathy and thiamin deficiency may be a source of diagnostic confusion in cats. Ventroflexion of the head and neck, apparent ataxia, dysmetria/abnormal gait, and weight loss are clinical signs common to both diseases. Nevertheless, thiamin deficiency runs a more acute course and is usually associated with other neurological signs including mydriasis, papilloedema, loss of righting reflexes, and convulsions (Jubb *et al* 1956; Rubin 1974; Deady *et al* 1981), none of which were observed in affected cats in this study. Snake bite is another differential diagnosis in cats which are presented with generalised muscle weakness or hindlimb ataxia accompanied by increased plasma CK activities (Hill and Campbell 1978; Barr 1984). However, these animals also usually show mydriasis with absence of pupillary light reflexes, unlike cats affected with hypokalaemic polymyopathy.

The age of the animal appears to be a factor in the development of hypokalaemic polymyopathy. Adult cats on the same diet before the experiment developed clinical signs after 5.5 to 8.5 wk (Leon *et al*, unpublished data) compared with less than 2 wk in all the young cats (< 6 mo old) during the present trial. This suggests that younger cats are more susceptible to the effects of hypokalaemia.

The lowered plasma potassium concentrations of cats during episodes of polymyopathy in the present study (2.45 ± 0.24 mmol/l; range: 2.2 – 3.1 mmol/l; n = 13) agree closely with those found in affected cats in veterinary practice by Dow *et al* (1987a, 1987b) (range: 2.0 – 3.1 mmol/l). In the present study affected cats recovered spontaneously, but recovery was not correlated consistently with an increase in plasma potassium concentrations. At the onset of the first bout of polymyopathy the mean plasma potassium concentrations of the 5 cats in the unsupplemented group was 2.30 ± 0.14 mmol/l (range: 2.2 – 2.5 mmol/l). Recovery from this first bout appeared to be associated with a consistent increase in these concentrations to a mean of 2.80 ± 0.27 mmol/l (Table 3). However, this trend was not followed during subsequent bouts and recoveries, with plasma potassium concentrations in some individuals actually decreasing between the onset of clinical signs and recovery. A similar finding has been reported in some cases of familial hypokalaemic periodic paralysis in man in which clinical recovery occurs even though serum potassium concentrations are actually decreased (Melnick *et al* 1983). The potassium concentrations in the extracellular fluid (which represent only a very small proportion of body potassium) may therefore not be directly related to the degree of myopathy. Another possible complicating factor in the interpretation of these figures could be apparent increases in blood potassium concentrations as a result of muscle membrane damage with leakage of potassium from the muscle into the extracellular fluid. The mechanism involved in the spontaneous recoveries in animals in our study may entail the uptake or redistribution of potassium ions within different intracellular compartments or between different organ systems, with consequent changes in intracellular potassium concentrations, which are not reflected by alterations in the plasma concentration.

All cats being fed the experimental diet showed decreased urinary potassium concentrations compared with animals fed normal cat food. While a more reliable method for examining urinary potassium concentration involves relating this to urine concentration, the marked difference between the control animals and the experimental cats highlights the grossly deficient nature of their diet. Even though the supplemented group of cats had normal plasma potassium concentrations their urinary concentrations were decreased, showing that they were not potassium-replete. The urinary potassium concentrations were decreased most in the unsupplemented group of cats.

Increased plasma CK activities indicated muscle damage in the hypokalaemic cats, whereas no consistent elevations in enzyme activity were noted in the potassium-supplemented animals (Table 4). All cats that developed clinical signs of hypokalaemic polymyopathy showed increased activity of this enzyme (Table 5), an association that has also been found by other workers (Dow *et al* 1987a, 1989). However, clinical recoveries in the present study were not accompanied by reductions in CK activity. Instead the enzyme activities remained increased with the continued hypokalaemia, indicating ongoing muscle damage. This finding is similar to that reported by De Keyser *et al* (1987) who found that in humans with hypokalaemic periodic paralysis, clinical recovery was associated with a rise in serum myoglobin, followed by a rise in serum CK. These workers suggested that hypokalaemia may cause muscle ischaemia, resulting in increased concentrations of free fatty acids within muscle cells and greater sarcolemmal permeability. The resultant release of potassium from muscle cells may then restore membrane excitability.

Most cases of hypokalaemia in cats in veterinary practice are associated with chronic renal dysfunction ('renal failure') and consequent excessive urinary potassium loss (Dow *et al* 1987b, 1989). However, plasma urea and creatinine concentrations of cats in the present study were not significantly increased, indicating that this was not the cause of the hypokalaemia in these animals. Urinary potassium concentrations were markedly low, as is the case in hypokalaemic periodic paralysis in man (Charness and Johns 1978; Mrak 1985), suggesting reduced excretion of the element, possibly as a result of potassium depletion in the extracellular fluid compartment. The cause of this depletion may be related to two factors. The concentration of dietary potassium was low (17 mg/100 g diet 1, and 26 mg/100 g diet 2) and resulted in insufficient potassium intake. In addition, the high dietary protein content (62 g/100 g diet 1, and 61 g/100 g diet 2) may have increased the cats' potassium requirement (Hills *et al* 1982).

All cats in the present study showed a rapid fall in plasma taurine to undetectable concentrations during the 6 wk period of the experiment. This is to be expected from the taurine deficient nature of the vegetarian diet used. Cats have a very limited capacity to synthesise taurine and are exquisitely sensitive to dietary concentrations of this amino acid (Knopf *et al* 1978). The possibility cannot be excluded, that taurine deficiency may contribute to the pathogenesis of polymyopathy in hypokalaemic cats. Certainly, taurine deficiency for periods greater than 1 year is known to cause feline cardiomyopathy (Pion *et al* 1987) and it has also been associated with hypokalaemia in cats fed commercial diets containing inadequate taurine concentrations (Dow *et al* 1987a). This link is further strengthened by the finding that potassium-deficient diets can induce significant taurine depletion, and this effect is exacerbated by diets that contain urinary acidifiers such as ammonium chloride which may cause negative potassium balance (Dow *et al* 1990; Dow *et al* 1992).

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The marked increases in plasma glutamic acid concentrations in all cats in this study undoubtedly reflected the high proportion of this amino acid in the two vegetarian diets (5.3 g/100 g diet 1, and 6.1 g/100 g diet 2). Deady *et al* (1981) found that kittens that were fed diets containing 9 – 12% glutamic acid developed clinical signs of thiamin deficiency. The clinical signs observed in cats in the present study cannot be attributed to such an induced thiamin deficiency. The percentage of glutamic acid in the experimental diet was less than 9%. Both the potassium-supplemented and unsupplemented groups of cats showed similar increases in plasma glutamic acid, yet only cats in the unsupplemented group developed clinical signs. Thiamin treatment of 2 affected animals did not influence their recovery rates, nor did it prevent recurrence compared with untreated animals. In addition, erythrocyte transketolase activities from clinically affected cats showed no evidence of thiamin deficiency (normally associated with a markedly increased TPP effect).

The most notable findings in the present investigation were the spontaneous recoveries (after 4.5 d on average) and recurrent bouts of polymyopathy in hypokalaemic cats. We have called this condition 'hypokalaemic episodic polymyopathy' because of its similarity to familial hypokalaemic periodic paralysis in humans. Periodic muscular weakness associated with hypokalaemia and increased CK activity has been recorded in several litters of Burmese kittens (Blaxter *et al* 1986). The clinical signs shown in the latter, apparently breed-related, condition were similar to those observed in cats in the present study.

There are species differences in the clinical manifestations of hypokalaemia. Rats on potassium-deficient diets develop renal lesions and cardiomyopathy, but demonstrate no changes of the skeletal muscles, whereas dogs may develop paralysis and cardiomyopathy (Smith *et al* 1950; Sugiyama *et al* 1988).

In humans, hypokalaemic polymyopathy may occur spontaneously, but it is usually familial with an autosomal dominant mode of inheritance (Charness and Johns 1978). It manifests most commonly in males with recurrent episodes of flaccid paralysis and hyporeflexia. The pathogenesis of the disease involves exaggerated shifts in the distribution of potassium between the muscle cells and the extracellular fluid compartment, in particular an increased potassium influx into muscle (Charness and Johns 1978; Mrak 1985). The paralysis was originally thought to be a result of hyperpolarisation of the muscle membrane as a consequence of the disturbed ratio of extracellular to intracellular potassium, but direct measurements have excluded this possibility. More recent work suggests that excitation fails to propagate from the motor end-plate region to the remainder of the sarcolemma and it is believed that this may be the result of a primary alteration of sarcolemmal function with an abnormal ratio between sodium and potassium conductances (Charness and Johns 1978; Mrak 1985; Grafe *et al* 1990). Hypokalaemic episodic polymyopathy in the cats in this study is a potentially useful animal model for investigation of the disease in man. The manifestations of the feline and human diseases share as yet undefined regulatory processes, which may yield more readily to direct animal experimentation. The role of the animal model may be in helping to devise new methods for management of the human disease. Veterinarians in clinical practice should be aware of the possibility that hypokalaemic cats, and in particular those fed potassium-deficient diets or certain diets containing urinary acidifiers, may show cyclical disease with episodes of polymyopathy recurring after periods of spontaneous clinical recovery.

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CORRECTION

Chronic renal failure and urolithiasis in a 2-years-old colt by JA Laing, AL Raisis, RJ Rawlinson and AC Small (1992) *Aust Vet J* **69**:199

The third paragraph of this article mentioned the smooth muscle relaxant, propantheline bromide, with a footnote giving the trade name of the product used as Proban B. This should have read Propan B, Nature Vet Pty Ltd, Agnes Banks, New South Wales.

Proban is the trade name for an ectoparasiticide (containing cythioate) for dogs and cats marketed by Boehringer Ingelheim Pty Ltd.

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