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Feline Nutrition: What Is Excess Carbohydrate?

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Abstract

The domestic cat (*Felis domesticus*) is metabolically adapted to low-carbohydrate diets that provide about 2% of metabolic energy (ME). These adaptations limit the rate and the amount of carbohydrate utilization in the cat compared to omnivorous species. High-carbohydrate intake and carbohydrate excess have been implicated in certain health disorders, but evidence for a cause and effect relationship is lacking. Because of the variability in carbohydrate source, processing, nutrient interaction, and the health status of cats, the identification of uniform recommendations for carbohydrate excess is not possible. While recommendations to limit carbohydrates to 4-8 g/100 Kcal ME are published, evidence that higher carbohydrate intake represents an excess is lacking.

Glossary of Abbreviations

AAFCO: Association of American Feed Control Officials
BW: Body Weight
DM: Dry Matter
ME: Metabolic Energy
NEFAs: Non-Esterified Fatty Acids

Introduction

The nutritional requirements of the domestic cat exemplify evolutionary adaptation to a strict carnivorous diet and predatory lifestyle. The feral domestic cat (*Felis domesticus*) eats a wide variety of prey, including small mammals, birds, insects, reptiles, and other animals. Because this prey-directed diet is composed exclusively of animal tissues, the typical composition of the natural diet has limited carbohydrate availability. The primary source of carbohydrates in the natural diet of adult feral cats is derived from tissue glycogen and the gut contents of the prey. As the cat became domesticated, the nutritional profile of the diet changed to include larger proportions of carbohydrates from milk products, sugars, grains, and other vegetable matter. In contrast to a whole rat carcass (carbohydrate 1.18% DM, dry matter; 0.18 g/100 Kcal),[1] carbohydrates in commercial cat foods may provide up to 50-fold the amount found in the natural diet. Dry cat foods commonly provide 30-40% ME (8-10 g/100 Kcal) as carbohydrates or 33-45% DM. The divergence of nutritional profiles of commercial cat foods from the cat's natural diet has led to debate regarding the impact of high carbohydrate feeding in this obligate carnivore with concerns that these levels represent a carbohydrate excess.

While definitions for carbohydrate content of cat foods are not standardized, published classifications for various levels have suggested high (> 50% ME), moderate (26-50% ME), low (5-25% ME) and ultra low (< 5% ME).[2] This definition of carbohydrate level refers to the content of simple carbohydrates (digestible starches and sugar) in foods as opposed to complex carbohydrates, such as fibers or resistant starches, that are largely undigested. This discussion will focus on digestible carbohydrates. Despite the nutritional adequacy of modern commercial cat foods, consumption of high-dietary carbohydrate levels are suggested to alter energy metabolism, promote insulin resistance, and contribute to increased risk for obesity, diabetes mellitus and other health disorders in the cat.[3] Many studies have been published evaluating the impact of various dietary carbohydrate levels on changes in body weight, on plasma glucose and insulin concentrations, and on insulin sensitivity and biomarkers for disease risk. While the majority of studies do not support a direct cause-and-effect relationship of carbohydrate intake to risk for obesity or diabetes, the diversity of study designs, animal populations, feeding methods, and diet variables allows for alternate interpretations of study findings.[a] Because changes in dietary carbohydrate content require changes in the proportion of protein and/or fat, it is difficult to isolate carbohydrate's effect. The question remains whether some levels or sources of carbohydrates are excessive and deleterious to the health of the cat.

Feline Carbohydrate Metabolism

Carbohydrates are included in feline commercial foods as a readily available energy substrate, a source of dietary fiber or for functional properties in the processing of foods. Gums, mucilage and starch serve as gelling agent in canned foods; starch aids expansion and kibble structure in dry extruded diets; and simple sugars reduce water activity to help preserve semimoist foods and treats. The proportion of carbohydrates in commercial foods varies with lower levels typically found in canned foods and moderate to high levels found in dry foods. Most domestic cats consume increased carbohydrate levels compared to their wild or feral counterparts, which derive approximately 2% ME from carbohydrates.[4]

Feline Requirement for Carbohydrates

Adult cats have evolved to a diet that is high in protein and low in carbohydrates. Nursing kittens consume up to 20% of their energy in the form of lactose, while the natural diet of adult cats is < 5% DM carbohydrate.[5] Similar to most mammals, adult cats do not have a dietary requirement for carbohydrates, although maximum lactation performance and minimization of weight loss are enhanced by higher carbohydrate intake in lactating queens.[6]

Evaluation of carbohydrate requirements in nursing neonatal kittens is not reported. Feeding studies using AAFCO protocols were conducted in kittens fed two raw meat formulations compared to a low-carbohydrate canned food. Health parameters and growth rates in kittens fed 0%, 3.9% or 7.3% DM carbohydrate were similar among female kittens and highest in male kittens consuming the 0% DM carbohydrate diet.[7] It is clear that kittens greater than 8 weeks of age have no dietary carbohydrate need if adequate protein is supplied to support gluconeogenesis.

Physiological Adaptations of Carbohydrate Metabolism

Several metabolic adaptations in carbohydrate metabolism differentiate the cat from more omnivorous species. Cats, like all other mammals, require metabolic glucose to support cellular requirements for ATP production in the glucose-requiring tissues, such as nervous tissues, red blood cells, renal medulla, and active reproductive tissues. Efficient metabolism of proteins via hepatic gluconeogenesis sustains blood glucose levels in the absence of dietary carbohydrates.

Several physiological changes in cats attest to their adaptation to low-carbohydrate diets. A cat's ability to rapidly digest and absorb sugars and carbohydrates is reduced through elimination, reduction or lack of adaptation of glucose metabolizing enzymes.[8] Cats lack salivary amylase, which is designed to initiate the digestion of starches, and in one study, were found to have pancreatic amylase levels that are 5% those of dogs.[9] Brush border disaccharidase activity is 40% that of dogs.[10] Disaccharidases, amylase, along with intestinal sugar transporters, are nonadaptive to changes in dietary carbohydrate levels.[8-12]

Enzymatic changes within the liver reflect the cat's evolutionary adaptation to a diet low in carbohydrates, especially simple sugars like glucose and fructose. The cat has low levels of hepatic glucokinase, which limit the ability to efficiently metabolize large glucose loads following dietary intake.[8,11] Reports of limited fructose utilization resulting in fructosemia and fuctosuria following high sucrose or fructose intake have implied there is a lack of active fructokinase in the liver of cats.[13] Interestingly, feline liver demonstrates fructokinase distribution similar to other animals and a higher activity of hexokinase compared to canine liver.[15,16] Therefore, altered enzyme activities do not necessarily limit total capacity for hepatic glucose uptake in cats as other pathways may be active; however, the rate of hepatic glucose disposal appears to be slowed.

Hepatic protein catabolic enzymes appear constitutively active and provide continuous carbon skeletons (ketoacids) for gluconeogenesis or oxidation. These adaptations facilitate ongoing gluconeogenesis to sustain blood glucose levels during consumption of a low-carbohydrate diet.[8,15]

Digestion and Utilization of Carbohydrates

The above metabolic adaptations have led many to suggest poor carbohydrate utilization by the cat and a state of adaptive insulin resistance described as "the carnivore connection."[3] In reality, cats readily digest, absorb and utilize many types and levels of dietary carbohydrates. Carbohydrate digestion in commercial foods is reported to be greater than 90% for starches and greater than 94% for most sugars, although some studies have reported values as low as 36% for uncooked potato starch.[13,14,17,18] While the impact of microbial fermentation of undigested starches in the colon likely overestimates apparent carbohydrate digestibility compared to true carbohydrate digestibility, the difference is not so great as to discount carbohydrates' high digestibility and intestinal uptake. Lactose digestion declines in weaning kittens, with both a decrease in intestinal lactase production and downregulation of sugar transporters.[12] Kittens tolerate up to 6 grams lactose/kg per body weight (BW) during nursing,[5] while adult cats can consume more than 1.3 g/kg BW of lactose/day without adverse gastrointestinal signs.[13] Starch intake up to 5 g/kg BW/day is readily digested and was suggested by Keinzle[19] as an upper limit for the cat, while de-Oliveira demonstrated excellent starch digestibility up to 6.7 g/kg BW/day in adult cats.[18]

Experimental feeding studies using uncooked starches and high levels of sugars demonstrated limited capacity for rapid absorption or utilization of these ingredients in cats. Carbohydrate digestibility varies based on the starch or sugar source, processing, particle size (fine grinding versus course meal), and the diet matrix.[13,14,17-19] Thus, defining a level of carbohydrate excess is specific to many ingredient and processing criteria along with specificity of the effect.

Carbohydrate Excess

While cats do not require dietary carbohydrates, identifying a level of carbohydrate excess is not straightforward. The definition of a carbohydrate excess presumes a negative health effect from consumption above a defined level. When maximum capacity for carbohydrate digestion is exceeded, excessive fermentation and osmotic effects of undigested sugars in the gastrointestinal tract lead to bloating, gas production, discomfort, and diarrhea. Excess lactose consumption (greater than 1.3 g/kg BW/d) and above 5 g/kgBW/day for simple sugars and certain starches represents a maximum intake for some adult cats without an increase in blood biomarkers of altered carbohydrate metabolism and various monosaccharide loss in the urine.[13,18] However, most cats tolerate complex starches in the food matrix at levels of a least 6.7 g/kg BW/d with no observable effect.[18]

Excess dietary carbohydrate also may be described as exceeding the practical amount of carbohydrate added to a food that will imbalance the nutrient profile by limiting the additions of other ingredients and diluting nutrient content. Based on the AAFCO nutrient guidelines[29] for adult cats, diets containing carbohydrates that are approximately 60% or greater DM or ME risks nutrient unbalance. Lesser carbohydrate amounts — 40% ME or 51% DM[19] — would impact kitten diets due to their higher protein requirements. Foods with marginal nutrient concentration or bioavailability may be altered by lower levels of carbohydrates, depending on the source and the impact of the altered nutrient digestion. Protein digestibility is sometimes reduced by high-carbohydrate feeding while the availability of certain minerals, e.g., phosphorus and magnesium, may actually increase with increased carbohydrate feeding.[21]

Carbohydrate Intake and Relationship to Disease

Levels of carbohydrate intake and source may influence metabolic function or disease parameters. Dietary carbohydrates, primarily in the form of sugars, have resulted in changes in water balance, glucose metabolism, secretion of gut incretins, and adipokines. While changes are observed in various metabolic pathways, evidence does not support carbohydrate excess as a factor but more likely reflects adaptive changes to altered nutrient profiles.

Carbohydrates and Urinary Tract Disorders

High-sugar diets may alter urinary tract health by exceeding the renal threshold for monosaccharides and disaccharide excretion resulting in increased water loss by osmotic diuresis or increasing risk for disease. Glycosuria was demonstrated in cats fed simple sugars from 11-40% DM, while cooked starches that were up to 40% of diet had no effect on renal glucose excretion or postprandial blood glucose level in healthy cats.[13] Renal histologic changes were noted in the kidney of a cat fed high sucrose (7.2 g/kg BW; 36.1 % DM).[13]

The impact of carbohydrate intake was reported in an epidemiological study by Lekcharoensuk, et al.[22] Cats fed increased carbohydrates in canned diets (mean carbohydrate 7.84 g/100 Kcal ME) were compared to the reference group (.52-4.15 g/100 Kcal ME). Cats fed increased carbohydrates were at increased risk of calcium oxalate urolithiases, while carbohydrate intake had no influence on struvite urolithiases.

Ocular Effects of Carbohydrates

Galactose toxicity was evident in intake of 5.6 g/kg BW in a single cat. Cataracts were observed in one cat fed 39% galactose and resolved with diet discontinuation.[13] Similar findings have been reported for other species but at higher levels of galactose. Thus, 5.6 g/kg BW of galactose intake clearly is in excess, but the threshold for such effect in cats is unknown.

Role in Satiety

Previous studies suggested high protein: low carbohydrate diets improved satiety by reduction of appetitive behaviors in cats. However, the effect of feeding carbohydrate levels at 0.94 g/100 Kcal (4.5 % DM) versus 10.2 g/100 Kcal (31.3% DM) demonstrated no difference in owner satisfaction related to appetitive behaviors in pet cats undergoing a weight -loss plan.[23]

Role in Obesity

Numerous laboratory and epidemiological studies have been published evaluating the impact of diet profile on the rate of weight gain and loss and the impact of neutering, energy requirements, glucose levels, and insulin response in healthy cats. While the results are not uniformly consistent, the major risk factors suggest excess energy consumption, neutering and limited exercise are the greatest risk factors for obesity.[a] Epidemiological studies suggest that high-carbohydrate, low-fat dry foods do not favor the development of obesity but that feeding energy-dense, high-fat dry foods in caloric excess is a dietary risk factor.[24] A benefit to feeding high-protein, low-carbohydrate foods during weight loss have been noted. There appears to be an energetic benefit to feeding high-protein diets for maintenance of lean body mass and the thermic effect of proteins. Most studies support the effect of weight loss and obesity reduction toward improved insulin sensitivity in obese cats.[a]

A recent paper investigated therapeutic low-carbohydrate foods and a moderate carbohydrate-high fiber for the management of diabetes mellitus compared to a maintenance high-carbohydrate diet. In five cats, a reduction of postprandial glycemia and insulin levels along with increased non-esterified fatty acids (NEFAs) were observed.[25] While the study is limited by the small number of cats, the findings suggest that low-carbohydrate intake or fiber fortification were beneficial as independent factors in improving glycemic regulation. Similar to this observation, mean plasma glucose concentrations were greater in cats fed 12.1 g carbohydrate/100 Kcal compared to 8.3 g or carbohydrate 3.2g /100 Kcal, estimated ME of 48%, 33% or 12.8%, respectively.[26]

An increase in fat and simple carbohydrate levels in rats and people are suggested to alter the gut microbiome toward lower levels of bacteroidetes and higher firmicutes, a pattern termed "obese microbiota" because of improved energy extraction from the diet in this microbial environment.[27,28] Diet is known to influence the microbial population of the feline intestine, but the influence of carbohydrates on an "obese microbiome" in cats has not been described.

While most studies suggest a limited role of carbohydrates in the cause of obesity, the above studies suggest carbohydrates in excess of 12.1 g/100 Kcal (48% ME) may be inappropriate in obese cats at risk for insulin resistance and impaired glucose tolerance.

Role in Diabetes Mellitus

Low- to moderate-carbohydrate diets are beneficial in the management of diabetes mellitus. Utilizing the cat's natural metabolic adaptations to provide a steady source of glucose from the liver via gluconeogenesis and avoiding postprandial fluctuations in glucose absorption appears beneficial in managing diabetic cats.

Sustained hyperglycemia by IV glucose infusion contributes to glucose toxicity of the feline beta cell leading to decreased glucose sensing, impaired insulin secretion, hydropic degeneration, and beta cell death.[29] Models of sustained hyperglycemia, 29 mmol/l (522 mg/dl) by IV glucose infusion results in transient diabetes mellitus in the cat.[b] In addition to glucose toxicity, chronic hyperglycemia leads to chronic stimulation of insulin secretion from beta cells. In people, carbohydrate intolerance, insulin resistance and hypersecretion of insulin increase the risk of beta cell exhaustion, pancreatic amyloid accumulation and overt Type 2 diabetes mellitus. A similar relationship to high-carbohydrate feeding has been suggested to occur in the cat and may contribute to the development of diabetes mellitus although evidence to support this hypothesis is lacking.

The lowest level of glucose infusion required to initiate glucose toxicity in normal cats has not been fully identified but appears to be that amount needed to increase blood glucose to approximately 29 mmol/l (522 mg/dl). Lower levels of sustained hyperglycemia (17 mmol/l (310 mgl/dl) did not result in glucose toxicity.[b] Postprandial elevation of blood glucose in nonstressed healthy cats is unlikely to reach such levels. Dietary carbohydrate intake across a range of available carbohydrate sources providing 1 g/kg of available carbohydrate was not associated with significant increases in plasma glucose in healthy cats.[c] Dietary carbohydrate ingestion resulted in minimal postprandial blood glucose change when diabetic cats were allowed to eat free-choice.[30] In normal cats fed once daily, plasma glucose levels increased (mean levels 6.2 mmol/l (112 mg/dl) and 4.7 mmol/l (85 mg/dl), respectively, from eight or more hours postprandially and remained elevated up to 12 hours following the rise.[26,31,d] Further study is needed to assess the relationship of these findings to cats that are fed dietary carbohydrate twice daily, cats that are fed free-choice, or cats that are obese and insulin-resistant.

In diabetic cats treated with long-acting insulin and low-carbohydrate foods, several studies have resulted in variable improvements in glucose regulation and improved insulin sensitivity. The high rate of diabetic remission appears to more closely relate to control of obesity, but improved blood glucose regulation and reversal of glucose toxicity with low carbohydrate may contribute to the positive outcome. While diabetic regulation was similar in diets containing carbohydrate levels of 3.5 g/100 Kcal (12% ME) and 7.6 g/100 Kcal (26% ME), remission rates were increased in cats eating the lowest carbohydrate level.[32] In a study by Hall[33] comparing 1.1 g and 7.9 g/100 Kcal, a reduction in serum fructosamine levels was observed when feeding the lowest carbohydrate, but no differences in other parameters of glucose regulation or remission rates were noted.

At present, a finite limit of carbohydrate intake for the treatment of diabetic cats is uncertain. From experience and the limited studies, it would appear diabetic regulation may benefit from feeding low-carbohydrate levels below 20% ME or 25% DM. However, feeding diets with moderate-carbohydrate levels, especially when supplemented with fiber, provides similar glycemic control. A level of carbohydrate excess for the diabetic cat remains uncertain but would appear to be greater than 8.3 g/100 Kcal in low-fiber foods and possibly higher in fiber-fortified foods.

Summary

Diet composition is known to alter metabolic processes, health and disease risk. The domestic cat has adapted to a naturally low-carbohydrate diet (< 2% ME) with resulting limitations on carbohydrate utilization or rate of glucose disposal compared to more omnivorous species. Cats have no dietary requirement for carbohydrates, yet commercial diets commonly provide levels of carbohydrates well above the evolutionary nutritional profile. It has been suggested that high-carbohydrate levels, especially those in dry foods, predispose cats to disorders including glucose intolerance, insulin resistance, obesity, and Type II diabetes mellitus. To date, no solid evidence is available to support these hypotheses.

Current studies suggest that cats have a rate-limiting capacity to digest or utilize large amounts of simple sugars but tolerate a wide range of starches and complex carbohydrates. Carbohydrate excess is evident for certain simple sugars at levels greater than 1.3 g/kg BW/day, with maximum intake of rapidly available starch limited to 4 g/kg BW/day. Practical limits based on formulation constraints suggest an approximate maximum of 60% ME carbohydrates in adult diets and a maximum of 40% ME carbohydrates in kitten diets as higher carbohydrate levels would limit protein inclusion and thereby create a nutritionally deficient diet.

High-carbohydrate intake does not appear to increase the risk for obesity. Energy excess, low-energy expenditure, neutering, and high-fat intake have the highest association with obesity development in cats. Remission of Type 2 diabetes mellitus in cats may benefit from low-carbohydrate foods along with insulin to improve glycemic control. Suggested limits on dietary carbohydrate for cats with Type 2 diabetes mellitus are 20% ME (5.8 g/100 Kcal ME; 25% DM) in low-fiber foods. While higher levels of carbohydrate levels combined with dietary fiber provide acceptable control and remission rates of Type 2 diabetes mellitus, a finite level of carbohydrate excess has yet to be defined.

Footnotes

a ACVIM Consensus Statement: The role of dietary carbohydrate in causing and managing feline obesity and diabetes mellitus. In 29th Annual ACVIM (American College of Veterinary Internal Medicine) Forum. 2011.

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c Cave NJ, Monroe JA, Bridges JP. Dietary variables that predict glycemic response to whole foods in cats. *Comp Cont Ed for Vet*. 2008;30:57. (Abstract)

d Coradini MA, Rand JS, Morton JM, et al. Delayed gastric emptying may contribute to prolonged postprandial hyperglycemia in meal-fed cats. In 24th Annual ACVIM Forum. 2006.

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