The Nutritional Requirements of Exercising Dogs[1,2]

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ABSTRACT The nutrient requirements of canine athletes are unique. Dogs have a greater capacity for fat oxidation than humans both at rest and during exercise. In dogs undertaking endurance exercise, such as sled dogs, high fat (>50% of energy) diets increase stamina and maximize energy production, and high protein (>30% of energy) diets prevent training-induced anemia. Nutrient requirements differ, however, for sprint racing dogs, such as greyhounds. Greyhounds run faster when fed moderately increased dietary fat but run more slowly when dietary protein is increased. Sled dogs have similar energy requirements to other breeds at rest in a thermoneutral environment (~$550W^{0.75}$ kJ/d where W is body weight in kg) but may require as much as $4200W^{0.75}$ kJ/d during a race. The energy requirement of greyhounds in training, however, is only ~$600W^{0.75}$ kJ/d. There is little information, however, concerning the vitamin, mineral or other nutrient requirements of athletic dogs; most sled dogs and greyhounds are fed "homemade" recipes. These recipes usually include raw meat and represent a health risk. More studies are required to improve the health and performance of working and racing dogs. J. Nutr. 128: 2686S–2690S, 1998.

KEY WORDS: • *exercise* • *nutritional requirements* • *greyhound* • *sled dog* • *dogs*

The purpose of this paper is to review the nutritional requirements of athletic dogs. The nutrition of exercising dogs is an emotive issue. This was illustrated recently by a headline in the Anchorage Daily News which stated, ". . . vitamin (E) deficiencies . . . killed Iditarod dogs" (Medred 1997). Unfortunately, the basis for this claim has not been published and the vitamin E requirements of athletic dogs are unknown. This emphasizes that more nutritional studies are required in athletic dogs and that the goal of exercise nutrition must be to minimize injury (caused by food-borne infection, dehydration, hyperthermia, myoglobinuria or orthopedic injury) as well as to maximize performance (speed, strength and stamina). Unfortunately, most canine nutritional studies have been performed with dogs undertaking little exercise.

Canine metabolism is unique. Mammalian muscle fibers have been classified into types I, IIa and IIb based on their metabolism. Type I fibers contain less ATPase activity compared with type II fibers. Types I and IIa are characterized by oxidative metabolism, whereas type IIb fibers are characterized by anaerobic glycolytic metabolism. Canine muscle contains mainly oxidative fibers (Armstrong et al. 1982, Gunn 1978a, Snow 1987). Guy and Snow (1981) describe some low oxidative muscle fibers in dogs but acknowledge that the activity of the oxidative enzyme succinate dehydrogenase in the low oxidative fibers was still greater than that in type IIb fibers from other species. Relative to metabolic body size, dogs also metabolize free fatty acids at twice the rate observed in humans (de Bruijne 1981). Dog muscle is, therefore, more adapted to use fat than human muscle and conclusions derived from human experiments may not be valid in dogs.

Most canine exercise studies have been performed using greyhounds or sled dogs. Greyhounds are uniquely adapted to sprinting. Their muscle mass comprises a larger proportion of total body weight (57 vs. 43%) compared with other dogs (Gunn 1978b). Greyhound limb muscles also contain mainly (80–100%) fast-twitch muscle type IIa fibers and few slow-twitch fibers, whereas the deeper extensor antigravity limb muscles of mixed breed dogs contain more (20–100%) slow-twitch type I fibers (Armstrong et al. 1982, Gunn 1978a and 1978b). Most limb muscle fibers in both greyhounds and crossbred dogs display high oxidative activity (Gunn 1978a, Guy and Snow 1981). Nevertheless, the activity of some aerobic and anaerobic muscle enzymes (aldolase and citrate synthase, respectively) is increased in greyhounds, whereas the activity of other enzymes (creatine kinase, lactate dehydrogenase) is not different compared with crossbred dogs (Guy and Snow 1981). This suggests that the balance between oxidative and glycolytic capacity in greyhound muscle is similar to that in other breeds. It should be possible, therefore, to extrapolate from greyhounds to less specialized sprinters such as retrieving gun dogs and dogs that chase Frisbees. It should also be possible to extrapolate the results obtained with sled dogs to less specialized endurance athletes such as hunting dogs and search and rescue dogs.

CURRENT PRACTICE AND FOOD SAFETY

The dearth of information about canine exercise nutrition has encouraged most greyhound trainers to develop their own recipes.

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Most trainers believe that raw meat (usually beef) and a few other ingredients such as vitamins, vegetables and buttermilk should be added to kibble dog food for optimum performance. Only 27% of greyhound kennels surveyed in the United Kingdom fed proprietary dog food and none fed proprietary dog food without adding other nutrients (Griffiths 1969).

Meat is not a balanced food and is deficient in essential vitamins and minerals. Feeding too much meat without adequate calcium supplementation can result in hyperparathyroidism, poor bone mineralization and increased risk of fractures in dogs (Morris et al. 1971). Fractures of the tarsus, carpus, metacarpi and metatarsi are common in racing greyhounds (Bloomberg and Dugger 1996). Bone mineral density may affect the incidence of fractures in racing sled dogs (Stoliker et al. 1976). Scintigraphy of the carpi and metacarpi of racing greyhounds shows many areas of increased bone remodeling, sometimes in the absence of radiographic signs of injury (Zuber et al. 1996). Calcium deficiency can be corrected simply by adding 1 g of bone meal to each 50 g of meat, but excess supplementation can increase the risk of osteochondritis in growing large breed dogs (Hazewinkel et al. 1985). Exercise and calcium may work together to increase this risk (Slater et al. 1992).

Food-borne infection. Food-borne infection is the other major complication of feeding fresh meat. All common food-borne human pathogens such as *Salmonella*, *Shigella*, *Escherichia coli*, *Campylobacter*, *Listeria*, *Clostridium perfringens*, *Mycobacterium bovis* and *Staphylococcus* are potential pathogens in dogs fed uncooked or unpasteurized food. Greyhounds are usually fed raw meat classified as "not for human consumption" that frequently (>40%) contains *Salmonella* spp. (Chengappa et al. 1993). A Shiga-like toxin produced by *E. coli* H157:O7 found in uncooked meat is responsible for the severe vasculitis, cutaneous necrosis, renal failure and death, termed "Alabama rot", in greyhounds (Fenwick 1996). Cooking meat would eliminate this risk, but most greyhound owners believe that meat needs to be raw to have a beneficial effect and cooking destroys potentially beneficial nutrients such as creatine. Defrosting frozen meat in a refrigerator or cooler reduces the proliferation of bacteria but the risk of infection remains high.

Meat may also contain inadvertent additives. Meat fed to greyhounds often contains procaine from procaine penicillin used to treat cattle before death (Sundlof et al. 1983). Procaine improves the fitness of human athletes (Prokop 1973) and may have a beneficial effect on performance in greyhounds. Greyhounds are, therefore, not allowed to compete if procaine is present in the urine. Fortunately, little to no procaine can be detected in the urine if meat is withheld for 24 h before a race (Sundlof et al. 1983).

Water, rehydration, heat loss and hyperthermia. Heat is generated during exercise because work is an inefficient process and rectal body temperature usually increases slightly (2–3°C) after sprint or endurance exercise (Bjotvedt et al. 1993, Kozlowski et al. 1985, Nazar et al. 1992). Sled dogs increase their metabolic rate to maintain body temperature *at rest* when the ambient temperature is very low (Grandjean and Paragon 1993), but maintaining a *low* body temperature and *losing* heat are the overriding concerns of a dog during exercise. Heat is lost by radiation, convection and evaporation. Hyperthermia, therefore, becomes a major concern when both ambient temperature and humidity are high. At our laboratory, the body temperature of most greyhounds increases to only 41°C after a 500-m race in the early morning when the ambient temperature is ~30°C and humidity is >50%. This increase in body temperature is unaffected by changes in dietary protein or fat but some dogs sporadically develop very high temperatures (>44°C) especially after afternoon races and when dogs are untrained (Bjotvedt et al. 1993, Nazar et al. 1992). This hyperthermia can be life threatening. Untreated hyperthermia may lead to collapse, shock, hemorrhage, widespread tissue necrosis and death (Bjotvedt et al. 1993). Hyperthermia also reduces time to exhaustion, increases depletion of muscle glycogen and high energy phosphate, and increases muscle lactate during endurance exercise (Kozlowski et al. 1985). Cold water baths and access to water immediately after a race limit the severity of hyperthermia but intravenous fluids are sometimes necessary to treat the most severe cases.

In humans, dehydration predisposes to hyperthermia. A 1% loss of body weight from dehydration is associated with a 2.5% decrease in plasma volume and a 0.5°C increase in body temperature (Hultman et al. 1994). In greyhounds, dehydration occurs before rather than during a race. At our laboratory, eight greyhounds were found to lose a mean of only 0.7% of their body weight (range 0.4–1.1%; 100–300 g) during a 500-m race. At commercial tracks, dogs are kept in pens without water before a race; thus, most dogs become slightly (<1%) dehydrated and some (5%) become >2.5% dehydrated (Blythe and Hansen 1986).

In sled dogs, water turnover increases dramatically from 1 L/d in kennels to 5 L/d during a 490-km race (Hinchcliff and Reinhart 1996). Exercise reduces the rate of gastric emptying of liquid in dogs (Kondo et al. 1994), and the rate of gastric emptying of fluids is known to determine the efficiency of rehydration solutions in humans (Hultman et al. 1994). Unfortunately, the ideal type, frequency and amount of rehydration solution has not been determined in dogs. Ideal rehydration solutions in humans contain 50–100 g/L sugar and 20–30 mmol/L sodium, are cool (6–12°C), and are administered in small volumes every 10–15 min (Hultman et al. 1994). Medium-chain triglycerides have been added to human oral rehydration solutions because they do not inhibit gastric emptying; however, little benefit has been demonstrated (Jeukendrup et al. 1996, Van Zyl et al. 1996).

Energy requirements. The daily maintenance energy requirement of dogs varies with body weight in kg (W),[4] life stage, breed, exercise and ambient temperature. The average maintenance energy requirement of sled dogs (500–550$W^{0.75}$ kJ/d) appears to be similar to that of other young adult (2- to 5-y-old) dogs kept in kennels in a thermoneutral environment (Durrer and Hannon 1962, Finke 1991, NRC 1985). The energy requirement of sled dogs may increase, however, in low ambient temperatures subject to the effect of wind chill. The ambient temperature below which metabolic rate increases to maintain body temperature (the critical temperature) of thin-coated breeds of dog (Labrador Retrievers and Beagles) appears to be 20°C (Blaza 1982, Durrer and Hannon 1962, Finke 1991). In sled dogs with thick hair coats, however, the critical temperature appears to be lower: <0°C (Finke 1991) and −20°C (Scholander et al. 1950). Nevertheless, sled dogs at rest may require ~900$W^{0.75}$ kJ/d when the ambient temperature is −20°C if dogs are in the open exposed to wind chill (Campbell and Donaldson 1981, Durrer and Hannon 1962, Hinchcliff and Reinhart 1996).

The energy required for movement is proportional to distance traveled rather than speed; therefore a greyhound race over 500 m should require much less energy than a sled dog race over many kilometers (Schmidt-Nielsen 1984).

[4] Abbreviations used: DIPA-DCA, diisopropylammonium dichloroacetic acid; DMG, dimethyl glycine; W, body weight in kilograms; $VO_{2\ max}$, maximal oxygen uptake.

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Several groups of greyhounds fed free-choice kibble dog food once daily at our laboratory and racing over 500 m twice weekly, have maintained constant body weight and ideal body condition for periods of 8–18 mo when consuming $\sim 600W^{0.75}$ kJ/d. This is little more than is suggested for other breeds in kennels (NRC 1985). Similar feeding experiments with racing sled dogs found that dogs consumed an average of $4200W^{0.75}$ kJ/d during a 3-d race in which dogs raced at an average of 7 km/h in ambient temperatures of −10 to −35°C (Hinchcliff and Reinhart 1996).

Major nutrients. The energy for muscle contraction comes from four chemical sources: ATP, creatine phosphate, anaerobic metabolism of carbohydrate or aerobic metabolism of glucose and fat. Energy is obtained from the high energy phosphate bonds of ATP. One molecule of ATP may then be regenerated from ADP at the expense of the high energy phosphate bond in creatine phosphate. High energy phosphate bonds are continually replenished either anaerobically by glycogenolysis and glycolysis, or aerobically from fat or glucose by oxidation. One ATP and one AMP molecule can also be generated from two ATP molecules; the AMP generated is metabolized to xanthine, hypoxanthine and uric acid. This involves xanthine oxidase and may represent an oxidative stress. Creatine phosphate may act as an energy buffer by moderating changes in ATP concentration, thus limiting AMP production and oxidative stress.

In humans, the maximum rate of energy expenditure varies for each substrate, but the amount of substrate limits the length of time that this maximum rate of expenditure can be maintained (Hultman et al. 1994). Only creatine phosphate and ATP are able to sustain a 100-m sprint, but because stores are small, this high rate of energy expenditure can be maintained for only a few seconds. Carbohydrate oxidation supports the intermediate speed of marathon runners for 20 miles until all glycogen stores have been used; then, fat oxidation becomes the only source of available energy and runners are unable to accelerate, i.e., they "hit the wall." Stamina is limited by the amount of glycogen in muscle.

In humans, high carbohydrate diets increase stamina because they increase muscle glycogen (Hultman et al. 1994). In dogs, however, high fat/low carbohydrate diets increase stamina. Beagles ran for 20 miles (140 min) when fed high fat (53–67% of energy) diets but became exhausted after only 15 miles (100 min) when fed a moderate fat (29% of energy) diet (Downey et al. 1980). A high fat/high protein diet containing no carbohydrate resulted in better performance and less evidence of exertional rhabdomyolysis when fed to sled dogs (Kronfeld 1973). A high carbohydrate (59% of energy) low fat (16% of energy) diet fed to sled dogs resulted in higher resting muscle glycogen concentrations compared with a high fat (62% of energy), low carbohydrate (14% of energy) diet, but glycogen was used more rapidly during a race; thus the final muscle glycogen concentration was unchanged (Reynolds et al. 1996).

In dogs, as in other species, fat oxidation provides most of the energy at low rates of energy expenditure (60% at 40% of maximal oxygen uptake; $VO_{2\ max}$). As exercise intensity increases, glucose oxidation increases, whereas fat oxidation remains constant so that glucose oxidation is the principle source of energy at high rates of energy expenditure (80% at 85% $VO_{2\ max}$) (Weibel et al. 1996). In dogs, however, the amount of energy from fat oxidation at rest and during exercise is twice that in less aerobic species such as humans and goats (McLelland et al. 1994, Meyer and Doty 1988). Albumin binds more free fatty acids in dogs than in less aerobic species; thus the concentration of free fatty acids in the blood is higher and delivery of free fatty acids to the tissues is enhanced (McLelland et al. 1994). Muscle glycogen and fat stores are larger in dogs than in less aerobic species (Weibel et al. 1996). High fat diets increase resting serum triglycerides and free fatty acids, mitochondrial volume and maximal energy expenditure (Reynolds et al. 1996).

No study has looked at the effect of different types of fat on performance. Exercise increased the plasma concentration of each individual fatty acid in proportion to the plasma concentration of that fatty acid at rest, i.e., oleate (18:1), the predominant fatty acid, increased 150%, which was more of an increase than palmitate (16:1), which increased more than linoleate (18:2), which increased more than stearate (18:0) (Miller et al. 1963).

It is much less clear whether greyhounds should be fed a high fat or high carbohydrate diet. Anaerobic glycogenolysis and glycolysis rather than fat oxidation should provide most of the energy for a sprint race >500 m that lasts only 30 s. Greyhounds develop a marked lactic acidosis (pH 7.0–7.1) and muscle glycogen declines markedly during a race (Rose and Bloomberg 1989); consequently, some authors have suggested that carbohydrate may improve performance (Gannon 1987). Nevertheless, most muscle fibers in greyhounds are of the high oxidative type; high fat diets may therefore increase maximal fat oxidation, total maximal energy expenditure and performance in greyhounds as in sled dogs. One brief report suggests that greyhounds run faster when fed a moderate fat (31% of energy) diet compared with a very high fat (75% of energy) diet (Toll et al. 1992). One abstract suggests that greyhounds run faster when fed a high fat (38% of energy) diet compared with a moderate fat (28% of energy) diet (Hill et al. 1996). These two studies together suggest that optimum performance may be achieved in greyhounds by feeding a moderately high fat diet.

Protein. Racing sled dogs require a high protein diet because an anemia develops during training in dogs fed a low protein diet. Hematocrit declined in dogs fed a diet containing 28% of energy as protein but not in dogs fed a diet containing ≥32% of energy as protein (Kronfeld et al. 1977). Plasma volume was greater in racing sled dogs fed a very high protein (>40% of energy) diet (Reynolds 1995). This "sports anemia" was also more marked in dogs fed a vegetable protein diet compared with an animal protein diet (Yamada et al. 1987). Greyhounds, however, ran more slowly when fed increased dietary protein (36 vs. 24% of energy) (Hill et al. 1998).

Fiber. Dietary fiber may have some health benefits for racing dogs. Volatile fatty acids produced by bacterial fermentation of soluble fiber in the canine colon promote water and electrolyte absorption (Herschel et al. 1981). Butyrate is the preferred fuel of the canine colonocyte (Roediger and Rae 1982). Rapid fermentation of oligosaccharides may decrease colonic pH and inhibit Clostridial growth promoted by feeding meat (Amtsberg et al. 1989). Fructooligosaccharides inhibit cecal colonization by *Salmonella* spp. in chickens (Bailey et al. 1991). Nevertheless, the colon is a complex ecosystem. The digestibility of carbohydrate in extruded dog foods is variable, and not all starch is digested in the canine small intestine (Schünemann et al. 1989). The concentration of volatile fatty acids is high in the colon of dogs fed meat and cornstarch diets containing no fiber (Hill 1993). Increased dietary fiber increases fecal weight and reduces nutrient availability. The benefits of additional fiber in canine athletes are, therefore, uncertain.

Minerals and vitamins. Meat is deficient in trace minerals and vitamins. Many dog owners feed vitamin supplements but

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take no account of vitamins and minerals already present in the food; thus toxicity is possible. Most commercial pet foods contain sufficient vitamins and minerals for sedentary dogs, but this balance of vitamins and minerals may have to be altered for exercising dogs. It is likely that endurance racing dogs, which consume large amounts of food, may require less vitamins and minerals per joule than greyhounds, which consume little more food, vitamins and minerals than sedentary dogs.

Gannon (1980) has suggested that exertional rhabdomyolysis may occur in greyhounds that are raced too frequently because the recurrent acidosis that follows each race increases potassium loss in the urine and leads to intracellular potassium deficiency. This seems unlikely, however, because Knochel et al. (1985) found that training increased intracellular potassium, skeletal sarcolemmal sodium:potassium ATPase activity and the muscle membrane potential, but reduced plasma potassium concentrations and reduced the increase in plasma potassium concentration after exercise.

Some vitamins, particularly antioxidant vitamins, may have a pharmacologic action during exercise. The antioxidant vitamins E and C may inhibit free radical production in skeletal muscle during rigorous exercise (Jenkins 1988). Very large doses of vitamin E are often given to racing dogs but an appropriate dose is unknown. Vitamin C is not an essential nutrient in sedentary dogs and is present in fresh meat but may also be conditionally essential in racing sled dogs. Signs of scurvy were observed in sled dogs fed stored frozen meat for long periods (Butson 1973). These signs were prevented by feeding fresh meat. A decrease in plasma ascorbate in racing sled dogs was also prevented by administering 4 mg/(kJ · d) by mouth (Kronfeld and Donoghue 1988). The oxidation of fat when meat is stored may also increase this requirement for antioxidants.

Other additives. Several food additives, including dimethyl glycine (DMG), pangamic acid (vitamin B-15), arginine, tryptophan, aspartate, carnitine, creatine/ATP and bicarbonate have been suggested to improve the performance of racing dogs. To date, no controlled studies have shown any benefit. Gannon found that DMG and diisopropylammonium dichloroacetic acid (DIPA-DCA) reduced the race time of greyhounds (Gannon and Kendall 1982). Pangamic acid or vitamin B-15 is a substance of uncertain composition. It consists of an ester of DMG and gluconic acid but may include DIPA-DCA (Herbert 1988). The beneficial effects described by Gannon can probably be ascribed to dichloroacetic acid, a potent drug that activates pyruvate dehydrogenase and reduces lactic acidosis caused by exercise in dogs (Merrill et al. 1980). The appropriate dose is uncertain, and neurologic, hepatic, testicular, pulmonary and pancreatitic toxicities have been described in dogs (Cicmanec et al. 1991). Both DMG and DIPA-DCA are considered “unsafe food additives”; thus their use cannot be recommended (Herbert 1988).

Commercial diets. Sled dogs appear to require a high protein (>30 or 40% of energy), high fat (>50% of energy) diet. Most extruded diets contain >25% of energy as carbohydrate. These extruded diets must, therefore, contain either <30% of energy as protein or <50% of energy as fat. High protein, high fat canned diets added to extruded diets before and during periods of heavy exercise may improve the stamina of working dogs, but increased cost can be prohibitive. Alternatively, adding beef to extruded diets increases dietary protein and fat because beef contains 25–40% of energy as protein and 60–75% of energy as fat (Anonymous 1997). Greyhounds, however, appear to require a moderately high fat (30–50% of energy), moderate protein (24% of energy) diet. It is possible, therefore, that a commercial extruded diet with this formula may give better performance than a high protein meat-based recipe.

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