Nutrition for Working and Service Dogs

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KEYWORDS

• Nutrition • Glycolysis • Fat • Protein • Glycogen repletion • Omega-3 fatty acids

KEY POINTS

- Sprinting dogs require a balanced moderate protein, fat, and carbohydrate diet for optimal performance.
- Endurance dogs (hunting and patrol dogs working more than 1.5–2 hours a day) require higher-fat diets to fuel mitochondrial biogenesis and to enhance oxidative phosphorylation capacity.
- High-intensity repeated exercise over a moderate duration (ie, agility and field trial/hunt test dogs) benefits from postexercise carbohydrate supplementation.
- The geriatric athlete with degenerative joint disease should receive supplemental dietary long-chain omega-3 fatty acids.

INTRODUCTION

Conformation, genetics, and behavioral drive are the major determinants of success in canine athletes, although controllable variables, such as training and nutrition, play an important role. The scope and breadth of canine athletic events has expanded dramatically in the past 30 years, but with limited research on performance nutrition. However, there are considerable data examining nutritional physiology in endurance dogs (eg, sled dogs) and in sprinting dogs (eg, racing greyhounds). Nutritional studies for more popular canine activities, such as agility, field trial, and detection, are rare. Therefore, application of translational principles from sled dogs and greyhounds to such activities is necessary. This article highlights basic nutritional physiology and interventions for exercise, and reviews newer investigations regarding aging working and service dogs, and canine detection activities.

THE ENERGETIC COST OF ACTIVITY

Exercise principally relies on ATP derived from the use of substrates, such as carbohydrate, protein, or fat. The energetic potential of a diet is commonly reported in

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Vet Clin Small Anim 44 (2014) 719–740
http://dx.doi.org/10.1016/j.cvsm.2014.03.008 vetsmall.theclinics.com

kilocalories (kcal) or kilojoules (kJ). Kilocalories, also referred to as calories, are equivalent to 4.16 kJ in the metric system. Metabolizable energy (ME), as reported on pet food labels, refers to the dietary energy remaining after factoring in energy lost in urine, feces, and gases. Current pet food regulations use the modified Atwater factors to estimate food energy, which assigns protein and carbohydrate an ME value of 3.5 kcal/g, and fat a value of 8.5 kcal/g.[1,2] However, the actual ME is principally determined by dietary fat, and by total dietary fiber content of a diet.[2] Because fiber not only dilutes calories in foods but also affects absorption of nutrients, it is not usually a significant concern when feeding athletic dogs, as little is incorporated into performance rations. Feeding trials are used to directly calculate the energetic potential of any given diet and are considered the gold standard.[2]

The National Research Council (NRC) has established energy requirements for dogs based on the available scientific literature.[2] A multiplication factor is applied to the exponential equation for metabolic body weight (MBW = $[\text{kg body weight}]^{0.75}$) to determine the energy expenditure of dogs in different conditions. The NRC estimates that active pet dogs require 130 $\times$ MBW kcal/d for maintenance energy requirements (MERs).[2] Overall, the active dog will typically require this amount of energy and, depending on the daily activity, these energy requirements will increase. In general, this can be minimally a 5% to 10% increase from the MER, as observed in greyhounds, up to an eightfold increase observed in racing endurance sled dogs. The effects of increasing physical activity and of training during treadmill exercise have been extensively studied in dogs. Such studies use indirect calorimetry, which determines caloric expenditure by measuring the rate of oxygen consumption. The maximum oxygen consumption during exercise (VO_2 max) reflects the maximal energy that can be generated via oxygen utilization in the mitochondrial electron transport chain; hence, is a direct correlation to the energy that can be generated for muscle activity. An average 20-kg foxhound or Alaskan sled dog working near VO_2 max requires approximately 700 to 900 kcal per hour of work based on the experimental conditions set forth in simulated treadmill exercise.[3–5] This caloric expenditure during exercise is directly related to the distance traveled. Therefore, the expected caloric needs for canine activities should be proportional to the distance of that activity, not the intensity of the exercise (**Table 1**). For example, whippet racing would

Table 1
The integrative energetic cost of selected common canine activities

Low (<25% Increase)[a]	Moderate	High (>100% Increase)[a]
Agility	Bikejoring (2–10 mi)	Sled dog racing (>20 mi)
Obedience or conformation	Carting (2–10 mi)	Bikejoring (>10 mi)
Disc dog	Field trials	Carting (>10 mi)
Dock jumping	Herding	Hunting (>3 h)
Greyhound racing	Hunting (<3 h)	
Earthdog	Search and rescue	
Low-activity service	Weight pulling	
Coursing	Sled dog racing (<20 mi)	
Flyball	High-activity service	

[a] The exercise amounts for many of these activities have not been reported. In general, short periods of activity, even if vigorous, have small effects on caloric requirements. The moderate and high categories depend greatly on the distance traveled and the ambient temperature. This is based on typical active dog lifestyle maintenance energy requirements of 132 $(\text{kg})^{0.75}$.

be expected to require less caloric expenditure as compared with field trials, which cover longer distances.

Both maximal oxygen consumption and endurance are directly related to skeletal muscle mitochondrial density and volume. However, there are many other factors to take into consideration during canine performance, such as ambient temperature, thermal stress (mitigated by panting), and variability in terrain, including slope.[6] Treadmill exercise with an incline decreases the efficiency of energy use and increases caloric expenditure because of the need for vertical rise. It has been hypothesized that larger dogs exert more energy to accommodate for the gravitational fall that occurs on decline.[4,5,7,8] Uneven footing or poor footing (snow and sand), as well as load bearing, also result in increased energy expenditure.[9]

Field studies examining energy expenditure of racing greyhounds have shown that the average 32- to 35-kg greyhound expends approximately 2050 to 2160 kcal (150–160 kcal/kg$^{0.75}$) per day for typical training activities, which is only slightly elevated from active dog maintenance energy values.[10,11] As the distance traveled per day in racing greyhounds is relatively short, this comparatively high MER for the limited activity may be a reflection of the increased muscle-to–fat mass ratio of greyhounds, rather than increased activity. Hill and colleagues[11] also suggest that feed restriction during racing from the normal daily intake of approximately 155 kcal/kg$^{0.75}$ to a restricted intake of only 137 kcal/kg$^{0.75}$ decreased racing times, suggesting that mild caloric restriction may provide performance advantages, at least in sprinters. Of course, this type of feed restriction would occur only for the 1 or 2 days of eventing, with resumption of normal feeding patterns after the event.

Numerous studies have examined the caloric needs of sled dogs during long-distance exercise. Daily caloric requirements have ranged from 228 kcal/kg$^{0.75}$ to 1052 $\pm$ 192 kcal/kg$^{0.75}$ body weight per day,[12,13] with the latter study being in extremely cold conditions over mountainous terrain with dogs running more than 12 hours per day.[14] These endurance sled dogs, which weighed on average 24 kg, would need to consume approximately 10,000 kcal per day to maintain their body weight in these conditions. Many dogs in such conditions use body reserves of lipids and amino acids to meet the caloric demands, as practical limits to food intake impair caloric consumption.

Studies of modest endurance activity suggest that an average medium-sized hunting dog with a body weight between 15 and 30 kg working approximately 3 hours in cooler climates would expend approximately 281 kcal/kg$^{0.75}$ per day, which is roughly double the NRC MER, which is consistent with the intermediate distance traveled.[15] The increased MER during such activities may not be recognized by owners, making underfeeding a potential issue during multiple-day events. Reciprocally, some owners may feed excessively, particularly treats, during a competition. Extra feeding and treat consumption should be taken into consideration as part of the daily caloric intake, particularly for agility and other speed-dependent activities where overfeeding can lead to need for defecation and increased fecal mass, which can effect event performance.

ENERGY AND DEMAND: FAT AND CARBOHYDRATE

The respiratory quotient (RQ) is the ratio of CO_2 production divided by oxygen consumption, and is generally measured using indirect calorimetry in laboratory studies. If the RQ is close to 0.7, fat is likely the primary energetic substrate (fat contains more carbon than other metabolic fuels). An RQ closer to 1 suggests glucose metabolism. Amino acid oxidation results in an RQ between that required to burn fat or carbohydrate (approximately 0.8). Early in exercise, generally within the first 20 to 30 minutes, protein oxidation is minimal, and therefore substrate use and changes in oxygen consumption can be examined when feeding diets differing in only carbohydrate and fat.[16]

Multiple studies have investigated energy intensity and duration as related to VO_2 max and RQ values.[17,18] These foundational studies suggest that dogs exercising at 40% of their VO_2 max, or 40% of maximal aerobic exercise, primarily use fat for energy. Exercise at 30% to 70% of VO_2 max relies on a mixture of glucose and fatty acid catabolism. An animal reaching 70% or higher of maximal oxygen consumption, as is common in sprinting athletes, primarily relies on glucose for energy, and therefore displays an RQ closer to 1.[16,19,20]

Animals performing at maximal speed during the first few seconds of exercise quickly deplete small ATP reserves and then use easily accessible energy from the phosphocreatine system that generates ATP through shuttling inorganic phosphate to ADP via creatine-phosphate stored in muscle. Prolonged exercise of high intensity then uses glycogenolysis (generation of glucose from glycogen), which subsequently generates energy through anaerobic glycolysis for a few minutes, generating ATP from pyruvate via the citric acid cycle. However, if the pyruvate cannot be fed into the citric acid cycle, then lactic acid is formed and can lead to pH changes and intracellular dysfunction.

Carbohydrate oxidation becomes a major source of energy for long-term exercise at greater than 50% of maximal oxygen consumption (20 minutes–2 hours) as long as sufficient glycogen is present for glycogenolysis and the rate of conversion of pyruvate to acetyl-CoA is adequate. Some protein oxidation and gluconeogenesis will take place if glycogen is depleted in endurance exercise, and the dog will subsequently be unable to sustain oxygen consumption above 50% to 60% of VO_2 max for extended periods.

Fatty acid oxidation begins within minutes, but does not peak until approximately 30 minutes of exercise and sustains an oxygen consumption rate between 30% and 50% of the maximum. Oxidation of fatty acids provides acetyl-CoA for the citric acid cycle at a constant rate, which allows some dogs to exercise at this low to moderate oxygen consumption for multiple hours with minimal fatigue.[16,21,22] Dogs display higher concentrations of type I (low myosin ATPase) and Type IIa (aerobic) muscle fibers than other species, such as the cat, which permits these higher rates of aerobic metabolism, especially from fatty acids.[23,24]

The time to exhaustion during low-intensity exercise in dogs does not correlate to glycogen depletion,[25] unlike in humans, who use carbohydrate loading to increase stamina.[26] The generation of energy from fat allows consumption of over 70% of the ME intake during long-duration low-intensity to moderate-intensity exercise, suggesting a propensity for fat utilization that may be due to the dog's aforementioned high aerobic activity in skeletal muscle and to an increased mitochondrial density as compared with humans.[27] Kronfeld and colleagues[28] showed that dogs perform equally well on diets containing almost no carbohydrate (1 g/1000 kcal) as compared with 2 diets with increasing carbohydrate content in moderate-intensity working sled dogs.[29] All diets contained elevated amounts of protein for gluconeogenesis as well. Interestingly, endurance huskies racing approximately 160 km per day over 5 days showed immediate glycogen depletion followed by an increase in skeletal muscle glycogen and a gradual depletion of skeletal muscle triglyceride over many days of running. This provides further support for the adaptation of dogs to fat utilization, which spares muscle glycogen during endurance activities.[20]

Diets containing approximately 60% to 70% of ME are recommended for endurance exercise, and in times of extreme demand fat may supply up to 85% of ME, particularly in endurance sled dogs. Owners and trainers are best advised to introduce fats to the diet slowly, based on observations in the previous studies. A transition to higher-fat diets is best performed over approximately 8 to 12 weeks to allow for mitochondrial and metabolic adaptation.[30] A slow transition also reduces steatorrhea, which is a common acute adverse effect from feeding high-fat diets. Excess fat in the diet may require dietary increases in divalent cation nutrients (calcium, iron, zinc, copper, and manganese), which may chelate with free fatty acids, thereby reducing their bioavailability.[22] In addition, a word of caution is that addition of fat will dilute the protein, vitamin, and mineral content of the food, which creates a risk of insufficient intake of certain nutrients. In our opinion, if fat is added to a ration, this added fat should to exceed 20% to 25% of the overall ME of the diet for the typical athlete, except for rare instances of endurance sled dog racing where more might be required for a short period of time.

The ideal fat and carbohydrate composition in diets for racing greyhounds is highly debated,[31] with the most convincing evidence that dietary carbohydrate may play a role. Hill and colleagues[10,11] showed that greyhounds fed a diet with 43% ME as carbohydrates performed better than those on diets containing either 30% or 54% ME as carbohydrate when protein replaced carbohydrate. Additional studies showed that greyhounds fed 24% ME protein and 37% ME carbohydrate ran faster than those on a diet containing 37% ME protein and 24% ME carbohydrate when there was an isocaloric exchange of protein for carbohydrate.[32] These results, taken together with other protein intake data, suggest that diets with 24% ME from protein (60 g/1000 kcal) and between 30% to 50% ME from carbohydrate (75–125 g/1000 kcal) are most appropriate for racing greyhounds and other sprinting athletes. This nutrient composition, approximately 24% to 28% dry matter (DM) protein (65 g/1000 kcal), 12% to 14% DM fat (33 g/1000 kcal), and 45% to 50% DM carbohydrate (120 g/1000 kcal) would be found in many maintenance commercial kibbles. Many owners of sprinting, service, and intermediate athletic dogs that work for 30 minutes or less at a time are feeding high protein (>30% DM), fat (>20% DM) and less than 40% carbohydrate commercial kibbles. As their dogs do not work excessively hard for long periods of time, a commercial diet with a carbohydrate content of 40% to 50% DM similar to the one outlined as a maintenance commercial kibble previously, may be a better option. Endurance working dogs, such as field trial dogs, hunting dogs, long-distance sled dogs, and working herding dogs, are likely the ones that would benefit from commercial dry food of more than 30% DM protein and more than 20% DM fat, restricting carbohydrate content to 30% or lower.

PROTEIN REQUIREMENTS FOR THE CANINE ATHLETE

Protein requirements are really a requirement for essential amino acids in the diet. Most of the animal-based and plant-based protein sources provided in the commercial dog foods will provide essential and nonessential amino acids to the diet. Dogs synthesize nonessential amino acids through amination, deamination, and carboxylation reactions using carbon precursors and essential amino acids. Many of the studies on protein requirements use nitrogen balance studies (nitrogen in via diet vs nitrogen out in urine and feces) as the measure of adequacy. Nitrogen is a marker of protein, as protein is 16% nitrogen and by far the major source of nitrogen in the diet. However, most nitrogen balance studies do not take into account loss of lean body mass. There are multiple additional methods to evaluate dietary protein adequacy, each with its own merits and disadvantages. Dietary protein helps maintain muscle integrity and appropriate total protein, albumin, and hematocrit.[33] The hematocrit and serum albumin tend to decrease with training and racing, which appears to be a result of an overtraining syndrome[33,34] that may respond in part to increased protein intake. Based on studies involving sled dogs, one investigator has suggested that approximately 30% of daily metabolizable energy (70–80 g protein/1000 kcal) should come from highly digestible animal-based protein.[33] Four groups of sprint-racing sled dogs training in the field and on a treadmill were fed 4 different diets containing either 18% ME protein (48 g/1000 kcal), 24% ME protein (60 g/1000 kcal), 30% ME protein (75 g/1000 kcal), and 36% ME protein (90 g/1000 kcal). The dogs were examined 12 weeks after a transition from a 26% ME protein diet with similar ingredients. Complete blood counts, serum chemistries, VO_2 max (indirect calorimetry), and physical assessments were performed after 12 weeks of feeding each diet. Six of 8 dogs in the lowest-protein diet (18% ME) sustained musculoskeletal injuries and showed a 25% drop in VO_2 max. Dogs in the highest protein groups displayed a 10% increase in plasma volume, and there was a linear correlation between protein intake and hematocrit, hemoglobin, and total blood volume.[5] Querengaesser and colleagues[35] examined diets of approximately 28% to 34% ME protein (72 and 85 g/1000 kcal) and found no difference in the hematocrit decline over a 6-month training period, but the higher-protein group had elevated postexercise hematocrit, which could be just a reflection of dehydration. Exercise is thought to cause transient polycythemia followed by anemia and then a compensatory period of erythropoiesis; this latter phase may be a marker of adequate protein intake.[6] Protein quality and source also may be important. A study of mongrel dogs exercised 4 hours per day at 12 km/h compared unsupplemented soy protein versus fish meal–based and meat meal–based protein at approximately 35% ME. Dogs fed soybean meal had decreased hematocrit and increased red blood cell fragility after 3 weeks,[36] suggesting that soybean as the sole protein source may not be ideal. Endurance dogs should receive minimally 70 g/1000 kcal (approximately 26% of ME) of highly digestible animal-source or mixed animal/plant-based protein with no upper limit yet defined. The NRC suggests an adequate intake of 35% ME protein (90 g/1000 kcal) and 49% ME fat (59 g/1000 kcal) for endurance athletes.[6]

Sprinting dogs require less protein for exercise than endurance athletes. Hill and colleagues[32] performed studies suggesting that racing greyhounds perform better on lower-protein diets of 24% ME protein (63 g/1000 kcal) versus 43% ME protein (106 g/1000 kcal). Most racing greyhounds are provided 0.25 to 0.5 kg of meat mixed with dry commercial dog food daily to meet their energy requirements,[37] which provides an estimated 43% ME protein (106 g/1000 kcal), which is the same upper value used by Hill.[38] A recent study in detection dogs showed normal performance when fed a high-fat, low-protein diet containing 18% ME protein (45 g/1000 kcal) for 12 weeks. This amount of protein is lower than the Association of American Feed Control Officials (AAFCO) standards, but above the NRC requirements for protein, suggesting that low-protein diets may not be detrimental to all athletic endeavors; however, long-term feeding of low-protein diets and their overall effect on performance has not been evaluated.[39–43] Therefore, 24% ME protein (60 g/1000 kcal) is likely a reasonably adequate intake for sprinters and intermediate athletes not participating in long-duration endurance activities. Endurance athletes may require more dietary protein (closer to 30% ME or higher); however, definitive studies to elucidate the ideal amounts of protein in endurance athletes have yet to be performed.

BODY CONDITION AND EXERCISE

Body condition measures tend to be the great equalizer across all breeds of dog, allowing veterinarians and owners to evaluate the body of the athletic dog. The traditional body condition scoring methods use a 5-point or 9-point system. The 9-point system has been validated through comparison with dual x-ray absorptiometry analysis,[44] and is preferred by the authors. Most owners of performance dogs are aware of their animals' body condition scores and ideal competitive body weights. Typically performance dog owners maintain their dogs at a 4 to 5 of 9 body condition score (BCS). At these BCS values, ribs are easily palpable, there is an obvious abdominal tuck, a waist is visible from the side and top, and the dorsal aspect of the spinous processes can be felt. Greyhounds, field trial, hunting, and sprinting athletes may benefit from being maintained at a body condition score between 3 and 4 of 9. Dogs in this condition have ribs easily visualized in shorter-haired dogs, prominent spinous processes and wings of the ilea, but with ample paralumbar musculature that extends between the wings of the ilea so that the sacral spinous processes can be identified but do not protrude. Dogs in sprinting and intermediate activities (10–30 minutes) need to be lean to achieve ideal performance (**Fig. 1**), and restricted meal feeding during competition is common. In endurance activities in which speed is less important and in which there is a greater chance for loss of body condition during extended activity, a body condition score of 4 to 5 may be ideal to prevent severe weight loss.[45] On the other hand, service and some detection dogs observed in the field can run the gamut of body condition scores from 4 to 7; however, from a performance perspective, it would be ideal to keep most service dogs between 4 and 5 to prevent fatigue and joint-related problems associated with carrying excessive body weight.

FAT: BEYOND ENERGY

Many authors speculate that fatty acid chain length and saturation affect a variety of issues from inflammation to oxidative stress during exercise despite very little information regarding optimal dietary fat intakes for canine athletes.[46] Medium-chain triglycerides liberate 8-carbon to 12-carbon free fatty acids when digested, which are directly transported through absorption into the blood, bound to albumin, to the liver via the portal circulation. There are suggestions that medium-chain triglycerides in the form of coconut and palm oils are used more rapidly at the initiation of exercise, leading to sparing of glycogen.[47,48] One pilot study in athletic dogs showed limited utility.

Fig. 1. Appropriate body condition for the canine athlete. Notice the rib cage showing just behind the elbow and the prominent musculature of the shoulder and hindlimb. This dog would be considered a 4 of 9 on the BCS chart. (*Courtesy of* Robert Downey, Sellersville, PA.)

Dietary increases in MCTs are not currently recommended as a strategy for working dogs.[49] The role of polyunsaturated fatty acids is described in greater detail with geriatric athlete nutrition, as the benefits on mobility and inflammation may be most pronounced in this population.

Fatty acid composition also could influence detection in scent-trained dogs and in many other performance animals that rely on scent, including foxhounds, hunting dogs, and service dogs. A small study showed that olfactory performance was diminished in dogs provided a diet rich in MCTs.[50] Another study using corn oil as a source of elevated polyunsaturated fatty acids (linoleic acid) demonstrated slightly improved find rates at detection thresholds in scent-trained Labradors.[39] The precise mechanism and magnitude of this effect has not yet been fully elucidated, but elevated polyunsaturated fatty acids may modestly improve performance in dogs that require olfactory acuity as part of their work.

CARBOHYDRATES: TIMING AND STRATEGY

The use of carbohydrate as a major dietary substrate is recommended in sprinting animals like greyhounds, ideally with approximately 40% to 50% of ME provided by highly digestible carbohydrates (100–125 g/1000 kcal). Endurance sled dogs require no more than 10% of ME as carbohydrates, and there is no definitive carbohydrate requirement in nonreproducing working dogs.[22,32] Carbohydrates also may be beneficial for sprinting and intermediate-distance athletes if muscle glycogen is depleted daily over the course of multiple-day events.[20,51,52] Studies in sled dogs demonstrated, for example, that postexercise supplementation with a maltodextrin supplement at 1.5 g/kg body weight within 30 minutes of exercise increased skeletal muscle glycogen within 4 to 24 hours.[51,52] Such strategic carbohydrate loading should be used only during competition to enhance glycogen repletion and should be done immediately after exercise and before any meals are provided to maximize absorption of the carbohydrate in a short period of time. If this type of supplementation was given daily during training, then the dog might use the increased carbohydrate for immediate energy preferentially rather than storing it as muscle glycogen. Therefore, postexercise carbohydrate repletion is recommended in dogs running between 5 minutes to 4 hours per day, particularly when expected to perform similarly the following day. The effectiveness of this strategy in endurance events is unknown and is not currently recommended by the authors.

DIETARY FIBER

Dietary fiber increases fecal bulk or moisture and is present in 2 forms: insoluble (nonfermentable) and soluble (fermentable). The increase in fecal volume during performance can lead to inappropriate defecation and increased fecal bulk, making the athlete slightly heavier. This is considered a negative attribute to fiber. On the other hand, during bouts of stress-diarrhea, insoluble fiber may affect gastrointestinal transit and reduce clinical signs of diarrhea. Soluble fibers may alter the large intestinal microflora, which produce short-chain fatty acids, some of which increase the absorptive surface of the large intestine through villous hypertrophy. Such properties have been used strategically in exercising canid athletes with stress-related diarrhea to ameliorate this condition. Several studies documented post-fiber production of volatile fatty acids, which promoted colonocyte regeneration and reduced recovery time from diarrhea.[53–55]

Many of the veterinary gastrointestinal therapeutic diets now contain small amounts of gums, soy fiber, fructooligosaccharides, other oligosaccharides, and mixed insoluble and soluble fiber sources (such as beet pulp) to improve fecal quality and intestinal absorptive surface area without increasing the overall fiber content of these diets too much. Commercial kibbles using whole grains, such as barley, oats, and sorghum, will naturally contain a mix of soluble and insoluble fiber and the true fiber content of many foods is unknown, as the crude fiber reported on the labels of commercial pet foods only represent the insoluble portion of fiber. The amount of soluble fiber in most performance and veterinary therapeutic foods is generally less than 2% of DM weight given that excess fermentation of this fiber source can decrease fecal quality by increasing the moisture content.[56] On the other hand, the addition of dietary psyllium husk powder in dogs can be helpful for resolving stress-diarrhea, which can be a common problem in working dogs. Psyllium husk fiber is a mucilage with water-binding properties and also acts like an insoluble fiber, providing a modest fermentation substrate for the microflora of the intestine. A starting dose of approximately 4 g fine psyllium powder (1 rounded teaspoon) daily has been recommended, with an upward titration to effect, not to exceed 16 g daily in a typical 20-kg to 30-kg canine athlete.[57]

ELECTROLYTES, MINERALS, AND VITAMINS IN THE WORKING CANINE

Minerals can be classified into major minerals and trace minerals. Deficiencies in major minerals have been observed in dogs fed nontraditional diets (meat-based without bone). Some athletic dogs, including racing greyhounds, are commonly fed all-meat diets. If raw or cooked meat-based diets are used, it is advisable that bones or bone meal be ground into the diet to improve the calcium and phosphorus balance. Calcium should be between 1.5 and 4.0 g/1000 kcal in most diets for adult athletic dogs (about 0.6%–1.2% DM), with similar amounts of phosphorus to maintain homeostasis for the structural integrity of bone, appropriate cellular signaling, and buffering capacity.[58] The calcium-to-phosphorus ratio is likely unimportant if adequate amounts of each are provided in the diet.[6] Deficiencies of the other major minerals, including sodium, potassium, and chloride have not been reported in adult working dogs, and therefore, the use of electrolyte supplements is not currently warranted when dogs are being sustained on commercial AAFCO-approved rations. The only studies that evaluated such mixtures showed either no beneficial effects or increased rates of diarrhea after activity.[59,60] Moreover, dogs cool primarily via panting, which is not associated with the same electrolyte losses as sweating in other species. The only dogs likely to benefit from electrolyte supplements may be dogs with protracted stress-diarrhea; veterinary diagnostics and other means of fluid therapy may be indicated in these cases.

Trace mineral intake will increase proportionally with the intake of commercial dog food, and will also increase, albeit to a lesser degree, when using raw or cooked meat to supplement commercial diets. If adding a fat source from animal or plant sources, the dilution of dietary vitamin and mineral intake will be even more egregious. Yet, to date, there are no reports of clinical deficiencies in copper, zinc, iron, manganese, iodine, or selenium in athletic canines being fed traditional commercial diets or commercial dog food and meat mixes. Currently it is unknown whether supplemental trace minerals are needed. Most exercising dogs have small to significant increases in caloric expenditure; as these animals will consume greater calories to maintain their body weight, they will also consume more of these minerals because the nutrient concentration of most diets is fixed.

Vitamins are classified as either fat-soluble or water-soluble. Water-soluble vitamins are typically included in the “B vitamin” family. Most of these vitamins are involved in cellular metabolism as intermediates or coenzymes within the citric acid cycle or as carriers and coenzymes for carbon transfer. An animal must be replete in these vitamins for normal energy metabolism. Most commercial dog foods and meats contain such vitamins well above the minimum requirement. Pet foods are typically supplemented with significant excesses of water-soluble vitamins to ensure adequate intake if there are any losses during production or storage, and these vitamins have large margins of safety.

The water-soluble vitamin C is synthesized in dogs through hepatic synthesis from glucose, unlike in humans and guinea pigs. However, dogs may not synthesize as much as other species.[61] The possibility for limitations in hepatic synthesis combined with observations that serum ascorbic acid concentrations decrease more than 50% after 190 minutes of sled racing have led to suggestions that supplementation may be beneficial.[33] Similar decreases in vitamin C were observed in unsupplemented greyhounds (1.8–2.8 mg/L).[62,63] Supplementation with 1 g ascorbic acid daily returns serum concentrations closer to what would be considered a normal baseline concentration (5–6 mg/L). However, similar supplementation in greyhounds for 4 weeks resulted in slower racing speeds by 0.3 km/h.[63] High doses of vitamin C also are associated with a pro-oxidant effect, which could be detrimental. Therefore, vitamin C supplementation cannot be recommended given the limited information available.

The fat-soluble vitamins (A, D, E, and K) have smaller margins of safety, and oversupplementation is the primary concern in performing athletes. Sufficient vitamin K is synthesized by bacterial flora in the gastrointestinal tract of normal dogs. Dietary vitamin A intake may be high if large quantities of organ meats are used in prepared or packaged meat-based diets, as liver tissue contains very high concentrations. Fortunately, dogs tend to be tolerant of high dietary vitamin A, although puppies and pregnant dogs have smaller safe upper limits.[64] Vitamin D also is found in organ meats, particularly liver, making a small amount of organ meat desirable if using meat as part of the diet (less than 15% as fed of total diet). Many commercial dog foods have at least twice the minimum requirement for cholecalciferol (vitamin D precursor), so with the increased energy consumption required by athletic dogs, the amount of cholecalciferol consumed should be adequate. Extremely high concentrations of vitamin D are associated with lethargy, gastrointestinal signs, and disorders in calcium homeostasis (parathyroid hormone, ionized calcium), with the most significant effects likely to occur during growth.

Vitamin E is sufficient in nearly all commercial pet foods, and most manufacturers add significantly more than the requirement, which makes vitamin E deficiency unlikely when feeding such diets. Deficiency has been observed in hunting dogs fed an all-meat diet, which led to retinal degeneration.[65] The effects of vitamin E have been examined extensively in endurance sled dogs. Low serum vitamin E levels were associated with an increased risk of failing to complete endurance sled dog races.[66] Additionally, serum vitamin E decreased after a single day of endurance activity in 2 separate studies.[33,67] Decreased serum vitamin E concentrations also have been observed in greyhounds racing 500 m.[68] Interestingly, compelling evidence for not supplementing high doses of vitamin E was provided by a study that showed that supplementing 100 to 1000 IU raised serum tocopherol concentrations, but that dogs receiving 1000 IU had slower racing times.[68,69]

Dietary composition is an important consideration. Diets high in polyunsaturated fatty acids (eg, fish-based sled dog diets) should contain higher amounts of vitamin E to prevent lipid peroxidation.[70] Diets high in selenium generally reduce vitamin E requirements, whereas those containing low amounts of selenium require more supplementation. However, tocopherol supplementation is generally not recommended in sporting dogs as long as they are being fed a complete and balanced dog food at their metabolic requirement. Dogs being fed nontraditional diets (primarily meats and fish) should consider vitamin E supplementation to prevent possible deficiency at a dose of 200 to 400 IU daily for a typical athletic dog of 40 to 80 pounds.

FEEDING STRATEGIES IN CANINE ATHLETES

Feeding patterns affect performance. The frequency and time of feeding can maximize metabolites that support increased activity and influence fecal volume, which affects competition. Sprinting dogs running for less than 20 minutes during a single bout of exercise benefit from modest feed restriction 24 hours before exercise (a decrease in total caloric intake of 20%–30%) to decrease fecal bulk. Some owners advocate small carbohydrate-rich meals before exercise to provide glucose as fuel for impending exercise, but there are few data to support this strategy in dogs.[71] However, sprinting and intermediate-distance athletes, particularly agility and field trial dogs, that perform multiple bouts of exercise in a day may benefit from immediate low-dose postexercise carbohydrate ingestion when they are expected to exercise again within 2 to 3 hours. If repetitive exercise is closer in frequency, feeding after exercise may not be recommended so as to avoid vomiting or regurgitation.[38] Postexercise glycogen repletion is advised for multiday events or trials, ideally administered within 30 minutes of the last exercise of the day.

Intermediate-distance athletes, which typically exercise once per day for 30 to 120 minutes, rely on both glycogen and fat for energy. Such animals should be fed diets moderate in protein and in carbohydrate (30% ME and 20% ME, respectively) and that are higher in fat (50% of ME). Fat will be used as a primary fuel at rest and fat oxidation will increase within 10 to 20 minutes of starting exercise to spare glycogen. This strategy of utilizing fat more readily available will allows dogs to run above 60% of VO_2 utilizing glycogen for more than 20 to 30 minutes. These athletes also benefit from postexercise carbohydrate supplementation to restore muscle glycogen concentrations, particularly during multiple-day events.[51,52] Provision of a single meal approximately 2 hours after exercise might be advantageous to promote continued lipolysis. Modest feed restriction (20%–30% of normal caloric intake) the day before competition decreases fecal bulk, helps prevent defecation during exercise, and promotes lipolysis.[11,16] Care should be taken to avoid feeding larger meals immediately after exercise, particularly in larger deep-chested breeds prone to gastric dilatation and volvulus. Dogs also should not be fed in the 8 hours before vigorous exercise to avoid a reduction in performance. Endurance athletes (ie, foxhounds and sled dogs) in heavy training tend to be fed 1 or 2 large meals daily, providing approximately 300 to 500 kcal/$kg^{0.75}$.[3,5,12,14] These meals should be approximately 30% ME protein (75 g/1000 kcal), 60% to 70% ME fat (>60 g/1000 kcal), and contain negligible carbohydrate, as described previously. However, data suggest that most mushers are feeding approximately 30% to 40% ME from protein (75–100 g/1000 kcal), 45% to 55% ME from fat (50–61 g/1000 kcal), and 10% to 20% from carbohydrate (25–50 g/1000 kcal).[72] Such rations are usually designed with 40% to 60% commercial dog food and the rest being high-fat meats so as to achieve the caloric density and digestibility needed for competitive racing and hunting. Search and rescue dogs, as well as foxhounds and pointing dogs that hunt or search for multiple hours over several days, may benefit from postexercise carbohydrate intake because they will rest for significant times (more than 8 hours) between exercises.

An entirely meat-based diet is not recommended by veterinary nutritionists or most veterinarians for endurance dogs because of the incomplete nature of such strategies, yet it is found as a common practice in some events and can be sustained for short periods of time without supplementation (5–10 days). Typically meats are provided raw, but most veterinary professionals recommend cooking the meat because cooking does not appear to decrease digestibility and might increase digestibility depending on the cooking process.[73] The extensive debate about the potential advantages and disadvantages of raw feeding are detailed elsewhere.[73]

All working dogs require more water than dogs at rest. Studies in sedentary dogs suggest that maintenance water requirements are between 0.6 and 1.0 mL/kcal ME.[6] However, dogs will continue to consume water even if the water concentration of the food is very high. The salt and protein content of the diet also influences drinking. As solutes (eg, Na and urea) increase, dogs adjust water intake. The amount of water required for exercise is dependent on the outside temperature, the ability to cool via evaporative means (panting), and the duration of the exercise (and therefore caloric expenditure). Some studies suggest that the timing of water administration after exercise is important.[74] For example, dogs in one study were offered water immediately after a run and drank to replace their losses; however, those dogs offered water 5 minutes after the run did not drink unless they were more than 0.5% dehydrated.[75] Racing greyhounds in training have been reported to increase daily water intake, resulting in an increase in plasma volume and a subsequent increase in blood volume. Dogs should be provided water immediately after intense exercise and routinely during training and feeding. Diets high in sodium are best avoided, as they may increase water intake and the severity of dehydration if it were to occur.

DIET IN THE GERIATRIC ATHLETE

Dogs display a slow deterioration of skeletal muscle mass known as sarcopenia with aging, a process that is likely similar to that documented in other species.[76] Dogs affected by peripheral neuropathies or chronic intervertebral disc disease also may display neurogenic atrophy, which can further exacerbate a decline in muscle condition score, and warrant rehabilitation or conditioning to help preserve lean body mass and to increase mobility. The VO_2 max decreases in geriatric dogs,[6] likely due to this reduction in muscle mass and efficiency. Dietary intervention is important in the aging athlete. Many “senior” dog foods restrict fat to reduce the caloric density and theoretically the propensity for obesity. Protein may be reduced in some diets due to a disproven theory that excess dietary protein accelerates the incidence and progression of renal disease.

However, it is likely that otherwise healthy senior performance animals should be fed diets high in caloric density and in protein. Older dogs also may have reductions in digestive capability, effectively decreasing the absorption of essential nutrients. Studies in young versus old dogs demonstrated that muscle protein turnover nearly doubles from 2.5 to approximately 5.0 g of protein per kilogram body weight daily in old dogs to maintain hepatic amino acid levels and skeletal muscle.[77] Unfortunately, evidence-based studies regarding the effects of diet in geriatric athletes are lacking. In the absence of definitive information, athletic senior dogs should receive approximately 5 g highly digestible protein per kg of body weight, or a diet containing more than 75 g/1000 kcal protein (26%–30% DM) and more than 35 g/1000 kcal fat (14%–16% DM). Normal adult dog or performance rations are the preferred choice when feeding older athletes, unless a “senior” diet conforms to the previously mentioned criteria or the senior athlete is experiencing weight gain because of reduced activity. For example, as some athletic dogs age, they may not be as active; therefore, caloric requirements decrease and a less energy-dense food may be desirable, which might be met by a commercial food with lower fat content (ie, 10%–14% DM fat). Currently there are few products on the market at more than 26% DM protein with fat content in the 10% to 14% DM range, although this may be ideal for some geriatric athletic dogs.

Geriatric animals are predisposed to arthritis, and performance athletes may suffer additional musculoskeletal pathology from repetitive strain injuries. Omega-3 fatty acids, specifically eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA), have received significant attention with respect to decreasing the clinical signs associated with osteoarthritis. Omega-3 fatty acids are polyunsaturated fatty acids. The most commonly studied include the 18-carbon alpha linolenic acid (ALA), the 20-carbon EPA, and the 22-carbon DHA. All unsaturated fatty acids are further characterized by the number of double bonds. The omega, or carbon "tail," position of the fatty acid contributes to nomenclature. Omega-3 fatty acids have a double bond in the third position from the methyl end; ALA contains 3 double bonds, EPA 5, and DHA 6. Dietary long-chain omega-3 fatty acids are incorporated in cellular membranes, and EPA serves as substrate for the COX and LOX enzymes. Omega-6 fatty acids are required in normal physiologic processes, but during inflammation are thought to contribute more to the formation of "proinflammatory" prostaglandins and leukotrienes, whereas omega-3 produces the less inflammatory 3-series prostanoids and 5-series leukotrienes.

The omega-3 fatty acids EPA and DHA have been studied in many clinically relevant conditions.[78] EPA and DHA are found in fish oils, although algal forms of DHA also exist. Dogs and humans have limited ability to convert ALA (found in flax seed and other oils) to EPA, and little to no conversion of ALA to DHA occurs. ALA-enriched diets must provide a high percentage (>7 times that needed of EPA/DHA) of fat as this precursor omega-3, because conversion to the longer-chain EPA and DHA is inefficient and at least 28 days are required to reach a steady state.[79] Any diet with elevated amounts of polyunsaturated fatty acids also requires increased amounts of vitamin E due to the increased lipid peroxidation from such supplementation.[80]

Diets containing elevated EPA and DHA have been recommended for degenerative joint disease,[81] with suggested daily doses of 230 to 370 mg combined EPA and DHA per body weight$^{0.75}$,[78] or roughly 2.5 to 4.0 g/1000 kcal in a diet for older dogs participating in short-distance performance activities. Common fish oil capsules contain about 300 mg of combined EPA and DHA. Therefore, a 25-kg dog requires 8 to 14 standard fish oil capsules daily to reach the recommended intake if the diet is low in these fatty acids, therefore dosing with teaspoon quantities of similar fish oil is recommended (2–3 teaspoons). EPA and DHA are thought to exert multiple functions in osteoarthritic joints. DHA may reduce intra-articular concentrations of proinflammatory cytokines, such as interleukin-1 and tumor necrosis factor, through eicosanoid modulation,[82] and there have been limited investigations of decreases in the matrix metalloproteinases that are involved in progressive cartilage degeneration following fish oil administration.[83]

Several clinical trials of fish oil–supplemented diets are available. One study of a commercial therapeutic joint diet with additional fish oil found that the greatest effect on scoring systems occurred with an estimated 7.5 g/1000 kcal of EPA and DHA.[84] Most commercial diets contain less than 0.5 g/1000 kcal for comparison. A multicenter study of a therapeutic joint diet, reported elsewhere to contain about 2.5 g of EPA and DHA per 1000 kcal, resulted in a decrease of carprofen dose from 4.4 mg/kg per day to 3.3 mg/kg per day in the treatment group, whereas the control group decreased from 4.2 mg/kg per day to 3.6 mg/kg per day over a 12-week period.[85] When fed for 90 days, the diet reportedly increased peak vertical force (PVF) by 5.6% in dogs versus

0.4% in dogs fed a control diet[86] and also improved osteoarthritis scoring.[87] A more recent investigation found that dogs fed fish oil (added to a base diet with an estimated 2.5 g EPA + DHA/1000 kcal total dietary intake) significantly increased PVF (+5.9%), decreased use of nonsteroidal anti-inflammatory drugs (NSAIDs), and increased quality-of-life scoring based on a visual analog scale when compared with a control group fed supplemental corn oil (estimated 0.04 g EPA + DHA/1000 kcal). Helsinki pain indices were reduced in both treatment and control groups, but the differences were not statistically significant because of a large standard deviation.[88]

There are significant differences between the nutrient profiles of diets purported to be suitable for the management of osteoarthritis.[81,89] Such diets are commonly recommended by practitioners, although over-the-counter fish-based diets also may contain high concentrations of omega-3 fatty acids. Liquid fish oil supplements are generally more cost-effective and pragmatic if fish oil is to be added to an unsupplemented diet. Fish oil will increase caloric intake if adjustments are not made to the base diet. Fish oil contains about 9 calories per gram, and a teaspoon of a fish oil product containing 1100 mg of combined EPA and DHA would add approximately 45 calories to the diet. At the current recommended dose of 2 to 3 tsp per day for a 25-kg dog, this would provide 90 to 135 additional kilocalories to the diet.

A variety of supplements are marketed for the management of osteoarthritis, some of which may be included in therapeutic diets labeled for such conditions. These include glucosamine, chondroitin, methylsulfonylmethane, avocado and soybean unsaponifiables, fatty acid products, green-lipped mussel, and turmeric. A recent meta-analysis of canine supplements for this purpose documented clear benefits for omega-3 fatty acids but only limited evidence for all supplements examined.[90] The most common joint supplements are products designed as chondroprotectants. Proteoglycans are thought to be critical in maintaining the features of cartilage, such as flexibility and elasticity, and are stabilized with long chains of hyaluronic acid. Glucosamine is a precursor to hyaluronic acid and other glycosaminoglycans. Chondroitin sulfate is also a precursor to major glycosaminoglycans, which in turn are complexed to proteins like aggrecan, to provide proteoglycans. These compounds are commonly used in humans and in animals, although efficacy has been significantly questioned in human meta-analyses.[91]

Both radiolabeled glucosamine and chondroitin are absorbed orally in dogs when administered as a radiolabeled supplement.[92] A double-blinded positive-controlled trial of a product dosed at 475 mg glucosamine HCl, 350 mg chondroitin sulfate, 50 mg N-acetyl-D-glucosamine, 50 mg ascorbic acid, and 30 mg Zn sulfate per about 20 kg of body weight found that subjective osteoarthritis scores were improved at 70 days with this product as compared with 42 days with carprofen (4 mg/kg/d for 7 days, 2 mg/kg/d for maintenance). Improvements were not significantly different between groups at day 70.[93] A shorter study compared a different glucosamine and chondroitin product to meloxicam and to carprofen, but only for 60 days, and found improvements only with the NSAIDs as measured by ground reaction forces and subjective scores.[94] Studies of other supplements included in therapeutic diets, such as green-lipped mussel containing omega-3 fatty acids, minerals, and other compounds, found that some owners perceive huge improvements in osteoarthritis even when dogs are given placebo.[95] Further research is necessary before definitive recommendations can be made on the efficacy of chondroprotectants. In the interim, if glucosamine and chondroitin are included in the medical management of osteoarthritis in the canine athlete, the compounds should likely be dosed at about 25 mg/kg and 15 mg/kg, respectively, and owners should be cautioned that improvements may not be evident for several months. The glucosamine and chondroitin concentrations in commercial pet foods are generally lower than those available in supplement form, and joint diets often do not contain appreciably more than normal commercial pet foods.[89]

Sporadic studies have examined evidence for the inclusion of supplements in the diets for geriatric pets. There is some evidence that acetyl-l-carnitine (27.5 mg/kg) and alpha-lipoic acid (11 mg/kg) improve cognitive performance in older animals, which could have applications for the canine athlete.[96] Carnitine is required for the transport of fatty acids across the mitochondrial membrane, and alpha-lipoic acid is an essential component of the pyruvate dehydrogenase complex, which converts pyruvate to acetyl-CoA. As a result, both are essential for normal cellular metabolism. Some over-the-counter supplements marketed for osteoarthritis contain herbal products. Uncontrolled trials of Boswellia resin (frankincense) in dogs have been reported,[97] which expand on some limited, but favorable, human trials. Curcumin, an extract from the spice turmeric, is another frequent inclusion in canine supplements because of its reported nuclear factor–κB inhibition, but this has been studied only in humans.[98] Additional information is required about these and other dietary supplements before determining their safety and efficacy.

DIETS FOR FUTURE CANINE ATHLETES: NUTRITIONAL CONSIDERATIONS DURING GROWTH

Future athletic performance is influenced by environmental and nutritional factors during growth. Nutrient flexibility will be reduced during growth, making nutrient balance more critical than in adults. Calcium homeostasis is of particular concern, as unbalanced or all-meat diets will predispose puppies to osteopenia and pathologic fractures.[99,100] Puppies generally have higher protein, essential fatty acid, and mineral requirements on a caloric basis.[70,101,102] Modulation of certain nutrients could produce benefits during early behavioral or performance training. DHA, for example, has been shown to improve a variety of cognitive and psychomotor parameters in puppies up to 1 year of age.[103] The diet with the greatest effect contained an estimated 1.25 g EPA and DHA per 1000 kcal (500 mg DHA/1000 kcal), but was also supplemented with additional vitamin E, taurine, choline, and L-carnitine, all of which could affect learning and memory.

Diets for large-breed puppies should be selected to control calcium and calorie intake. Excess calcium intake in large-breed puppies, such as Great Danes, has been associated with alterations in endochondral ossification, delayed skeletal maturation, and decreased osteoclastic activity.[104] Passive diffusion of calcium is increased in growing puppies, creating a linear absorption not observed in adults.[105] Excess vitamin D also may be problematic because of the increased concentration of 24,25-hydroxyvitamin D, which may adversely affect skeletal maturation. Diets for large-breed puppies should contain 3.0 to 4.5 g/1000 kcal calcium to prevent nutritional induction of skeletal abnormalities.[70]

Maintenance of lean body weight is critical during growth. Most puppies consume the same daily caloric intake at 4 months of age as they do when fully grown at 2 years old. As a result, if the weight of the same-gendered parent is known, this value can be used to approximate daily energy requirements after 4 months using the following equation: $130 \times (\text{parental body weight in kg})^{0.75}$ kcal/day. This equation approximates the calculated values for complex equations given by the NRC and other sources. Ad libitum feeding and overnutrition are associated with a greater incidence of osteochondrosis lesions,[106] skeletal abnormalities,[107] and hip dysplasia,[108] presumably because of the structural effects of excess weight[107] combined with other factors.

The provision of diets labeled for growth should be sufficient to prevent nutritionally induced developmental orthopedic disease. However, large-breed dogs may benefit from large-breed formulations, which generally contain less than 4 g calcium/1000 kcal and allow for modest energy restriction to maintain appropriate body condition. Some all-life-stages foods may contain excess calcium for such dogs, as they are formulated to provide adequacy for pregnancy and lactation. There is no evidence that elevated protein causes skeletal abnormalities or developmental orthopedic disease. Therefore, the practice of feeding adult pet foods to growing puppies of any breed is unfounded. Such foods would be expected to be deficient in one or more nutrients required for growth.

The concept of conditioning and training a dog during dynamic growth is equally important in puppies. Rigorous conditioning programs are not advised because of potential growth plate damage. All training and conditioning activities should be low intensity and low impact to prevent such damage during dynamic growth in puppies younger than 6 months of age. Training should be gradually increased over time and rigorous training activities are not advised until skeletal maturity, which is often between 9 and 12 months of age for the average performance dog. Therefore "pushing" young dogs may lead to musculoskeletal injury with long-term detrimental consequences.

SUMMARY

Canine endurance athletes benefit from nutritional strategies tailored to their high rates of aerobic fat metabolism. The caloric expenditure of most exercise is best predicted by assessing the distance traveled rather than the speed or intensity of the activity. Sprinting athletes, such as racing greyhounds, agility dogs, and other high-intensity short-duration activities have modest increases in daily energy expenditure (<25%) and benefit from a diet moderate in carbohydrate, protein, and in fat, similar to most maintenance pet foods. Endurance, prolonged hunting, field trial, working herding, or long-distance activities require larger increases in daily food intake and often need supplemental fat to meet energy demands of exercise. Appropriate diets for such dogs are moderate in protein (>75 g/1000 kcal) and high in fat (>60 g/1000 kcal). Post-exercise carbohydrate supplementation may replenish glycogen stores in dogs competing for several straight days, and water should always be offered immediately after exercise to prevent dehydration. Aging athletes require increases in dietary protein to preserve lean body mass and benefit from elevations in dietary omega-3 fatty acids. Growing large-breed puppies with performance potential should be maintained in ideal body condition during growth by feeding a diet with appropriate amounts of calcium. Service dogs typically live within the lifestyle of those that they serve and may have nutritional needs similar to normal active dogs; however, they should be watched for unnecessary weight gain that may hinder their ability to work as efficiently. Additional research is needed for activity-specific nutritional requirements to better understand the role of performance nutrition in the diverse sports/service work in which dogs and owners participate.

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