CHAPTER 33

Nutritional Factors Affecting Semen Quality in Felids

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Proper nutrition is being increasingly recognized as a critical component of captive breeding programs for nondomestic cats.[1] In many cases, especially when commercial feline diets are not available, the lack of reproduction may serve as a sensitive indicator of nutritional deficiencies and provide an early warning for the development of diet-related pathologic conditions. If nutritional problems are not addressed, conservation and breeding programs may fail to achieve their tremendous potential.

There is limited information on the nutrient requirements of most nondomestic felid species. Some digestibility studies have been conducted in small felids, such as the serval *(Leptailurus serval),* lynx *(Lynx lynx),* caracal *(Caracal caracal),* and sand cat *(Felis margarita),*[6,10] and in large felids, including the tiger *(Panthera tigris),* lion *(Panthera leo),* puma *(Puma concolor),* and leopard *(Panthera pardus).*[9,29,31] Although diets may be digested differently,[15] the type of diet offered to captive nondomestic felids is based on nutritional requirements for domestic cats (Table 33-1).[3,19] Until more descriptive research is conducted regarding the nutrient requirements of nondomestic felids, extrapolation from domestic cats is necessary. In North American zoos, this strategy of using the domestic cat as a model for nutrition in the 36 species of nondomestic cats has been effective.

Most felid species maintained in North American zoologic institutions typically are fed a commercial raw meat–based diet (frozen or canned) that has been supplemented and formulated to meet the requirements for domestic cats. Additionally, certain nutrients of specific concern, such as protein, vitamins, and minerals (especially calcium) are formulated into these cat diets. In contrast, some institutions feed raw muscle meat (slab meat) and add a commercial vitamin and mineral supplement formulated for the extensive deficiencies in an all-meat diet (e.g., calcium, fat-soluble vitamins A, D, and E). Regardless of the primary diet, "whole-prey" carcasses and large bones often are provided as nutritional supplements to maintain healthy teeth and gums, as well as being excellent items for animal enrichment.

PROTEIN AND AMINO ACIDS

The protein requirement of the cat is higher than that of most mammalian species studied.[7] Generally, a protein requirement is actually a requirement for individual amino acids. The cat's higher protein requirement may result from a need for more total protein, not only an increased requirement for essential amino acids.[23] In general, proteins from animal matter contain a more balanced amino acid profile and better digestibility than plant proteins. However, the perfectly balanced protein complete in all essential amino acids has not been found for cats. Even the amino acid deficiencies of beef are evident when compared to the nutrient requirements of domestic cats.[7] Amino acid availability also may be influenced by storage and food processing. Long-term storage may cause degradation of some nutrients. Certain amino acids may be either destroyed or rendered unavailable by the heating that often occurs during canning or extrusion processes.

Two amino acids have a special significance for cats, arginine and taurine. The cat is unusual in its reliance on the amino acid *arginine.* The cat with an arginine deficiency is unable to metabolize nitrogen compounds (through the urea cycle), which produces rapid elevation of blood ammonia levels resulting in ammonia toxicity and death.[18] Other species may require arginine for growth, but in general they do not need it for adult maintenance.

Taurine also is an essential amino acid for cats. The particular importance of taurine in cat nutrition has been studied for more than 20 years. Cats depend on

Table 33-1

Minimum NRC* Nutrient Concentrations Required in Purified Diets for the Growing Domestic Cat Compared with AAFCO† Nutrient Profiles for Growth and Reproduction of Cats Fed Practical Diets

Nutrient	NRC	AAFCO	Minimum‡	Maximum‡	Expected‡
Moisture, %				70	66
Crude protein, %	24	30	30		56
Arginine, %	1.0	1.25			4.8
Histidine, %	0.3	0.31			2.3
Isoleucine, %	0.5	0.52			2.8
Leucine, %	1.2	1.25			4.3
Lysine, %	0.8	1.2			4.3
Methionine + cysteine, %	0.75	1.1			Unknown
Methionine, %	0.4	0.62			3.4
Phenylalanine + tyrosine, %	0.85	0.88			Unknown
Phenylalanine, %	0.4	0.42			1.9
Taurine, %	0.04	0.1-0.2			0.3
Threonine, %	0.7	0.73			2.5
Tryptophan, %	0.15	0.25			0.3
Valine, %	0.6	0.62			2.9
Crude fat, %		9	10	40	20
Linoleic acid, %	0.5	0.5	0.5		Unknown
Arachidonic acid, %	0.02	0.02			Unknown
Crude fiber, %				3	3.0
Acid detergent fiber, %				5	5.0
Ash, %				8	7.8
Calcium, %	0.8	1	0.8	1.6	1.3
Phosphorus, %	0.6	0.8	0.6	1.2	1.2
Magnesium, %	0.04	0.08	0.05	0.09	0.09
Potassium, %	0.4	0.6	0.5		0.5
Sodium, %	0.05	0.2	0.2		0.5
Chloride, %	0.19	0.3			0.3
Iron, ppm	80	80	80		183
Copper, ppm	5	5-15	5		17
Iodine, ppm	0.35	0.35	1		1
Zinc, ppm	50	75	75		110
Manganese, ppm	5	7.5	7.5		20
Selenium, ppm	0.1	0.1	0.1	2	0.5
Vitamin A, IU/kg	3333	9000	10,000		14,000
Vitamin D_3, IU/kg	500	750	1000		2400
Vitamin E, IU/kg	30	30	200		470
Vitamin K, IU/kg	0.1	0.1	1		2.5
Thiamin, ppm	5	5	7		15
Riboflavin, ppm	4	4	6		17
Vitamin B_6, ppm	4	4	6		28
Niacin, ppm	40	60	60		226
Pantothenic acid, ppm	5	5	10		15
Folacin, ppm	0.8	0.8	0.8		1.0
Biotin, ppm	0.07	0.07	0.1		0.29
Vitamin B_{12}, ppm	0.02	0.02	0.03		0.1
Vitamin C, ppm					470
Choline, ppm	2400	2400	2000		2700

*National Research Council: *Nutrient requirements of cats,* Washington, DC, 1986, National Academy Press.

†Association of American Feed Control Officials: Official publication, Atlanta, 1997, Georgia Department of Agriculture, Plant Food, Feed and Grain Division.

‡The minimum or maximum nutrient concentrations allowed in frozen carnivore diets and the expected nutrient concentrations (dry matter basis) are based on the Zoo Diet Analysis database.

taurine for the formation of bile salts and cannot synthesize sufficient taurine to meet their needs. Taurine deficiency is linked with dilated cardiomyopathy and retinal degeneration.[5,20,21,23] In leopard cats *(Prionailurus bengalensis),* taurine deficiency was observed in males and females fed a commercial canned cat food for 10 to 24 months, resulting in retinal degeneration ranging from focal tapetal lesions to diffuse pigment atrophy and blindness.[12] Composition of the canned diet was modified to prevent dietary deficiencies. Interestingly, taurine deficiency and retinopathy had no influence on male reproductive function in these leopard cats. High concentrations of normal motile spermatozoa were detected each month during the diet-induced taurine deficiency.[12]

In female domestic cats, taurine depletion severely compromises reproductive performance, including an increase in fetal resorption, abortion, and stillbirth.[26] Live-born kittens demonstrate numerous neurologic abnormalities, low birth weight, and poor postnatal survival rate caused by inadequate maternal lactation.[26] The domestic cat's minimum taurine requirement was studied,[5,23] and a taurine content of 500 mg/kg dry matter of the diet was adequate for pregnancy in cats.[19] However, when fed commercial canned diets, 2000 mg taurine/kg dry matter was needed.[8,21] The cause may have been reduced gastrointestinal absorption of taurine or excessive excretion from the digestive tract. New studies suggest that heat treating of cat food may bind the free taurine, making it unavailable to the animal.[20]

Table 33-2 lists the protein concentrations in "whole-prey" carcasses, with several common commercial diets and various types of muscle meats. An exclusive whole-prey diet consisting of an intact carcass containing bones and viscera is a complete and balanced diet for felids, similar to the diets consumed by wild, free-ranging cats. Although an excellent diet for felids, it is usually expensive and cost-prohibitive to provide sufficient quantities of whole prey for large felids as a daily diet.

FAT

The most concentrated source of energy in the diet is fat, which also gives palatability to foods. Fat provides essential fatty acids and is a carrier of fat-soluble vitamins. The essential fatty acids (linoleic, alpha-linolenic, and arachidonic acids) are involved in many aspects of health, including skin and coat condition, kidney function, and reproduction. Another unusual characteristic of the felid is that essential fatty acid requirements cannot be met solely from linoleic or linolenic acids, as occurs in most mammals studied. In addition, cats require a long-chain fatty acid, arachidonic acid, which is available only from animal sources.[22] This requirement appears to stem from low activity of hepatic desaturase enzymes required to convert linoleic to arachidonic acid.

The crude fat content of most whole prey is higher than the minimum dietary levels for felids. In some species of whole prey (e.g., chicken), neonates have lower body fat concentrations than older prey animals, and skinned, eviscerated carcasses contain lower fat concentrations than the whole bodies of prey animals of the same age.

CAROTENOIDS AND VITAMINS

The functions of many carotenoids remain unknown. Historically, it was thought that the biochemical function of beta-carotene was as a precursor to vitamin A. Recently, the antioxidant function of a few carotenoids, especially beta-carotene, has been revealed. All animals require vitamin A, but certain species may convert some carotenoids to vitamin A. In contrast, the cat requires a preformed dietary source of vitamin A and thus requires a source of animal matter in its diet.

The liver is the major vitamin A storage organ for those species that have been studied. All whole-prey diets (including viscera) analyzed to date would appear to exceed the dietary requirements for cats (~3333 IU/kg dry matter) (see Tables 33-1 and 33-2)[19] without a need for further supplementation. In contrast, all-meat or chicken-neck diets are known to be deficient in essential vitamins, including vitamins A, D, and E.[29] Vitamin A deficiencies have reproductive consequences in female felids, primarily pregnancy loss and small litter size.[24] Although comparative data are lacking for male felids, vitamins A and E have a pronounced effect on spermatogenesis in other mammals.[16,17] A 2-month deficiency of vitamin A was reported to cause endocrine changes and complete aspermia in rats.[13,14] Vitamin E deficiency also influences spermatogenic development in the boar[17] and causes incomplete spermatogenesis and epididymal dysfunction in the rat.[4]

Levels of vitamin A, D, and E in various feline diets are listed in Table 33-2.

MINERALS: CALCIUM AND PHOSPHORUS

The cat's requirements for other nutrients, such as calcium and phosphorus, appear to be similar to those

Table 33-2

Nutrient Composition of Vertebrate Carcasses, Manufactured Diets, and Muscle Meats Compared with the Estimated Nutrient Requirements (Dry Matter Basis) for the Domestic Cat

Diet Source	Dry Matter (%)	Crude Protein (%)	Crude Fat (%)	Ash (%)	Vitamin A (IU/kg)	Vitamin D[1] (IU/kg)	Vitamin E (IU/kg)
Carcass[2]							
Mouse, neonate (~4 g)	26.7	50.3	35.5	8.0	ND[3]	ND	ND
Mouse, juvenile (~18 g)	29.5	59.2	24.2	10.0	ND	ND	ND
Mouse, adult (~37 g)	33.5	57.4	23.6	11.3	ND	ND	ND
Rat, juvenile (~64 g)	27.7	62.1	20.4	11.3	ND	ND	ND
Rat, adult (~300 g)	34.8	58.6	22.8	10.1	ND	ND	ND
Rabbit, adult (~1900 g)	28.1	63.5	15.3	9.4	ND	ND	ND
Rabbit, eviscerated (~1700 g)	33.5	71.2	14.6	11.1	ND	ND	ND
Chick, 1 day old (~33 g)	21.6	65.8	13.5	8.8	ND	ND	ND
Chicken backs (~340 g)	41.5	21.9	66.7	6.4	ND	ND	ND
Chicken, adult (~1400 g)	40.5	45.0	51.1	6.2	ND	ND	ND
Manufactured Diets							
Feline (Nebraska)[4]	38.0	47.3	31.6	11.8	10,512	1025	ND
Feline (ZuPreem)[5]	36.7	43.0	43.0	5.9	ND	ND	ND
Canine (Nebraska)[6]	31.0	52.0	22.6	8.1	13,125	1250	ND
Carnivore (Dallas Crown)[7]	40.0	56.0	20.0	7.8	14,000	2400	470
Carnivore (Natural Balance)[8]	38.0	61.3	22.3	6.5	18,515	ND	403
Muscle Meats[9]							
Horse meat	28.2	71.0	20.9	3.8	—[10]	—	—
Beef	28.7	76.2	21.9	3.6	—	—	—
Pork	27.1	75.6	20.0	3.9	177	—	—
Chicken (dark and light meat)	24.5	87.3	12.6	3.9	578	—	11
Estimated requirements[11]	—	>30	—	—	3333	500	30

[1]Vitamin D synthesis in the skin of the cat (from 7-dehydrocholesterol) has not been demonstrated. It is believed that cats must obtain sufficient amounts from the diet.
[2]Carcass data from United States: Ullrey, Michigan State University, and Allen and Baer Associates.
[3]*ND,* No data; component was not analyzed.
[4]Nebraska Brand Feline Diet; raw, horse tissue base (frozen); www.nebraskabrand.com.
[5]ZuPreem Canned Feline Diet; www.zupreem.com. Data from Allen et al, 1996.
[6]Nebraska Brand Canine Diet; raw, horse tissue base (frozen); www.nebraskabrand.com.
[7]Dallas Crown Carnivore Diet 15; raw, horse muscle base (frozen); www.dallascrown.com.
[8]Natural Balance Zoo Carnivore Diet 10; raw, beef muscle base (frozen); www.naturalbalanceinc.com.
[9]Muscle tissue is a poor source of the fat-soluble vitamins A, D, and E. Data from Allen et al, 1996.
[10] "—," Assumed zero.
[11]Based on minimum nutrient requirements for the growing domestic cat (National Research Council, 1986). There is no specific water, ash, or fat requirement, except that the cat requires the essential fatty acids, linoleic acid and arachidonic acid.

in other mammals. As a food source, a whole-prey vertebrate carcass generally is similar in nutrient composition across species (e.g., rat, mouse, chick, rabbit) and provides adequate amounts of calcium (Ca) and phosphorus (P) and in a satisfactory Ca/P ratio (~1.5:1). In contrast, muscle meat is different in nutrient composition from whole prey.[2] Muscle meat is a good source of protein (see Table 33-2), but it is extremely low in calcium, resulting in an inverse Ca/P ratio (Table 33-3).[1] In felids, dietary calcium deficiency causes resorption of bone mineral, greatly reduced bone density, and ultimately metabolic bone disease.[28]

Table 33-3

Calcium (Ca) and Phosphorus (P) in Vertebrate Carcasses, Manufactured Diets, and Muscle Meats Compared with the Estimated Nutrient Requirements (Dry Matter Basis) for the Domestic Cat

Diet Source	Calcium (%)	Phosphorus (%)	Ca/P Ratio
Carcass[1]			
Mouse, neonate (~4 g)	4.0	1.6	2.5:1
Mouse, juvenile (~18 g)	3.8	1.7	2.2:1
Mouse, adult (~37 g)	2.9	1.9	1.5:1
Rat, juvenile (~64 g)	3.1	2.1	1.5:1
Rat, adult (~300 g)	4.8	1.6	3.0:1
Rabbit, adult (~1900 g)	2.4	1.7	1.4:1
Rabbit, eviscerated (~1700 g)	1.9	1.4	1.4:1
Chick, 1 day old (~33 g)	1.8	1.2	1.5:1
Chicken backs (~340 g)	2.2	1.1	2.0:1
Chicken, adult (~1400 g)	1.7	1.3	1.3:1
Manufactured Diets			
Feline (Nebraska)[2]	1.6	1.3	1.2:1
Feline (ZuPreem)[3]	1.2	0.9	1.3:1
Canine (Nebraska)[4]	1.9	1.6	1.2:1
Carnivore (Dallas Crown)[5]	1.3	1.2	1.1:1
Carnivore (Natural Balance)[6]	1.9	1.3	1.5:1
Muscle Meats[7]			
Horse meat	0.07	0.5	0.14:1
Beef	0.02	0.7	0.03:1
Pork	0.02	0.8	0.03:1
Chicken (dark and light meat)	0.05	0.7	0.07:1
Estimated requirements[8]	0.8	0.6	1.3:1

[1]Carcass data from United States: Ullrey, Michigan State University, and Allen and Baer Associates.
[2]Nebraska Brand Feline Diet; raw, horse tissue base (frozen); www.nebraskabrand.com.
[3]ZuPreem Canned Feline Diet; www.zupreem.com. Data from Allen et al, 1996.
[4]Nebraska Brand Canine Diet; raw, horse tissue base (frozen); www.nebraskabrand.com.
[5]Dallas Crown Carnivore Diet 15; raw, horse muscle base (frozen); www.dallascrown.com.
[6]Natural Balance Zoo Carnivore Diet 10; raw, beef muscle base (frozen); www.naturalbalanceinc.com.
[7]Muscle tissue is a poor source of calcium and results in imbalanced Ca/P ratios. Data from Allen et al, 1996.
[8]Based on minimum nutrient requirements for the growing domestic cat (National Research Council, 1986).

Over time, bone demineralization results in fibrous osteodystrophy and nutritional secondary hyperparathyroidism.[25,28]

The calcium and phosphorus levels of various whole-prey carcasses and several common commercial diets are listed in Table 33-3. For comparison, muscle meats also are listed to illustrate the calcium deficiency and imbalance in calcium and phosphorus.

IMBALANCED DIETS AND FERTILITY IN FELIDS

Latin American Cats

Data from a reproductive survey of felids in Latin America (Mexico, Central America, South America) demonstrate the importance of diet on reproductive health and breeding programs.[27] Reproductive evaluations were conducted on 185 captive, adult male felids representing eight endemic Latin American felid species, including the ocelot *(Leopardus pardalis)*, margay *(Leopardus wiedii)*, Geoffroy's cat *(Oncifelis geoffroyi)*, tigrina *(Leopardus tigrinus)*, pampas cat *(Oncifelis colocolo)*, jaguarundi *(Herpailurus yaguarondi)*, jaguar *(Panthera onca)*, and puma, that were maintained under a variety of dietary and other management conditions in 44 zoos or private facilities in 12 Latin American countries. Of the 185 males in the survey, 172 (93%) were wild-born. The remaining 13 individuals were captive-born from wild-born parents. Almost all the small cats (126/129, 98%) were wild-born compared with the larger cats (46/56, 82%).

Diets at 29 of 44 (66%) facilities (representing 128 surveyed males) were considered nutritionally inadequate and were composed almost entirely of red meat (horse or beef) or chicken heads and necks without supplementation with vitamin/mineral mixtures. The remaining 15 (34%) institutions supplemented the diets with whole-prey carcasses, organ meat, or commercial vitamins/minerals. Overall, only 57 of 185 (31%) cats received nutritionally adequate diets.

Of the 185 male cats assessed, the level of successful captive breeding was low, with only 37 males (20%) classified as proven breeders (produced at least one offspring).[27] The majority of these proven breeders were jaguars, pumas, and ocelots. Reproductive evaluations of these 185 males revealed that 131 males (71%) had sperm in their ejaculates; however, the mean number of sperm/ejaculate for each species was low compared with counterpart values measured in U.S. institutions. More than half of all ejaculates contained less than 1 million total sperm, which is an extraordinarily low number for felids.[11,30] Except for the pampas cat, aspermic individuals were observed in all species. Only 87 males (47%) had at least 1×10^6 total sperm/ejaculate, and only 53 males (29%) had 10×10^6 or greater total sperm/ejaculate.

Although multiple management factors (diet, exhibit design, public interaction, general stressors) likely affect reproductive function in male cats, the recurring linkage of poor diets with poor reproduction, under variable management conditions, supports the perception that nutrition is vital for male felid reproductive success in breeding programs.

Semen Quality in Male Felids

Studies conducted in the United States and Southeast Asia further support the importance of nutrition on reproduction, specifically concerning male seminal traits. Reproductive evaluation of captive pumas in Florida and numerous felid species in Thailand receiving unsupplemented chicken-head or chicken-neck diets revealed males with either a high incidence of *oligospermia* (low sperm concentration per ejaculate) or *aspermia* (no sperm in ejaculate) compared with control individuals fed a commercially prepared, balanced feline diet. Interestingly, most of the pumas in Florida appeared to be in good health and generally exhibited normal blood values, as assessed by complete blood count (CBC) and serum chemistry. Most importantly, serum calcium and phosphorus were within normal limits, despite the diets being low in calcium. This is a common finding with imbalanced diets because normal serum calcium is maintained by the continual depletion of calcium from the bones, which may result in metabolic bone disease. The reduced reproductive potential in these cats was only apparent by semen collection and analysis of sperm concentration (sperm density).

Pumas in United States

The most direct evidence of the influence of diet on male reproductive health in nondomestic cats is provided by a dietary study we conducted on pumas held at a private cat facility in Florida (Table 33-4). Six male pumas were maintained solely on chicken-neck diets for periods of at least 10 months before reproductive evaluation. Semen was collected by electroejaculation and assessed for semen quantity (volume, sperm concentration/mL, sperm/ejaculate, motile sperm/ejaculate) and quality (sperm motility, sperm morphology). Puma diets then were changed to a balanced commercial diet (Nebraska Brand Frozen Feline Diet) for at least 6 months, and then cats were reevaluated for the same reproductive traits. No difference existed in body weight or testicular volume between the cats fed an imbalanced chicken-neck diet and the balanced commercial feline diet. With the new balanced diet, sperm motility and sperm morphology were only slightly improved, but the greatest change was in sperm production (Table 33-4). Sperm concentration increased from 2.6×10^6 sperm/mL to 12.0×10^6 sperm/ml of ejaculate. Total sperm per ejaculate also increased from 3.5×10^6 sperm to 32.9×10^6 sperm. Compared with a control puma population (22 males) in North American zoos fed a commercial balanced diet with adequate calcium (Nebraska Brand Frozen Feline Diet), these new values in the six pumas still were relatively depressed, but represented a marked improvement from earlier findings.

Table 33-4

Body Weight, Testicular Volume, and Ejaculate Traits in Pumas Fed a Chicken-Neck Diet before a Commercial Feline Diet Compared with Control Cats in North American Zoos Fed Commercial Feline Diets*

	TYPE OF DIET (DURATION OF DIET)		
	Chicken Necks (>10 months)	Nebraska Brand (>6 months)	Control Pumas
Body weight (kg)	43.9 ±2.8	54.4 ±4.4	53.7 ±1.8
Testicular volume (cm^3)	16.7 ±2.8	20.8 ±3.6	19.3 ±1.0
Ejaculate volume (mL)	1.9 ±0.5	2.8 ±0.6	2.7 ±0.3
Sperm concentration/mL ($\times 10^6$)	2.6 ±2.2[a]	12.0 ±3.2[b]	33.4 ±7.9[c]
Sperm concentration/ejaculate ($\times 10^6$)	3.5 ±2.3[a]	32.9 ±9.8[b]	73.2 ±12.8[c]
Sperm motility (%)	40.0 ±11.7	56.0 ±12.5	53.9 ±4.9
Motile sperm/ejaculate ($\times 10^6$)	2.5 ±2.0[a]	23.4 ±7.2[b]	39.3 ±7.8[c]
Sperm progression[†]	2.6 ±0.1	3.5 ±0.7	3.3 ±0.1
Normal sperm (%)	8.9 ±2.4	20.3 ±10.0	14.0 ±2.3

*Values = mean ±SEM. Six male pumas were fed an imbalanced chicken-neck diet (for at least 10 months) before changing to the balanced commercial Nebraska Brand Feline Diet (for at least 6 months). Control males (n = 22) were maintained in North American zoos and fed the balanced commercial Nebraska Brand Feline Diet. Within rows, means with different superscript lowercase letters differ (p <0.05).
[†]Sperm progression is based on a scale of 0 to 5 (5 = best).

Because all other management factors remained constant, these findings provide powerful evidence that nutrient-deficient diets impact directly on male reproduction, especially semen traits and sperm production.

Felids in Thailand

The importance of diet on animal health and reproductive potential also was demonstrated in an international conservation project initiated between zoos in the United States and Thailand. The goal of the project was to develop a comprehensive captive management program for endemic small felids, including fishing cats *(Felis viverrina),* golden cats *(Felis temminckii),* leopard cats *(Felis bengalensis),* and clouded leopards *(Neofelis nebulosa),* maintained in zoologic institutions in Thailand. The project initially focused on assessment of health, reproduction, and nutrition. A total of 54 cats (31 males, 23 females) representing four small felid species in five institutions were evaluated. A physical and dental examination, CBC, serum chemistry, and reproductive evaluation were conducted on each animal. Major health problems were detected, including fractured canine teeth (open root canals), cardiac arrhythmias, heart murmurs, and metabolic bone disease. A high incidence of obesity also was detected, especially in the golden cats (4/7, 57.1%) and clouded leopards (4/13, 30.8%). The majority of the CBCs were normal, except for elevated white blood cell counts associated with dermatitis or infected root canals. Most serum chemistries were normal, with the exception of compromised renal function in certain cats.

Initial reproductive assessments in 31 males revealed a high incidence of oligospermic ($<10 \times 10^6$ sperm/mL) males and overall reduced total sperm per ejaculates compared with control individuals evaluated in North American zoos. Ejaculates from 12 of the 31 males (38.7%) were oligospermic, which was most severe in the golden cats (4 of 5 males, 80%) and fishing cats (3 of 5 males, 60%) (Table 33-5). Three of 8 leopard cats (37.5%) and only 2 of 13 clouded leopards (15.4%) produced low sperm concentrations. A high incidence of *teratospermia* (abnormal sperm forms) was detected in the fishing cat, golden cat, and clouded leopard, and percentages of abnormal sperm in each species were similar to captive felids in North America. These results were especially noteworthy because the majority of the cats were wild-caught. Nutritional assessment of the diet (chicken heads and necks) revealed an excessive amount of fat and an inadequate amount of protein, essential vitamins, and some minerals. Therefore, nutritional deficiencies were suspected to be the etiology of the bone deformities and the low sperm concentrations.

Recommendations for dietary changes were developed and implemented to include an increase in

Table 33-5

Influence of Nutrition on Sperm Production in Endemic Felid Species in Thailand Zoos Fed an Unsupplemented versus Supplemented Diet Compared with Control Cats in North American Zoos

	Unsupplemented Diet (Chicken Heads/Necks)	Supplemented Diet (Chicken Meat and Vitamins/Minerals)*	Control Cats†
Golden Cat			
Number of males	5	4	19
Number of oligospermic ejaculates‡ (%)	4 (80.0%)	0 (0%)	8 (42.1%)
Sperm concentration ($\times 10^6$/mL)	7.4 ±3.9[a]	48.0 ±22.0[b]	64.2 ±21.2[b]
Total sperm/ejaculate ($\times 10^6$)	5.4 ±3.5[a]	26.8 ±12.0[b]	21.2 ±8.5[b]
Leopard Cat			
Number of males	8	5	48
Number of oligospermic ejaculates (%)	3 (37.5%)	2 (40.0%)	0 (0%)
Sperm concentration ($\times 10^6$/mL)	61.6 ±12.4[a]	134.4 ±50.4[b]	153.9 ±17.8[b]
Total sperm/ejaculate ($\times 10^6$)	11.8 ±5.4[a]	31.2 ±13.9[b]	28.7 ±5.9[b]
Fishing Cat			
Number of males	5	9	16
Number of oligospermic ejaculates (%)	3 (60.0%)	1 (11.1%)	2 (12.5%)
Sperm concentration ($\times 10^6$/mL)	75.7 ±34.2	110.8 ±29.6	157.2 ±58.2
Total sperm/ejaculate ($\times 10^6$)	40.3 ±25.4	58.3 ±15.7	51.8 ±19.1
Clouded Leopard			
Number of males	13	9	132
Number of oligospermic ejaculates (%)	2 (15.4%)	1 (11.1%)	20.0 (15.2%)
Sperm concentration ($\times 10^6$/mL)	31.4 ±5.9	24.0 ±5.7	41.2 ±4.6
Total sperm/ejaculate ($\times 10^6$)	31.7 ±8.9	22.0 ±7.7	296 ±2.9

Within rows, means with different superscript lowercase letters differ ($p < 0.05$).
*Centrum vitamin/mineral supplement added to 2 kg of eviscerated chicken.
†Control cats were maintained in North American zoos and fed a commercial balanced diet.
‡Oligospermic ejaculates contained a low sperm concentration ($<10 \times 10^6$ sperm/mL).

protein (using eviscerated chickens with bones) and the addition of a Centrum vitamin/mineral supplement (Wyeth Consumer Healthcare, Madison, NJ). After at least 1 year on the improved diet, reproductive assessments were conducted in 27 males (see Table 33-5). Only 4 of 27 males (14.8%) exhibited low sperm concentrations containing less than 10×10^6 sperm/mL, compared with 38.7% of the males before the improvement in diet. The most striking difference was observed in the golden cats. None of the four male golden cats was oligospermic, in contrast to 80% previously observed on the imbalanced diet (see Table 33-5). Similarly, only one of the nine fishing cats (11.1%) produced an ejaculate with a low number of sperm, compared with 60% before the diet change. A twofold to sixfold increase in sperm production was detected in the golden cats and leopard cats (see Table 33-5). Fishing cats demonstrated a more subtle increase in sperm concentration, and minimum changes were observed in the clouded leopards.

Overall, these data confirm the important link between nutrition, health, and reproduction in a captive breeding program. Because reproduction is the ultimate key to species survival, it is critical that a suitable diet and feeding strategy be developed for international breeding programs of genetically valuable endangered species.

MUSCLE MEAT DIETS

Vertebrates (whole carcasses) are the predominant prey of many mammalian carnivores. The vertebrate carcass generally is similar in nutrient composition

Table 33-6

Diet Alternatives That Are Nutritionally Balanced for Felids

	Dry Matter (%)	Diet 1	Diet 2
Horse meat, g	27.2	1983.5	1983.5
Calcium carbonate, g	100	5.0*	—
Dicalcium phosphate, g	97	10.0*	—
Steamed bonemeal, g	97	—	15.0*
Centrum tablet† (1), g	100	1.5	1.5
TOTAL (wet basis), g		2000	2000
TOTAL (dry basis), g		556	556

From Ullrey D, Bernard J: *J Zoo Wildl Med* 20(1):20-25, 1989.
*Combination of 5 g (~1 teaspoon) and 10g (~2 teaspoons), or use of 15 g (~3 teaspoons) is approximately equivalent to 1 tablespoon, although each product should be weighed at least once because of differences in volume/weight relationships.
†Centrum: From A to Zinc; Wyeth Consumer Healthcare, Madison, NJ 07940; www.centrum.com.

across species, at least with respect to major nutrients (see Table 33-2). Protein concentrations are typically quite high. Calcium and phosphorus usually are present in adequate amounts and in a satisfactory ratio (see Table 33-3). In contrast, muscle meats are quite different in composition from whole prey (see Tables 33-2 and 33-3). Although muscle meats typically are good sources of amino acids, some minerals (e.g., sodium, potassium, iron, selenium, zinc) and some B vitamins (e.g., niacin, B_6, B_{12}) are very low, in addition to low calcium (Ca/P ratios ~1:15-1:30), manganese, and fat-soluble vitamins (vitamins A, D, and E).

Use of muscle meats as the sole diet of carnivores once was widespread in North American zoos, with the predictable result: severe and often fatal nutritional bone disease. In both wild and domestic animals, pathologic bone disease resulting from dietary imbalances of calcium, phosphorus, and vitamin D manifests most readily in growing or lactating animals. Although awareness of the problems associated with such diets now is common among zoo staff, slab meat is still often used with problem eaters. Currently, most North American zoos feed commercially prepared, complete carnivore rations to felids (see Tables 33-2 and 33-3). These diets typically are prepared using horsemeat or beef, balanced with vitamin and mineral premixes, and are available as frozen or canned products. The formulations of these diets are quite similar in proximate analysis to whole vertebrate prey, except that the frozen foods lack hide, hair, and hooves. In some zoos, rats, chickens, rabbits, or other vertebrate prey also are offered on a regular or periodic basis in addition to the commercial preparations. It is important that the whole vertebrate prey also are fed a balanced diet.

In contrast, many zoos outside North America use muscle meats extensively because commercial diets are not readily available or too expensive to import. Furthermore, following outbreaks of avian influenza in Asia, many international zoos have switched from poultry diets to beef muscle meat diets for zoo carnivores. When used, these muscle meat diets should be supplemented with vitamins and minerals, particularly calcium.

The feeding of unsupplemented muscle meat also may lead to vitamin A deficiency in some circumstances. Liver may be used as a source of vitamin A; 10 g of beef liver added to 1 kg of muscle meat will provide approximately 15,000 IU vitamin A/kg dry matter. Because the vitamin A content of liver varies greatly, and because other nutrients will be limited in a diet of muscle and liver, a more consistent method of providing appropriate levels of vitamins and minerals has been suggested. Ullrey and Bernard[29] propose that appropriately formulated multivitamin/mineral tablets, in addition to steamed bonemeal or a combination of calcium carbonate and dicalcium phosphate, will satisfy nutritional requirements for cats that must be fed muscle meat (Table 33-6).

Supplementing Muscle Meat or Eviscerated-Carcass Diets

Nutritionally (optimally) balanced diets are presented here for supplementing muscle meat or an eviscerated carcass. These diets are based on basic nutritional requirements estimated from the National Research Council (NRC) recommendations for growing domestic cats.[19] Key supplements to the diets presented next

Box 33-1

Nutrient Composition and Directions for a Commercial Vitamin and Mineral Product to Supplement Raw Meat Diets for All Carnivorous Species*

Nutrient Composition of Supplement

Calcium, %	19.2
Zinc, ppm	1200
Manganese, ppm	150
Copper, ppm	160
Iodine, ppm	20
Vitamin K (as menadione), ppm	50
Thiamin, ppm	200
Riboflavin, ppm	200
Niacin, ppm	500
Pantothenic acid, ppm	125
Folic acid, ppm	16
Pyridoxine, ppm	200
Biotin, ppm	5.0
Vitamin A, IU/g	200
Vitamin D_3 (added), IU/g	40
Vitamin E, IU/kg	8000
Vitamin C, ppm	5000
Taurine, %	5.0

Directions for Use

Mazuri Carnivore Supplement for Slab Meat (#58QC) is designed to be added at 2.0% of wet weight of slab meat (without bone).

Calculations:

1000 g meat × 0.02 = 20 g supplement/kg meat

For 20 g supplement/kg meat, add 4 teaspoons (5 g each) supplement/kg meat.

*Ingredients in Mazuri Carnivore Supplement for Slab Meat (#58QC) include calcium carbonate, cooked chicken, taurine, menadione dimethyl-pyrimidinol bisulfite (vitamin K), dl-alpha-tocopheryl acetate (vitamin E), l-ascorbyl-2-polyphosphate (vitamin C), zinc sulfate, copper sulfate, nicotinic acid, vitamin A acetate, pyridoxine hydrochloride, riboflavin, thiamine mononitrate, calcium pantothenate, cholecalciferol (vitamin D_3), calcium iodate, folic acid, and biotin.

For locations of Mazuri products (St. Louis, Mo) sold internationally, find dealers on website at www.mazuri.com, or call Mazuri Customer Service Department at 1-800-227-8941.

are a calcium source in sufficient quantity and a multivitamin/mineral source. For muscle meat diets, calcium deficits may be alleviated by using calcium carbonate. However, phosphorus concentrations would still be marginal, and Ca/P ratios would be wider than desirable.[29] An optimum calcium and phosphorus supplement may be made by using proportions of one-third calcium carbonate (39% calcium) and two-thirds dicalcium phosphate (22% calcium, 18% phosphorus)[29] (see Table 33-6). The proportions of calcium and phosphorus in this mixture are similar to bone. As an alternative, steamed bonemeal (30% calcium, 12% phosphorus) may be substituted for an equal weight of the calcium carbonate–dicalcium phosphate mixture.

Supplemental vitamins and additional minerals may be provided by using Centrum: From A to Zinc tablets (www.centrum.com), a multivitamin/mineral for humans readily available throughout most of North, Central, and South America; Europe; and Asia (see Table 33-6). These tablets weigh about 1.5 g each, and 1 tablet is sufficient supplement for 2 kg of muscle meat (27% dry matter).[29] These tablets are scored and may be broken in half for use with 1 kg of muscle meat.

Another option for supplementing muscle meat is a commercial vitamin/mineral premixed supplement containing sufficient levels of calcium (Mazuri Carnivore Supplement for Slab Meat, product #58QC, St. Louis, Mo). The product is available in North America, and information on international dealers in Taiwan, Korea, Japan, and Hong Kong is listed on the website (www.mazuri.com). This product may be added to muscle meat for a balanced diet for carnivores (Box 33-1).

The following diets describe how to supplement all-meat diets or eviscerated whole carcasses for a balanced diet for carnivores.

Muscle Meat Diet (Beef): Diet 1

1. Muscle meat needs to be supplemented with 1 multivitamin/mineral tablet (Centrum: From A to Zinc), 5 g calcium carbonate, and 10 g dicalcium phosphate for every 2 kg of meat.
2. The multivitamin/mineral tablet (Centrum) and the calcium supplements need to be provided in the proper amounts each time muscle meat is fed (see Table 33-6).

Muscle Meat Diet (Beef): Diet 2

1. Muscle meat needs to be supplemented with 1 multivitamin/mineral tablet (Centrum) and 15 g steamed bonemeal (as the source of calcium) for every 2 kg of meat.
2. The multivitamin/mineral tablet (Centrum) and the bonemeal calcium supplement need to be provided in the proper amounts each time muscle meat is fed (see Table 33-6).

Muscle Meat Diet (Beef): Diet 3

Muscle meat may be supplemented with a commercial powder containing both a multivitamin/mineral and a calcium source (Mazuri Carnivore Supplement for Slab Meat). This supplement should be added at 2% of wet weight of slab meat (without bone). For each 1000 g of muscle meat, a total of 20 g of supplement (~4 teaspoons) is added (see Box 33-1).

Eviscerated Whole Chicken/Rabbit/Rat: Diet 4

1. No vitamin/mineral supplement is required when a whole carcass is fed, including all the viscera (the intestinal tract may be removed).
2. The viscera (including liver, heart, kidneys, spleen) are an important source of vitamin/minerals and must be included in the diet.
3. It is ideal to feed each cat a whole-prey carcass, with body size chosen according to the cat's size. If the carcass must be divided, it should be split lengthwise so that each cat receives half the carcass. Divide the liver, heart, and other viscera or alternate viscera daily between cats.
4. Prey animals must be healthy and maintained on a nutritionally complete feed before their use as food for cats.
5. If the viscera are not available, the eviscerated carcass must be supplemented with the correct amount of vitamin/mineral supplement (1 Centrum tablet for every 2 kg meat). No additional calcium source is needed if the eviscerated carcass contains the bones.

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References

1. Allen ME, Ullrey DE:. Relationships among nutrition and reproduction and relevance for wild animals, *Zoo Biol* 23(6):475-487, 2004.
2. Allen ME, Oftedal OT, Baer DJ: The feeding and nutrition of carnivores. In Kleiman DG, Allen ME, Thompson KV, Lumpkin S, editors: *Wild mammals in captivity: principles and techniques,* Chicago, 1996, University of Chicago Press, pp 139-147.
3. Association of American Feed Control Officials (AAFCO): Official publication, Atlanta, 1997, Georgia Department of Agriculture, Plant Food, Feed and Grain Division.
4. Bensoussan K, Morales CR, Hermo L: Vitamin E deficiency causes incomplete spermatogenesis and affects the structural differentiation of epithelial cells of the epididymis of the rat, *J Androl* 19:266-288, 1998.
5. Burger I, Barnett K: The taurine requirement of the adult cat, *J Small Anim Pract* 23:533-537, 1982.
6. Crissey SD, Swanson JA, Lintzenich BA, et al: Use of a raw meat–based diet or a dry kibble diet for sand cats *(Felis margarita), J Anim Sci* 75:2154-2160, 1997.
7. Czarnecki G: Protein and amino acid utilization in carnivores, *Proc Third Ann Dr Scholl Nutr Conf,* Chicago, 1983, pp 28-43.
8. Earle K, Smith P: The effect of dietary taurine content on the plasma taurine concentration in the cat, *Br J Nutr* 66:227-235, 1991.
9. Hackenburger M, Atkinson J: The apparent digestibilities of captive tigers (*Panthera tigris* spp.), *Proc Third Ann Dr Scholl Nutr Conf,* Chicago, 1983, pp 70-83.
10. Hamor G: Results of a digestion trial evaluating six species of carnivore, *Proc Third Ann Dr Scholl Nutr Conf,* Chicago, 1983, pp 97-109.
11. Howard JG: Semen collection and analysis in carnivores. In Fowler ME, editor: *Zoo and wild animal medicine: current therapy,* ed 3, Philadelphia, 1993, Saunders, pp 390-399.
12. Howard JG, Rogers QR, Koch SA, et al: Diet-induced taurine deficiency retinopathy in leopard cats *(Felis bengalensis), Proc Am Assoc Zoo Vet,* Turtle Bay, Hawaii, 1987, pp 496-498.
13. Huang HFS, Hembree WC: Spermatogenic response to vitamin A in vitamin A–deficient rats, *Biol Reprod* 21:891-904, 1979.
14. Huang HFS, Dyrenfurth I, Hembree WC: Endocrine changes associated with germ cell loss during vitamin A–induced recovery of spermatogenesis, *Endocrinology* 112: 1163-1171, 1983.
15. Kendall P, Holme D, Smith P: Comparative evaluation of net digestive and absorptive efficiency in dogs and cats fed a variety of contrasting diet types, *J Small Anim Pract* 23:577-587, 1982.
16. Livera G, Rouiller-Fabre V, Pairault C, et al: Regulation and perturbation of testicular function by vitamin A, *Reproduction* 124:173-180, 2002.
17. Marin-Guzman J, Mahan DC, Pate JL: Effect of dietary selenium and vitamin E on spermatogenic development in boars, *J Anim Sci* 78:1537-1543, 2000.
18. *Morris J, Rogers Q:* Arginine: an essential amino acid for the cat, *J Nutr* 108:1944-1953, 1978.
19. National Research Council (NRC): *Nutrient requirements of cats,* Washington, DC, 1986, National Academy Press.
20. Odle J, Roach M, Baker D: Taurine utilization in cats, *J Nutr* 123:1932-1933, 1993.
21. Pion P, Kittleson M, Rogers Q: Cardiomyopathy in cats and its relation to taurine deficiency. In Kirk RW, editor: *Current veterinary therapy X,* Philadelphia, 1989, Saunders, pp 251-262.
22. Rivers J: Essential fatty acids in cats, *J Small Anim Pract* 23:563-576, 1982.
23. Rogers Q, Morris J: Do cats really need more protein? *J Small Anim Pract* 23:521-532, 1982.
24. Scott PP, Scott MG: Vitamin A and reproduction in the cat, *J Reprod Fertil* 8:270-271, 1964.

25. Slusher R, Bistner SI, Kircher C: Nutritional secondary hyperparathyroidism in a tiger, *J Am Vet Med Assoc* 147:1109-1115, 1965.
26. Sturman JA, Moretz RC, French JH, Wisniewski HM: Taurine deficiency in the developing cat: persistence of the cerebellar external granule cell layer, *J Neurosci Res* 13:405-416, 1985.
27. Swanson WF, Johnson WE, Cambre RC, et al: Reproductive status of endemic felid species in Latin American zoos and implications for ex situ conservation, *Zoo Biol* 22:421-441, 2003.
28. Ullrey D: Metabolic bone disease. In Fowler ME, Miller RE, editors: *Zoo and wild animal medicine,* ed 5, Philadelphia, 2003, Saunders, pp 749-756.
29. Ullrey D, Bernard J: Meat diets for performing exotic cats, *J Zoo Wildl Med* 20(1):20-25, 1989.
30. Wildt DE, Brown JL, Swanson WF: Cats. In Knobil E, Neill JD, editors: *Encyclopedia of reproduction,* New York, 1998, Academic Press, pp 497-510.
31. Wynne JA: Comparative digestibility values in four species of felidae, *J Zoo Wildl Med* 20(1):53-56, 1989.