Chapter 18

Feeding Working and Sporting Dogs

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"We derive immeasurable good, uncounted pleasures, enormous security, and many critical lessons about life by owning dogs."
Roger Caras, A Celebration of Dogs

INTRODUCTION

Working and sporting dogs undertake a wide range of activities (**Table 18-1**). Depending on the activity, there is a need for athletic performance, scent detection or both. Athletic performance and scent detection depend on genetics, training and nutrition. All three must be optimal for maximal performance. A deficiency in any one of these factors limits performance; therefore, each factor must be assessed in light of the activity performed by an individual dog.

Genetics

The genetic characteristics of the dog must be appropriate for the type of activity it does. Mental, physical and metabolic characteristics all play a role. As an example, rat terriers are bred to have the physical and mental characteristics that make them effective in the pursuit and capture of rats and other burrowing animals. Also, as a result of genetic selection, sight hounds excel at pursuing and capturing prey in open fields. Physical characteristics such as conformation, heart size and muscle fiber type dictate the limits of athletic performance. Genetics likely also play a role in a dog's desire to perform. Certainly, it is desirable that sporting or working dogs be willing, or even eager, to perform the tasks asked of them. For example, if a Labrador retriever has no desire to enter the water or a sheepdog has no desire to herd, or a sled dog no desire to pull, whether or not physical characteristics are ideal becomes irrelevant. Thus the basis of a dog's performance depends on its innate physical and mental potential. This generalization assumes that any lack of desire that may be present is not due to injury, illness, improper training or malnutrition. But, if a working or sporting dog has the desired physical, metabolic and mental characteristics, its performance can be optimized by appropriate training and nutrition.

Training

Assessment of training should ensure that the intensity, duration and frequency match the desired level of performance. Many canine athletes are poorly trained. This is especially true for intermittent athletes such as hunting dogs that spend much of the year in a run or small yard but are expected to hunt for many hours at the onset of hunting season. This also applies to other "weekend athletes" (i.e., dogs that compete or participate in weekend activities with their owners). It seems the trend is for more dogs to participate as workout companions with their owners.

Table 18-1. Working and sporting dog activities listed by exercise type.

Exercise type	Activity
Sprint (high-intensity physical activity that can be sustained less than two minutes)	Coursing (sight hounds) Racing (greyhounds, whippets) Weight pulling
Intermediate (physical activity lasting a few minutes to a few hours)	Agility Border patrol, customs Drug detection Exercise with people (running, bicycling) Field trials Frisbee trials Guarding Hunting (game birds, rabbits) Livestock management (cattle, sheep, hogs) Military Police work Pursuit (raccoon, coyote, fox, deer, wild boar) Search and rescue Service work (guide dogs, assistance dogs) Tracking
Endurance (physical activity that last many hours)	Sled pulling (racing, expedition)

Table 18-2. Popular books about training scent-detection dogs.

Pearsall MD, Verbuggen H. Scent. Training to Track, Search and Rescue, 1982. Alpine Publications, Inc. PO Box 7027, Loveland, CO 80537.
Tweedie J. On the Trail! A Practical Guide to the Working Bloodhound and Other Search and Rescue Dogs, 1998. Alpine Publications, Inc. PO Box 7027, Loveland, CO 80537.
Syrotuck WG. Scent and the Scenting Dog, 1972. Barkleigh Productions, Inc. 6 State Road #113, Mechanicsburg, PA 17050.
Johnson GR. Tracking Dog. Theory and Methods, 1975. Barkleigh Productions, Inc. 6 State Road #113, Mechanicsburg, PA 17050.

Exercise training is simply the consistent performance of some type of exercise over an extended period of time. Although genetics dictate the mental, anatomic and metabolic characteristics of an individual dog, training can alter some of these characteristics and enhance exercise and scent-detection performance. **Table 18-2** lists four popular books that include methods for training scent-detection dogs.

Exercise training means subjecting a dog to a workload of sufficient intensity, duration and frequency to produce a measurable adaptation of the systems being trained. The types of adaptations produced by training are specific; that is, physiologic changes occur that favor the type of activity performed. To improve aerobic power, exercise intensity should be greater than 50% of maximum oxygen consumption (VO_2 max) for sedentary individuals. As the level of training or fitness improves, intensity and duration must be increased to produce further improvement. The general principle is that intensity and duration must be increased until a level of overload is reached for the systems being trained to induce adaptation. Furthermore, training adaptations are specific to the type of exercise performed.

Examples of training-induced changes include increased bone mass, muscle hypertrophy, increased mitochondrial density in muscle and plasma volume expansion. All of these changes support enhanced performance. Muscle hypertrophy is a well-known phenomenon. Muscle size and strength increase with use. Changes in content of various muscle enzymes and numbers of mitochondria can occur depending on the type of activity performed. Bones, ligaments and tendons also hypertrophy in response to increasing stresses but at a slower rate than muscle.

Cardiovascular function increases to meet increased needs of muscle for substrates and waste removal. Plasma volume expansion is a well-known result of long-term exercise training that supports increased cardiac output (McKeever et al, 1985; Convertino et al, 1980). Heart rates of trained animals are lower for a given workload because of greater cardiovascular efficiency. Training also influences the type and amount of substrate that can be used to support exercise.

Nutrition

Nutrition cannot overcome deficits in genetics and training. However, matching the food and feeding methods to the type of activity (i.e., intensity, duration and frequency) allows a sporting or working dog to perform to its genetic potential and level of training. The feeding goals for sporting and working dogs are to provide appropriate nutrition to optimize exercise and olfactory performance and long-term health.

Because many successful working and sporting dogs rely on both athletic and scent-detection abilities, this section of the chapter reviews exercise and olfactory physiology, followed by a discussion of how to assess the nutritional needs of individual sporting and working dogs. The key nutritional factors are developed as the basis for ensuring that the best food is selected to help achieve the goals of optimizing performance and long-term health.

The second section covers the feeding plan and how well the feeding plan meets the feeding goals (reassessment). The feeding plan includes food selection and how the food should be fed including amount, how it is offered and the timing of feeding. Depending on the results of the reassessment process, changes to the original feeding plan may be required to ensure delivery of the feeding goals.

CLINICAL IMPORTANCE

Canids represent one of the most diverse mammalian species. The wide range of athletic ability and types of sporting and working dogs come as no surprise in light of this diversity. In regards to athleticism, at one extreme is the racing greyhound, which is capable of sprinting a quarter mile in less than 26 seconds and reaching maximum speeds in excess of 40 mph (64 km/hr). At the other extreme is the sled dog, which is capable of running vast distances, day after day, in arctic conditions. In between these extremes is a plethora of different kinds of working, hunting and sporting dogs that participate in a wide range of athletic activities (**Table 18-1**).

The American Kennel Club lists 26 sporting breeds, 18 herding breeds and 25 breeds of working dogs; however, it is difficult to quantify how many of these dogs actually participate in athletic events (American Kennel Club, 2007). Eighty different breeds of hounds are found worldwide and all these breeds were originally hunting dogs. In addition, there are 13 sight hound breeds, 49 herding or shepherd dogs and 31 recognized terrier breeds (Palmer, 1994; van Lier, 1995; van Leeuwen, 1995). Another classification system lists 91 hounds, 43 working breeds, 44 herding dogs, 49 gun dogs and 31 terriers (Palmer, 1994).

Scent-detection type working dogs are employed by many government agencies including those involved in national defense, customs service and border patrol. Additionally, in the United States, more than 28,000 dogs work for state and local law enforcement agencies. Numbers of active scent-detection type sporting dogs are difficult to document. In the United States, survey results from one publisher estimate that readers of their hunting magazines own more than 700,000 active hunting dogs.[a] These same readers spend 150 to 200 hours per year training their dogs and 40 days per year hunting in the field with their dogs. In the United States, the National Greyhound Association registered about 26,000 greyhound puppies per year in 2004 and 2005 and about 22,900 in 2006 (National Greyhound Association, 2007). There are 37 dog tracks in 14 states.[b]

Because dogs participate in a wide variety of working and sporting activities, and the level of participation varies from full-time athlete to intermittent activity, it is difficult to assess how much of the canine population participates in sporting and working events. It is clear, however, that large numbers of dogs participate in these activities.

OLFACTORY PHYSIOLOGY

Olfaction is a very important special sense for dogs. Besides the obvious value of facilitating obtaining prey, olfaction is significant in the overall communication process of canids. For dogs, communication is fundamental to maintaining affiliations, reducing competition and identifying individuals (Simpson, 1997). Urine scent marking by dogs is one example. It is thought that a dog can identify the sex and even specific individuals from the odor of another dog's urine (Houpt, 1998). Urine is not the only olfactory cue for dog-to-dog communication. Anal gland and ear secretions are also thought to function in individual identification. Common greeting behaviors for dogs include sniffing under each other's tails and investigating odors of each other's ears (Houpt, 1998; Fox and Bekoff, 1975). Also, as writing is to people, dogs can use olfaction-based communication to send a message that can be transmitted and received in their absence. The sender must be present for visual or auditory signals to be sent, but an odor persists for minutes to many days after the sender has gone (Houpt, 1998). Olfactory cues may help newborn puppies locate their mother and its teats (Houpt, 1998a) and later might confer survival advantages by promoting the acquisition of information about safety of different foods (Hepper and Wells, 2005).

Table 18-3. Various scent-detection activities conducted by working and sporting dogs.

Brown tree snake detection
Cadaver detection
Conservation work
Drug detection
Explosives detection
Fire accelerant detection
Game hunting
Identification of individuals
Pipeline leak detection
Search and rescue
Termite detection
Tracking for work or sport
War dogs

Scent-detection ability is important to the function of many classes of sporting and working dogs. Based on tomb evidence, the use of dogs as chemical detectors dates back to their use as hunting dogs 12,000 years ago (Furton and Meyers, 2001). Today many scent-detection dogs do potentially life-saving work including detecting explosives, leading search and rescue teams, finding and detaining potentially dangerous criminals or alerting to the presence of enemies. Interestingly, with minimal training, dogs are reportedly able to closely match biopsy results in distinguishing between normal controls and lung and breast cancer patients by sniffing breath samples (McCulloch et al, 2006). Dogs can also distinguish patients with bladder cancer on the basis of urine odor. Apparently tumor-related volatile compounds are present in the urine, imparting a characteristic odor signature (Willis et al, 2004). **Table 18-3** includes various activities in which scent-detection dogs are used.

A review of the physical and chemical aspects of scent and the functioning of the olfactory system under different conditions sets the stage for understanding how exercise training and proper nutrition can affect olfactory performance and scent detection.

Physics and Mechanics of Scent

The following discussion pertains primarily to scent trails from animals or people. However, much of the information also applies to odors from inanimate and/or stationary objects. There are thought to be two general types of odors that are left on a scent trail: individual odor and contact/disturbance odor. Sources of individual odors could be skin cells, glandular secretory products (sebaceous, apocrine and eccrine secretions) and, in the case of people, the smell of their clothes, deodorants, soap, etc. Contact/disturbance odors are generated as an animal or person walks over the ground. In the process, their footsteps disrupt the surface, crushing vegetation, soil and other materi-

Box 18-1. Genes and Olfaction: People vs. Dogs.

Olfactory receptors constitute the largest gene family in vertebrates. Species that have highly developed olfactory senses are referred to as macrosmatic (e.g., dogs), whereas species with a weak sense of smell are termed microsmatic (e.g., people). There are likely several reasons dogs are much better at odor detection than people. The surface area of the canine olfactory epithelium is as much as 20 times greater than that of people. The density of neuronal cells and the number of olfactory receptors that are expressed on their surface as well as the size of the olfactory bulb have to be taken into consideration when comparing the olfactory capabilities of different species. The canine olfactory epithelium can express up to 20 times more olfactory receptors than that of people. This contributes to the ability of dogs to detect odorant molecules at a much lower concentration. The binding affinity of odorant molecules for their related olfactory receptor is also likely to be an important variable that could explain differences in sensing abilities between people and dogs. The range of types of olfactory receptors of dogs is around 30% larger than for people, which could contribute to the wider range of odorant molecules that dogs can detect.

The Bibliography for **Box 18-1** can be found at www.markmorris.org.

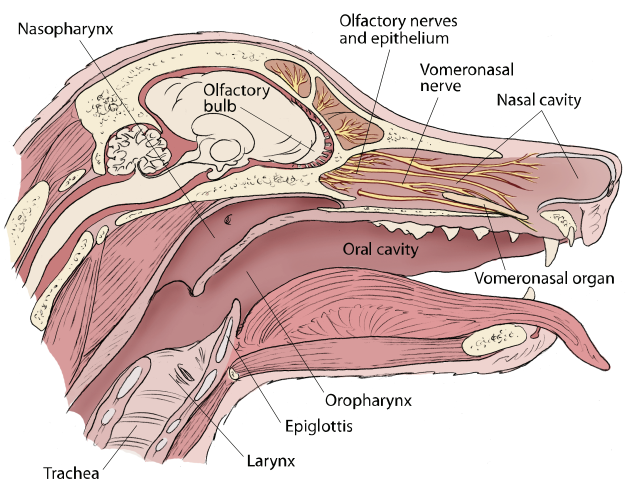

Figure 18-1. Drawing of a mid-sagittal section of a canine head showing olfactory and upper respiratory anatomy.

als, and as a result, these materials release odors. When following scent, dogs may be detecting airborne odors arising directly from air moving past an animal or person, from contact/disturbance odors that become airborne if such odors are volatile or from the ground, which could include both individual odors and contact/disturbance odors (Hepper and Wells, 2005).

Scents tend to be concentrated at their source. Odors spread and become less concentrated, forming a scent cone. When air is stagnant around the source of an odor, scent pools can form. Factors such as wind, terrain, air temperature, humidity and soil temperature can affect the scent cone or scent pool, including where and how far it is dispersed (Jones et al, 2004). Hunters using dogs generally agree that the best scent conditions include moderate humidity and moderate ambient temperatures (early morning and late afternoon on warm sunny days) (Holloway, 1961). Wind can be channeled by obstructions or terrain and can rapidly disperse scent in unexpected directions (Jones et al, 2004). Thus, odors do not disperse in a linear continuous gradient but result in odor fragments or patches. These pockets of odors vary in concentration and are separated by areas of clean air where no odor is present. Thus, dogs are often exposed to variable and intermittent odor signals. In the face of this complexity, dogs and many other animals are able to determine the direction of a trail and find the source of an odor. Furthermore, they can be trained to identify specific odors (Hepper and Wells, 2005). Human handlers who are aware of factors affecting odor dynamics can improve detection success by directing the activity of a scent-detection dog accordingly (**Table 18-2**).

Olfactory System

The olfactory system consists primarily of the nose, nasopharynx (including the vomeronasal organ and olfactory epithelium), olfactory and vomeronasal nerves and the olfactory bulb (**Figure 18-1**). The pulmonary system and oro- and nasopharynx facilitate olfaction by moving and directing air over the olfactory epithelium.

The olfactory epithelium contains the olfactory receptors. This is where odor molecules interact to stimulate an olfactory sensation. Chemicals that are best detected by the olfactory system are volatile and both water and lipid soluble. Such molecules are readily made airborne and dissolve in the mucus that covers the olfactory epithelium. After this occurs, they bind to specific substances called G-protein-coupled-receptors, which are on the cilia of the olfactory receptor neurons. As a result, a signal transduction of smell is initiated (Jones et al, 2004). **Box 18-1** discusses gene-based differences between the olfactory capabilities of people and dogs.

For olfaction to occur, odorants need to contact the olfactory receptors in the olfactory epithelium. Thus, air from the environment must pass into the nasal cavity to reach the olfactory epithelium. The course taken by air as it passes through the nasal cavity is difficult to predict because of the complex anatomy of the nasal cavity. There are distinctly different routes of airflow during normal inspiration and during sniffing. Sniffing draws considerably more air over the olfactory epithelium as opposed to normal inspiration. During normal inspiration, air tends to route below the olfactory epithelium, a more efficient route for pulmonary function (Becker and King, 1957).

Sniffing occurs at 160 to 240 breaths/min. compared to 40 to 44 breaths/min. in typical bird dogs while ranging. When bird dogs are pointing, their mouth is slightly open, their nasal openings move in accordance with sniffing and the head is stretched forward. These postures and movements might be optimizing airflow over the olfactory epithelium (Steen et al, 1996).

Dogs exhibit three types of scenting behavior: 1) air scenting, 2) trailing and 3) tracking. While air scenting, dogs are thought to be following the airborne scents emanating directly from the source of the odor and being carried away by air currents. These dogs are nearly always working upwind. When trailing, dogs follow the trail with their head up while moving upwind and head down while following the scent downwind. They usually do not follow directly on the trail path and may overrun a path if it turns. The assumption is that when dogs are trailing they are following the individual's scent deposited by contact with the ground surface. When tracking, dogs follow the trail with their head down and nose on the path and very closely follow the footsteps of the subject being tracked. It is assumed that while tracking, dogs are following odor deposited on the ground and contact/ground disturbance odor. It should be noted that these three characterizations are based on observations (Hepper and Wells, 2005). Also, dogs can be trained to do primarily one type of these three scent-detection behaviors (Jones et al, 2004).

In addition to the general scent-detection behaviors characterized above, dogs seem to display three different phases when ground tracking. During a searching phase, they move quickly and sniff intermittently, supposedly trying to find a track. After they find a track they usually stop for a moment. Then they enter a deciding phase, characterized by moving slower and by more frequent sniffing episodes. The deciding phase can be as short as following two to five human footprints while they determine the direction of the track. After the direction of the track is decided upon, the tracking phase follows. During this phase they move more quickly, suggesting that following the track is a simpler task than determining its direction. Apparently the deciding phase is based on decay/dilution of the odorants as a result of time. In the case of human footsteps, this time frame can be as short as three to five seconds (Thesen et al, 1993).

Hunting dogs often air scent while running at top speed. During these periods they are usually mouth breathing. One question is how they mouth breath and detect scents at the same time because scent detection requires ambient airflow inward through the nasal cavity. One explanation is based on the Bernoulli principle as follows. Because the oropharynx has a larger cross sectional area it offers less aerodynamic resistance than the nasopharynx. If the mouth is open during heavy breathing, air moves more easily back and forth via the oropharyngeal route. The more restrictive anatomy of the nasal airway suggests that air moving through this passage would do so at a lower speed. Thus (based on the Bernoulli principal), during heavy breathing, air velocity in the oropharynx would likely be high, and the pressure would be low compared to the air velocity and pressure in the nasal cavity. Thus, air would flow into and through the nasal cavity and then into the oropharynx. This would allow ventilating the nasal cavity and the olfactory mucosa while performing open-mouthed breathing during inhalation and exhalation (Steen et al, 1996). However, this phenomenon would not allow simultaneous sniffing and panting. Sniffing improves olfactory acuity, apparently by exposing the olfactory epithelium to more ambient air and thus more odors (Laing, 1983).

Effect of Physical Fitness on Olfaction

The rate a dog is panting and the quality of its olfactory work are inversely related. As mentioned above, dogs cannot pant and sniff at the same time. Panting results from a need to cool and dogs cool primarily by panting (Box 13-2). This can pose a dilemma for detection dogs in hot, humid environments. It is exacerbated if physical exercise is imposed and/or if the dog is neither physically fit nor properly fed. There is a direct correlation between rate of sniffing and efficiency of olfaction and an inverse relationship between the rate of panting and ability to detect scents. The searching phase is prolonged in dogs that have exercised and are panting. Dogs that are panting also have difficulty in determining the direction of a track (Gazit and Terkel, 2002). In a treadmill exercise-based study, physically trained dogs did not experience a decline in olfactory acuity following moderate physical stress compared to untrained stressed dogs. In this study, the olfactory acuity of the untrained dogs declined by 67% (Altom et al, 2003). Many bird-hunting dogs are pets, or kept in kennels, and hunt only a few weekends each year. They are asked to perform seasonal, intermittent endurance exercise coupled with scent detection. Their ability to hunt successfully could be enhanced by increasing their physical training before and through the hunting season.

A dog's ability to perform physically can also be improved through proper nutrition, which, as discussed above, could indirectly improve olfaction. Separately, a dog's olfactory ability can be improved directly through proper nutrition. The nutritional approaches to improved performance are discussed later in the chapter.

EXERCISE PHYSIOLOGY

Exercise requires increased function of several organ systems and energy metabolic pathways. Dramatic changes take place within dogs to support exercise, and as a result, of exercise. Certainly, nutritional needs are affected by exercise. An understanding of exercise physiology is fundamental to assessing and developing a feeding plan for canine athletes.

The following review of exercise physiology relates particularly to nutrition of canine athletes. This discussion includes: 1) a review of muscle metabolism that outlines the energy needs of working muscles, substrate requirements and the by-products of energy metabolism, 2) exercise type and intensity, which determine the preferred metabolic substrates and therefore the nutrient profile, 3) some of the physiologic changes that occur

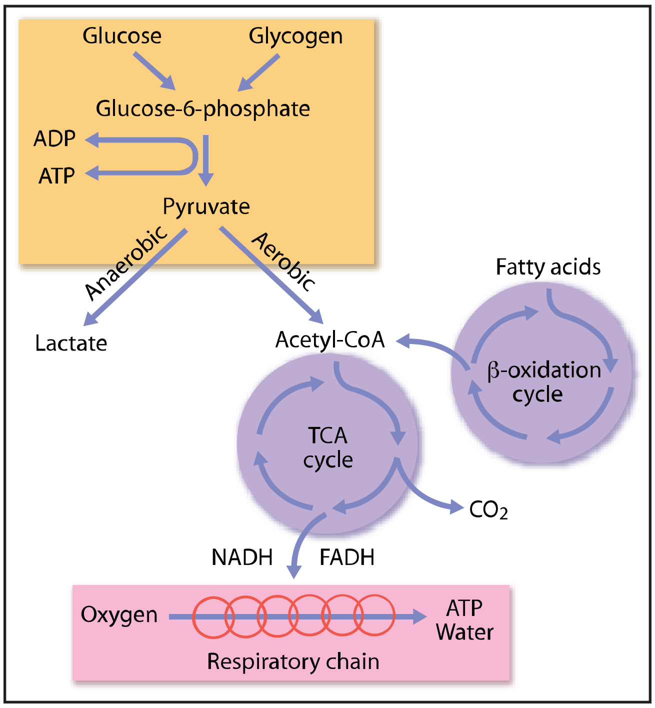

Figure 18-2. Summary of major energy-generating pathways used during exercise. Key: ADP = adenosine diphosphate, ATP = adenosine triphosphate, TCA = tricarboxylic acid, NADH = reduced form of nicotinamide dinucleotide, FADH = reduced form of flavin-adenine dinucleotide.

during exercise and how they may affect nutrient needs and 4) the energy cost of running, which dictates dietary energy needs. All of these factors are important to nutritional assessment of canine athletes and form the basis for a good feeding plan.

Muscle Metabolism

Muscle Fiber Types

Muscles are not homogeneous. They are composed of fibers with different contractile and metabolic characteristics. Muscle fibers are classified into two groups based on contractile properties and histochemical staining: Type I or slow twitch and Type II or fast twitch. Type I fibers have high oxidative capacity and endurance. These fibers are smaller than Type II fibers and have high capillary density and high numbers of mitochondria. They are low in glycolytic ability and low in staining for myofibrillar ATPase, an enzyme associated with fast contraction and relaxation. Conversely, Type II fibers are high in myofibrillar ATPase, larger, contain more glycolytic enzymes and have greater strength. In most species, Type II fibers can be further subdivided into Type IIa and Type IIb. Contraction characteristics are similar for Type IIa and Type IIb fibers, but Type IIa fibers have greater oxidative capacity than Type IIb fibers; the latter are more fatigable. However, dogs and perhaps other members of their genus and subfamily, appear not to have classic Type IIb fibers but, instead, two other kinds of Type II fibers that are more oxidative (called Type IIDog and Type IIC). This fits with the general observation that dogs are tireless runners (Snow et al, 1982; Latorre et al, 1993; Rivero et al, 1994).

The fiber composition varies between muscles and between individuals. High-power athletes such as racing greyhounds have a higher proportion of Type II fibers, whereas endurance athletes have a higher proportion of Type I fibers (**Table 18-4**). Because the work performed by most intermediate athletes resembles that done by endurance athletes, but is of shorter duration, the muscle fiber-type profile of intermediate athletes should resemble that of endurance athletes more than that of sprint athletes. Muscle fiber type is a function of genetics and dictates the type of exercise for which an individual is best suited. However, some modification is possible through training. Endurance training increases the number and volume of mitochondria and increases capillary density in all fiber types (Åstrand, 1986).

Muscle Energetics

Exercise requires the transfer of chemical energy into physical work. Chemical energy stored in high-energy phosphate bonds of adenosine triphosphate (ATP) is the sole source of energy for muscle contraction. ATP is cleaved to ADP during contraction. The amount of ATP used is proportional to the amount of work performed (i.e., Fenn effect). ATP is vital not only for the events of contraction but also for relaxation and maintenance of important ion gradients (**Box 18-2**). Normal excitability of nerve and muscle is due to an electrochemical gradient maintained by the sodium-potassium pump at the expense of ATP. The calcium pump uses ATP to maintain a low concentration of calcium in the muscle cell in the relaxed state. An estimated one-third of the basal energy requirement is used to maintain electrolyte concentration gradients across cellular membranes (Blaxter, 1989; Pivarnik, 1994).

Although ATP is the high-energy compound that cells use as fuel to perform work, the energy required for exercise can ultimately come from a variety of sources. Because the concentration of ATP in muscle cells is relatively low in comparison to the cell's need during exercise, ATP must be replenished from other fuel sources. These metabolic fuels are stored in muscle (endogenous) and at other body sites (exogenous). The metabolism of these fuels occurs either with oxygen (aerobic) or without oxygen (anaerobic). The anaerobic pathways (i.e., the creatine phosphate shuttle and glycolysis) occur in the cytoplasm, whereas the aerobic pathways (i.e., complete oxidation of glucose, fatty acids and amino acids) take place in mitochondria. **Figure 18-2** shows an overview of these pathways. The proportion of each pathway used is determined by the duration and intensity of the task performed and by the conditioning and nutritional status of the animal (Blaxter, 1989; Nadel, 1985; Williams, 1985; Kronfeld and Downey, 1981; Kronfeld et al, 1977; Hammel et al, 1977). **Table 18-5** lists metabolic fuels, their uses and storage sites.

The concentration of ATP is tightly regulated, although it is rapidly consumed during exercise (Blaxter, 1989; Nadel, 1985; Stryer, 1988; Rusko et al, 1986). Resting muscle cells have only enough ATP to fuel muscle contraction for a few seconds. If work continues beyond this point, ATP must be regenerated from other metabolic fuels at a rate comparable to that at which

Box 18-2. The Events of Muscle Contraction.

Muscle contraction occurs when a nerve excites a muscle fiber resulting in a muscle action potential (loss of the normal -90 millivolt resting membrane potential). The action potential travels throughout the muscle fiber causing calcium to be released into the cytoplasm from the sarcoplasmic reticulum. This flood of calcium around the contractile proteins elicits a conformational change that allows the contractile proteins (actin and myosin) to bind together (**Figure 1**). This attachment allows the energy stored in the "pre-cocked" head of the myosin filament to be discharged in a "power stroke" that causes muscle shortening. The two filaments are released when ATP binds to the myosin active site. The head of the myosin filament is re-cocked when this ATP molecule is cleaved. When the calcium concentration remains high, the head of the myosin filament binds to another site on the actin filament and the sequence is repeated. This sequence of events continues until either minimum fiber length (maximum shortening) or maximum load is exceeded. Relaxation occurs when the calcium concentration drops to pre-contraction levels because of the action of the calcium pump.

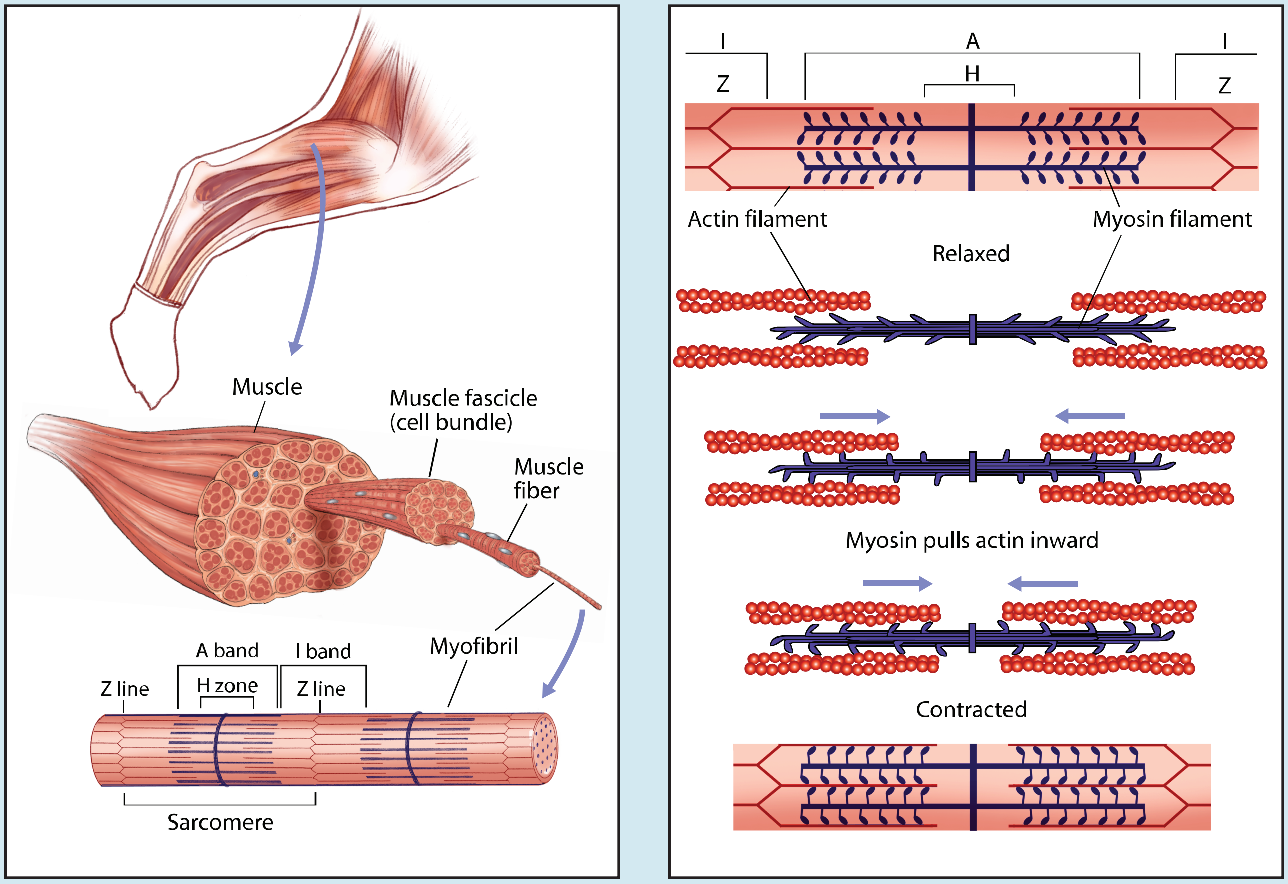

Figure 1. Components of striated muscle cells. Each striated muscle cell or fiber contains hundreds to thousands of myofibrils. Each myofibril contains a series of interlocking myofilaments (i.e., actin and myosin filaments). The **H band** is the center of the myosin filaments, the **A band** is the entire length of the myosin filaments, the **Z disk or plate** is the center and attachment site of the actin filaments, the **I band** encompasses the entire length of the actin filaments except for the portions that overlap the myosin filaments. The compartments between the Z plates are called **sarcomeres**. During contraction, the Z plates are pulled towards one another as the degree of overlap of thick and thin filaments increases; I band and H bands shorten. Maximum contraction is attained when the ends of the thick filaments butt against Z plates.

it is being consumed (Blaxter, 1989; Nadel, 1985; Williams, 1985; Rusko et al, 1986; Pate and Brunn, 1989). Creatine phosphate (Cr-P) is an endogenously stored fuel that muscles can rapidly convert to ATP. The Cr-P shuttle permits the maximum rate of ATP synthesis possible; however, this pathway can only support maximal efforts for five to 15 seconds (**Figure 18-3**) because muscle Cr-P stores are very limited (Williams, 1985; Pate and Brunn, 1989; Newsholme, 1986).

Glucose is a versatile metabolic fuel that is stored endogenously as muscle glycogen and exogenously as glycogen in the liver and to a much smaller extent as free glucose in the blood. Glucose can be metabolized to regenerate ATP by both anaerobic and aerobic pathways. Anaerobic metabolism of glucose (glycolysis) results in very rapid ATP production (**Figure 18-3**) or high metabolic power (**Box 18-3**), but only yields two ATP per molecule of glucose. Aerobic metabolism, the complete oxi-

Table 18-4. Percent fast twitch fibers (Type II) by selected canine breeds.*

Muscle	Greyhound	Crossbred	Foxhound
Biceps femoris	88.6	67.2	63.0
Semitendinosus	98.9	85.3	69.6
Triceps (long head)	94.2	77.2	64.9
Vastus lateralis	96.6	61.4	80.7

*Adapted from Guy PS, Snow DH. Skeletal muscle fibre composition in the dog and its relationship to athletic ability. Research in Veterinary Science 1981; 31: 244-248.

Table 18-5. Metabolism, use and storage sites of metabolic fuels.

Fuel	Metabolism	Use	Storage sites
ATP	Anaerobic	Primary fuel for synthetic processes, ion pumps and muscle contraction	Muscle cells (concentration is low and highly regulated)
Cr-P	Anaerobic	Regenerate ATP	Muscle cells (low concentration)
Glucose	Anaerobic (glycolysis) and aerobic (TCA cycle)	Rapidly available energy source	Muscle and liver glycogen (1 to 2% of body weight)
Fatty acids	Aerobic (β-oxidation and TCA cycle)	Long-lasting energy source	Adipose tissue (2 to 20% of body weight)
Amino acids	Aerobic (TCA cycle)	Small contribution to energy (may contribute up to 5 to 15%)	Structural proteins

Key: ATP = adenosine triphosphate, Cr-P = creatine phosphate, TCA = tricarboxylic acid.

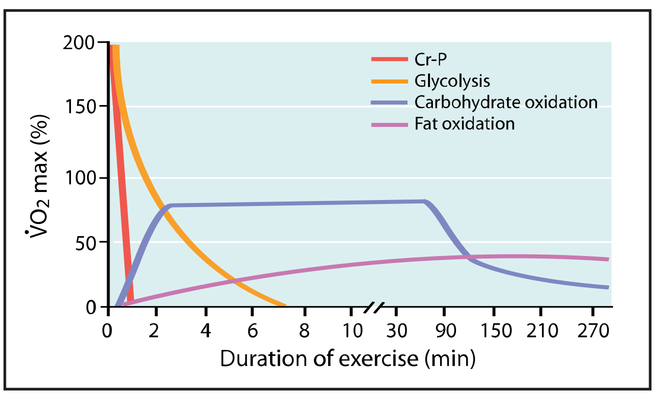

Figure 18-3. Relative contributions of the four energy-generating pathways, depending on exercise intensity and duration. Key: Cr-P = creatine phosphate.

dation of glucose to CO_2 and water, regenerates ATP less rapidly (**Box 18-3**), but results in a much greater yield (36 ATP per molecule of glucose). Because total body glucose stores (glycogen) are relatively small (1 to 2% of body weight), even aerobic metabolism of glucose cannot sustain exercise for extended periods of time. Fatty acids are stored in ample supply in adipose tissue and within muscle. They are the primary energy source for long-lasting exercise. Although small amounts of fatty acids are stored in muscle, this source may contribute up to 60% of the fatty acids oxidized during the first two to three hours of exercise (Weber et al, 1993).

Amino acids are usually not a primary energy source for exercise. Oxidation of amino acids may contribute up to 5 to 15% of the energy used during exercise, depending on the intensity and duration of the task (Young et al, 1962; Zackin, 1990; Hickson and Wolinsky, 1989). Most of this energy comes from the oxidation of the branched-chain amino acids leucine, isoleucine and valine (Miller and Massaro, 1989; Blomstrand et al, 1988). Most amino acids are structural or functional components of proteins and the size of the labile amino acid pool is very small, making amino acids a less significant fuel source for exercise in most circumstances.

The proportion of energy substrates and metabolic pathways used during exercise depends on the intensity and duration of the exercise. As exercise intensity increases, the power output and the rate of energy metabolism must also increase. As exercise duration increases, total substrate availability and energy yield become more important (**Box 18-3**). High-power activities (e.g., sprinting) rely heavily on anaerobic metabolism, whereas more prolonged activities require the higher energy yield provided by oxidation of glucose and fatty acids. As the duration of exercise increases, oxidation of fatty acids becomes more important (**Figure 18-3**).

By-Products of Muscular Work

Heat is the primary by-product of muscle contraction; 75 to 80% of the energy used during muscular work is converted to heat. A 10-fold increase in metabolism results in a 10-fold increase in heat production. Unless the animal is working in a very cold environment, this heat is a by-product that must be removed (even some sled dogs overheat). In dogs, the respiratory tract is responsible for dissipating most of this heat. Normal body temperatures of dogs doing physical work are higher than their normal resting temperatures. During very intense exercise or exercise in hot environmental temperatures, heat production exceeds the ability of the respiratory tract to lose heat, increasing body temperature. The body temperature of racing greyhounds may increase more than 1˚C (1.8˚F) after a 30-second race (Rose and Bloomber, 1989). Pointing breeds can have normal working temperatures up to 41.1˚C (106˚F) (Gillette, 2002). Labrador retrievers can have normal working temperatures up to 41.6˚C (107˚F) (Matwichuk et al, 1999). Because evaporative heat loss is the primary way dogs dissipate heat, ensuring adequate hydration is crucial for maintenance of normal body temperature.

Metabolic acid is another by-product of energy metabolism that must be eliminated during and after exercise. Aerobic metabolism generates ATP by combustion of carbohydrates and fats to CO_2 and water. Lactate is the endpoint of anaerobic metabolism. Either way, acid is produced that must be eliminated in some way for exercise to continue. Muscle enzyme

Box 18-3. Metabolic Power and Yield.

Metabolic power is the speed with which energy substrates can be converted to ATP, whereas metabolic yield is the amount of ATP that can be made from energy substrates. High-intensity exercise (e.g., sprinting) requires rapid mobilization of stored energy for a very short time; therefore, metabolic power is very important. Because duration of exercise is very short for sprinters, metabolic yield is less important. Conversely, endurance activities are longer in duration and lower in intensity. For these activities, the rapidity with which ATP is made from substrates (power) is less important than the amount of ATP made (yield). **Tables 1** and **2** show maximum power and yield from various substrates using aerobic and anaerobic pathways.

Clinically, canine sprint athletes rely heavily on anaerobic metabolism of carbohydrates whereas canine endurance athletes rely more on oxidation of fats.

CLINICAL EXAMPLE

Compare a 30-kg racing greyhound with a 30-kg sled dog. Assume the racing greyhound runs an 800-m race in about 48 seconds. The total energy needed for the race is about 24 kcal, whereas the energy use rate or metabolic power is about 30 kcal per minute (an increase of more than 25 times resting). Total daily energy requirement (DER) is about 1,600 kcal. In contrast, consider a sled dog that runs 80 km pulling a sled (its share is about 15 kg) for five hours. The sled dog needs about 3,600 additional kcal for the event and uses them at a rate of 12 kcal per minute. Total DER is about 5,000 kcal (more than 5 x resting energy requirement). To convert to kJ, multiply kcal x 4.184.

Table 1. Estimated maximum metabolic power output for human skeletal muscle using different substrates and metabolic profiles.*

Process	Metabolic power output (μmole of ATP/g of muscle/min.)
Aerobic metabolism	
Fatty acid oxidation	20.4
Glycogen oxidation	30
Anaerobic metabolism	
Glycogen glycolysis	60
Creatine phosphate and ATP hydrolysis	96-360

*Adapted from Hochachka PW. Design of energy metabolism. In: Prosser CL, ed. Environmental and Metabolic Animal Physiology, 4th ed. New York, NY: Wiley-Liss, 1991; 332.

Table 2. Energy yield using different substrates and metabolic pathways.*

Process	Energy yield (moles of ATP/moles of substrate)
Aerobic metabolism	
Triglyceride oxidation (glycerol + 3 palmitate)	403
Fatty acid oxidation (palmitate)	129
Glycogen oxidation	38
Glucose oxidation	36
Proline oxidation	21
Lactate oxidation	18
Anaerobic metabolism	
Glycolysis (glycogen)	3
Glycolysis (glucose)	2
Creatine phosphate hydrolysis	1

*Adapted from Hochachka PW. Design of energy metabolism. In: Prosser CL, ed. Environmental and Metabolic Animal Physiology, 4th ed. New York, NY: Wiley-Liss, 1991; 327-329.

The Bibliography for **Box 18-3** can be found at www.markmorris.org.

activity is highly pH sensitive. Therefore, if energy metabolism and muscle contraction are to proceed optimally, muscle pH must be tightly regulated. Intracellular buffers can blunt some of the acute effects of increased concentrations of CO_2 and lactate. However, elimination of organic acids from muscle cells is the primary strategy for avoiding deleterious decreases in muscle pH. Because it is a weak electrolyte, CO_2 has less effect on pH than lactate (a strong salt of lactic acid) and is handled differently by the body.

Assuming no other primary acid-base changes, CO_2 and bicarbonate (HCO_3^-) increase in parallel because of the following relationship:

$$CO_2 + H_2O \leftrightarrow HCO_3^- + H^+$$

The CO_2 load produced during exercise can be eliminated via two routes: 1) respiratory loss of CO_2 (acute) and 2) renal excretion of HCO_3^- (long-term). The ability of the kidneys to respond acutely may be impaired because of decreased plasma volume and renal blood flow during exercise. The respiratory

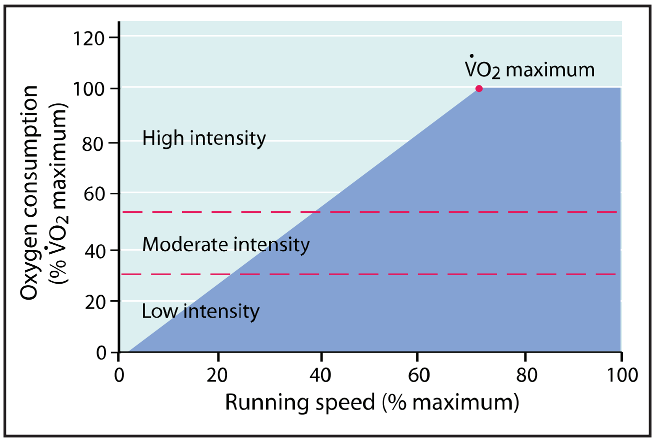

Figure 18-4. Relationship between energy consumption (VO_2) and running speed (workload). VO_2 max is the point at which VO_2 no longer increases with increasing workload.

system responds very quickly by increasing ventilation to excrete excess CO_2 (and excess heat). Aerobic exercise generally does not produce large acid-base changes, because the respiratory system can excrete CO_2 as fast as it is produced.

The acid-base consequences of anaerobic metabolism are more severe and less easily handled by the body. Lactate is the anionic form of a strong organic acid and does not participate in any dissociation equilibria. This means that lactate has a greater effect on pH than CO_2 and its acid-base effects must be ameliorated by other compensatory changes until it is metabolized. Lactate is oxidized for energy by muscle or converted back to glucose in the liver (Cori cycle).

Exercise Intensity and Duration

Energy and other nutrient requirements for canine athletes are determined by the intensity and duration of exercise. Exercise intensity can be described in a variety of ways depending on body weight and type of activity. Exercise intensity is a measure of work done per unit time. For dogs, the type of work done is usually running and the amount of work done depends on body weight, distance traveled and changes in elevation. The amount of work done is directly proportional to the amount of energy used. Therefore, energy use describes work done.

For example, a 30-kg dog expends about 30 kcal to cover 1 km on a flat surface, regardless of how fast it walks or runs (minor differences may occur due to differences in efficiency of various gaits for running at a specific speed). Running speed (distance/time) is a measure of exercise intensity (work/time) or power (energy/time). A direct relationship exists between running speed (km/hr) and energy use rate (kcal/hr or kJ/hr) for an individual of a given size. However, individuals of different sizes expend different amounts of energy to run the same speed, making running speed a poor measure for comparison of workload between individuals of different sizes.

Exercise physiologists have traditionally used oxygen consumption (VO_2) as a measure of workload. The body only uses oxygen for combustion of substrates to produce energy. Each liter of oxygen consumed represents an energy expenditure of about 4.8 kcal or 20.1 kJ. Therefore, the VO_2 indicates the rate of energy use, at least at submaximal exercise levels. At very high workloads, exercise intensity can be increased without a further increase in VO_2 (**Figure 18-4**). The workload at which this occurs is called maximal oxygen consumption (VO_2 max).

Exercise intensity is frequently expressed as a percentage of VO_2 max in order to compare different types of activities for individuals of different size within a species and between species. Exercise intensity dictates the severity and types of physiologic changes associated with exercise, including substrate use, metabolic pathways and waste production. Low-intensity exercise is up to 30% of VO_2 max and is completely aerobic, using mostly fatty acids. Exercise intensities from 30 to 50% of VO_2 max (moderate intensity) are still completely aerobic, but carbohydrates become an important energy substrate (carbohydrate threshold). At high-intensity exercise (75 to 100% of VO_2 max), anaerobic metabolism becomes important and lactate begins to accumulate in the blood. The anaerobic threshold is the workload at which lactate concentrations in the blood increase to 4 mmol/l or more (Hollman, 1985). When working at exercise intensities at or above the anaerobic threshold, lactate in the blood begins to accumulate at an exponential rate, potentially limiting the duration of the exercise. Workloads above VO_2 max are called either maximal or supramaximal, are highly dependent on anaerobic metabolism and result in large increases in blood lactate concentrations.

Exercise intensity dictates metabolic pathways and substrate use. High-intensity activities (sprinting) depend on anaerobic metabolism of carbohydrate (glucose and glycogen), which is supported by high-carbohydrate foods. The severe acidemia produced by high-intensity activities underscores the need for adequate electrolyte and water intake. Endurance events that take place at low to moderate intensity for long periods are completely aerobic and rely mostly on oxidation of fatty acids. Thus, as exercise duration increases, the fat fraction of the food becomes more important to supply energy needs. Intermediate exercise (as performed by most canine athletes) is usually of low to moderate intensity, but may include some short periods of high-intensity work. Both fats and carbohydrates are important fuel sources in intermediate exercise.

Physiologic Changes Due to Activity Anticipation

Anticipation to perform work can affect metabolism in dogs. Foxhounds, Labrador retrievers and sled dogs have significant blood parameter changes as a result of anticipation to perform specific tasks. Labrador retrievers had a significant increase in serum calcium and total bilirubin and a significant decrease in serum glucose, total protein, cholesterol and insulin associated with anticipation (Gillette et al, 2001). A regimen of physical conditioning had a significant affect on the anticipatory changes in foxhounds and sled dogs (Gillette et al, 2006). The effects of anticipation can play a role in a dog's ability to perform selected activities.

Physiologic Changes Due to Exercise

The hallmark of exercise is increased metabolism. Many organ systems increase their activity, some by several-fold, whereas some systems decrease their function. The systemic changes that occur during exercise seem to be driven by the muscles' need for substrates and removal of metabolic waste. Working muscle metabolizes substrates (mostly fatty acids and glucose) to release energy stored in chemical bonds for contraction. The products of muscle metabolism are contraction, heat, CO_2, NH_3/NH_4^+, water, and in some cases, lactate.

Muscle metabolism can increase more than 20-fold in dogs, depending on the intensity of the exercise. Likewise, cardiac output increases proportionally with the workload. Both stroke volume and heart rate increase. Blood is the transport medium that carries oxygen and other substrates to the working muscle and removes by-products such as heat, CO_2 and lactate. Increased function of the respiratory system (both increased rate and depth) supplies more oxygen and disposes of more CO_2. Dogs and other mammals with contractile spleens can increase effective circulating blood volume and hematocrit by expelling red blood cells from the spleen before or during exercise. For example, racing greyhounds increase blood volume as much as 24% before racing, even in the face of a 10% shift of plasma volume to other fluid compartments. Probably as a result of both the plasma shift and splenic contraction, hematocrit can increase as much as 29% (Toll et al, 1995) (**Box 18-4**). Plasma volume decreases during exercise because of hydrostatic and osmotic forces. Increases in blood pressure during exercise cause a shift of fluid from the intravascular space to the interstitial compartment (Harrison et al, 1975). Muscle activity tends to increase intracellular osmotic pressure, encouraging fluid movement from the interstitial to the intracellular spaces (Pivarnik, 1994). The kidneys conserve plasma volume losses during exercise. Decreases in plasma volume that decrease central venous pressure cause renal vasoconstriction and diminish glomerular filtration rate (GFR) (Pivarnik, 1994; Houpt, 1984). Decreasing GFR will normally decrease urine output and thus diminish plasma volume losses. Increases in plasma osmotic concentration that occur during prolonged exercise also stimulate secretion of antidiuretic hormone (ADH), which conserves plasma volume by stimulating production of a more concentrated urine (Pivarnik, 1994; Houpt, 1984).

Exercise affects plasma volume and composition. Loss of fluid to the intracellular compartment increases the concentrations of plasma proteins, electrolytes and all other solutes in the extravascular compartment. Other primary plasma changes that are needed to support increased muscle activity are a direct result of that activity. Glucose concentration may increase or decrease depending on the intensity and duration of exercise. The concentration of free fatty acids increases during prolonged exercise. At very high workloads, the partial pressure of oxygen may fall dramatically. Acidemia is also common with maximum intensity exercise because of anaero-

Box 18-4. Acute Physiologic Changes in Racing Greyhounds.

Because racing greyhounds exercise at a very high intensity, they exhibit very dramatic physical and biochemical changes during and after racing. Packed cell volume (PCV) may increase to 68%, jugular venous pH values may decrease to 6.95 and plasma lactate concentrations may increase to 32 mEq/l (normal 1 to 2 mEq/l). Hyperventilation after a race can result in jugular venous pCO_2 values as low as 14 torr (normal = 40 torr) and rectal temperatures can increase more than 1°C (1.8°F) during a 30-second race. After the race, plasma sodium concentrations may reach 171 mEq/l (an 18 mEq/l increase from rest) and potassium concentrations may increase to 7.8 mEq/l (normal = 4 mEq/l). Plasma protein concentrations also increase after racing, implying a fluid shift out of the plasma compartment.

A study examined the effect of excitement before racing on these variables and quantified the effects of fluid shift on plasma volume, blood volume and PCV before and after racing. Arterial blood samples were obtained at rest, just before and five minutes after a 704-m race to quantify changes in hematologic variables, plasma electrolyte and protein concentrations, osmolality and acid-base variables. Changes in plasma volume were estimated from the change in plasma protein concentration. Immediately before the race, plasma volume decreased by 10% from rest and total circulating red blood cell (RBC) volume increased by 60% attributable to increased RBC numbers rather than size. Increases in blood volume (BV) by 24% and PCV by 29% also were detected before the race. Five minutes after the race, plasma volume was 21% below the resting value and total circulating RBC volume had increased 73% above the resting value, resulting in a 40% increase in PCV. Contraction of the spleen appeared responsible for the increased PCV and BV before the race and maintenance of BV after the race.

Plasma chloride concentration was the same before and after the race, meaning it decreased by the same fraction (22%) as the plasma volume, indicating Cl^- loss from the plasma. Plasma Na^+ content decreased by a smaller fraction (13%), causing Na^+ concentration to increase from 151 mEq/l at rest to 167 mEq/l after the race. Assuming that Na^+ concentration was the same throughout the extracellular fluid, water likely moved into the intracellular compartment. As a consequence of these changes, the inorganic strong ion difference in plasma increased by about 16 mEq/l, which tended to minimize the acid-base disturbance induced by the 33 mEq/l increase in lactate concentration.

These results indicate that the physiologic changes taking effect during strenuous sprint exercise in racing greyhounds enhance blood volume and aid in acid-base homeostasis, both of which are adaptive for this type of exercise.

The Bibliography for **Box 18-4** can be found at www.markmorris.org.

Table 18-6. Caloric cost of running 1 km for dogs of varying size.

Body weight (kg)	Cost of running (kcal) 1 km/kg body weight*	Cost of running 1 km (kcal)**
5	1.77	9
10	1.41	14
15	1.23	19
20	1.13	23
25	1.05	26
30	0.99	30
35	0.94	33
40	0.90	36
45	0.87	39
50	0.84	42
70	0.76	53

*Formula: $Energy_{(kcal)}/BW_{(kg)} = 1.77 \times distance_{(km)} \times BW_{(kg)}^{-0.4} + 1.25 \times BW_{(kg)}^{-0.25}$.
**To convert to kJ, multiply kcal x 4.184.

bic metabolism and accumulation of lactate in the blood.

The important points from the above discussion are: 1) exercise increases metabolism and therefore increases the need for energy, 2) cardiovascular function increases and fluid shifts/losses occur during exercise-adequate water intake is important to support these needs and 3) transient changes also occur in the composition of blood that can influence the interpretation of results from blood samples drawn soon after exercise.

Energy Cost of Running

The energy cost of running depends on body size and distance traveled. **Table 18-6** shows the caloric cost of running 1 km for dogs of various sizes. This table also illustrates an important principle about the mass-specific caloric cost of running as size changes. As body size increases, the efficiency of running increases (i.e., larger animals use fewer kcal/kg to run the same distance). By using the data in **Table 18-6**, it is possible to estimate the energy requirement for a dog of a known size to run a given distance (**Box 18-5**).

PATIENT ASSESSMENT

History

In addition to the normal historical information that is usually obtained about a patient, the following information should be gathered from owners: environmental/housing data, medications, dietary history and exercise type, amount, frequency and performance. Detailed information should be gathered about how the dog is housed, including: indoors or outdoors, size and type of housing, opportunity for spontaneous exercise, type of surfaces, number of dogs housed together and access to food and water. All medications used should be recorded, including drugs used to suppress estrus and drugs used to enhance performance.

The dietary history should include all foods and supplements used. The amount fed, nutrient profile and timing of feeding in relation to exercise should be noted. The amount eaten should also be assessed (i.e., Does the dog have a normal appetite and is it actually consuming a reasonable amount?). In some cases, the composition of the overall diet (food plus supplements) may be complex and individual meals may vary in composition. It is also important to ascertain the duration of a particular feeding plan. Abrupt or frequent changes in food or feeding method may affect performance.

Exercise Type

Functionally, exercise can be divided into three types (**Table 18-1**) based on intensity and duration: 1) sprint-high-intensity physical activity that can be sustained less than two minutes, 2) intermediate-physical activity lasting a few minutes to a few hours and 3) endurance-physical activity that lasts many hours. These definitions are arbitrary and vague, but are useful for assessing and developing feeding plans.

Most canine sprinters are sight hounds, racing greyhounds being the most notable example. Metabolically, weight-pull dogs might also fit into this category. Some racing sled dogs that participate in shorter, high-speed events are referred to as "sprinters." However, they fit better in the intermediate or endurance categories from a metabolic and nutritional standpoint because their events may last several hours. Other breeds that engage in activities such as agility, fly ball and lure coursing also do considerable sprinting. However, because they compete multiple times per day, they too fit better in the intermediate category.

Based on energy needs, most canine athletes participate in intermediate exercise activities. Most of these activities are of low to moderate intensity and last only a few hours. Intensity and duration of exercise vary widely within this category. For example, most guide dogs work at a low level of physical exertion for variable lengths of time throughout the day, whereas a search and rescue dog may work at a much higher level for many consecutive hours. Other dogs at the upper end of the intermediate exercise range can include foxhounds, coonhounds and other hunting dogs in the field. At times, they work at levels that are near the lower end of the energy requirement range for endurance dogs. Dogs that work at a relatively high intensity level for many hours, such as racing sled dogs, have much greater energy requirements and are true endurance athletes.

Exercise amount can be quantified as hours per day or week. Frequency is how often the animal exercises: daily, weekly, weekends only or seasonally. Many hunting dogs only work hard on weekends during hunting season, whereas some livestock dogs may work several hours daily. Canine athletes should be categorized as either "full-time" or "part-time" athletes.

Environmental Influences on Exercise

Ambient temperature and humidity, psychological stress and geography are environmental factors that may influence performance and nutritional needs of working and sporting dogs. Of these, ambient temperature and humidity exert the greatest effect. Hot temperatures result in increased work and water loss (i.e., to excrete metabolic heat and maintain body temperature

Box 18-5. The Energy Cost of Running.

Daily energy requirement (DER) for canine athletes is highly variable and is directly related to the amount of work done in a day. Work for canine athletes is usually running. A racing greyhound that usually only runs a fraction of a mile in a race has a DER very similar to that of a house pet (1.6 to 1.8 x resting energy requirement [RER]). At the other extreme is the sled dog that runs many miles a day pulling a load and has a very high DER (up to 11 x RER). Understanding the energy cost of running and being able to quantify it in kcal is central to the correct feeding of canine athletes.

The following discussion and calculations are based on experimental data and on running on a flat surface. However, these data show good agreement with data from food consumption records. These calculations are essential for assessing feeding methods (food dose) and making feeding recommendations for canine athletes.

RUNNING

Running is the predominant type of work done by canine athletes. Force generation in the muscle is transmitted through the skeleton to move the dog's mass through a distance. The physics and biomechanics of running are complicated and are described elsewhere. The rate of energy use (power) is proportional to running speed. However, the amount of energy used to cover a given distance is independent of velocity. For running on a flat surface, energy use is a function of body size and distance. One study described the effect of size on the energy cost of running for a variety of mammals; the study used an equation to relate VO_2 to velocity and body weight. The following equation, which was derived from the research equation, relates the energy cost of running to body weight and distance, assuming an energy yield of 4.8 kcal (20.1 kJ)/l of oxygen consumed.

$ERR = 1.77d \times BW^{-0.40} + 1.25BW^{-0.25}$

Where ERR is the energy requirement for running in kcal/kg, d is distance in km, and BW is body weight in kg. Larger animals have a biomechanical advantage resulting in greater efficiency of running and lower mass specific cost of running (kcal/kg) for a given distance. The negative exponents in the equation make calculations difficult. Therefore, **Table 18-6** summarizes the caloric cost of running for dogs of various sizes.

RUNNING WITH WEIGHTS

The caloric cost of running with weights is the sum of the cost of running without added weight and the incremental cost of carrying that weight. When carrying added weight, VO_2 increases the same percentage as gross weight. In other words, the percentage increase in the cost of running is equal to the percentage increase in gross weight. This is not the same as simply increasing the dog's size. Efficiency of running changes with body size whereas simply adding weight increases workload without affecting efficiency (increased gross weight with no change in body size). The total cost of running (ERR_{tot}) is calculated by adding the cost of running (ERR) and the incremental cost of running with added weight (ERR_{incr}). The incremental cost of running is the product of ERR and the percent increase in gross weight.

$ERR_{incr} = ERR \times \%$ increase in gross weight

$ERR_{tot} = ERR + ERR_{incr}$ or

$ERR_{tot} = ERR \times$ gross weight $\div$ body weight

Clinical Example

What is the caloric requirement of 30-kg dog carrying a 3-kg pack on a 15-mile (25-km) hike with its owner? The energy requirement of running for a 30-kg dog is 30 kcal/km (**Table 18-6**) or 750 kcal for 25 km. The incremental energy required for carrying the 3-kg pack is 750 kcal x 3 kg ÷ 30 kg or 75 kcal. The total energy required for exercise is 750 kcal + 75 kcal or 825 kcal. The DER for an average dog this size is 1.6 x RER or 1,435 kcal/day. With the added activity of carrying extra weight, the DER becomes 2,260 kcal/day (2.5 x RER). To convert to kJ, multiply kcal x 4.184.

PULLING WEIGHT

The kinematics of running and center of mass seem to be unaffected with added weight, at least up to 30% of body weight (i.e., the biomechanics do not change with added weight). This finding is unlikely to be true for dogs pulling weight such as sleds. However, it seems reasonable to assume that the cost of pulling a weight on a flat surface is similar to that of carrying the same weight. When applied to sled dogs, the calculations used above agree well with food record data. The incremental cost of running for a sled dog is based on the fraction of sled weight pulled by that dog.

Clinical Example

What is the caloric requirement for a 25-kg racing-sled dog that runs 167 km (100 miles) per day pulling a sled and driver with a combined weight of 180 kg in a team of 12 dogs? The cost of running (ERR) for this 25-kg dog is 4,342 kcal, based on an efficiency of a 25-kg dog of 26 kcal/km (**Table 18-6**) and a distance of 167 km. Assuming all dogs pull equally, the weight pulled by this dog is 15 kg (total sled weight ÷ number of dogs) or 60% of the dog's body weight. The incremental cost of running (ERR_{incr}) is 60% of ERR or 2,605 kcal. The total cost of running (ERR_{tot}) for this dog is 6,947 kcal. Note that RER for a 25-kg dog is 783 kcal (3.28 MJ). The energy needed for exercise is almost 9 x RER. The DER for this dog is 10 x RER, assuming no additional energy is needed for thermogenesis. To convert to kJ, multiply kcal x 4.184.

The Bibliography for **Box 18-5** can be found at www.markmorris.org.

Table 18-7. Disorders affecting olfaction in people.*

Disorder	Effect on olfaction
Adrenal cortical insufficiency	Increased detection
Allergic rhinitis	Absent or diminished
Bronchial asthma	Absent or diminished
Chronic kidney failure	Absent or diminished
Cobalamin deficiency	Absent or diminished
Cushing's syndrome	Absent or diminished
Diabetes mellitus	Absent or diminished
Head trauma	Absent or diminished
Hepatic cirrhosis	Absent or diminished
Hypothyroidism	Absent, diminished or distorted
Nasal polyposis	Absent or diminished
Upper respiratory infections	Absent, diminished or distorted
Viral hepatitis (acute)	Absent, diminished or distorted

*Many of these diseases would also be expected to cause similar problems in dogs. Adapted from: Schiffman SS. Taste and smell in disease. New England Journal of Medicine 1983; 308: 1275-1279.

Table 18-8. Drugs that can cause changes in the sense of smell in dogs and people.*

Drug	Effect on olfaction
Amiodarone	Abnormal sense of smell reported in 1 to 3% of human patients
Amlodipine	Disturbance of smell reported rarely in human patients; resolves after drug withdrawal
Bromocriptine	Olfactory hallucination in 9% of human patients receiving 0.5 to 5 mg/day
Cimetidine	Decrease in olfactory acuity in human patients; reported rarely
Dexamethasone	Reduced olfactory acuity in dogs after only one week
Doxycycline	Loss or distortion of sense of smell in a small number of human patients
Nifedipine	Disturbance of sense of smell in human patients; rare and symptoms resolve after drug withdrawal
Phenylephrine	Decreased ability to smell in 1% of human patients

*Adapted from: Bleasel AF, McLeod JG, Brown ML. Anosmia after doxycycline use. Medical Journal of Australia 1990; 152: 440. Ezeh PI, Myers LJ, Hanrahan LA, et al. Effects of steroids on olfactory function of the dog. Physiology and Behavior 1992; 51: 1183-1187. Henkin RL. Drug induced taste and smell disorders: Incidence, mechanisms and management related primarily to treatment of sensory receptor dysfunction. Drug Safety 1994; 11: 318-377. Levenson JL, Kennedy K. Dysosmia, dysgeusia and nifedipine. Annals of Internal Medicine 1985; 1102: 135-136. Product Information: Amiodarone, 2004.

homeostasis). High humidity impairs evaporative cooling thus adding to the work of heat excretion. Cold temperatures without exercise increase the energy requirement for thermogenesis. For working dogs, cold environmental temperatures aid in heat dissipation during exercise. Excitement or stress associated with some activities increases body temperature and respiration, leading to greater requirements for energy, water and perhaps electrolytes. Stress may also negatively affect food intake. Geographic factors such as high elevation, changing elevation (running up and down hills), bodies of water (swimming) and the presence of sand or tall grass underfoot can increase workload. These factors are important to consider for their potential effects on exercise and olfactory performance. Dogs that are out of breath and are panting excessively have reduced ability to detect scent (Gazit and Terkel, 2002).

Physical Examination

During the physical examination, the veterinarian should evaluate the dog's general health, musculoskeletal soundness, hydration, upper respiratory function, cardiopulmonary function and body condition. A complete physical examination is crucial because disease affecting any body system can impair performance. For example, severe periodontal disease can cause sufficient pain to affect food intake, thus causing a retriever to retrieve poorly or a greyhound to run poorly. Likewise any injury or deterioration of the musculoskeletal system affects performance. All major muscle groups and joints should be palpated and moved through a complete range of motion during the routine physical examination of canine athletes.

Certain infectious, traumatic, endocrine and metabolic diseases can affect olfaction. **Table 18-7** summarizes diseases that modify olfaction in people. Many of these diseases would be expected to cause similar problems in dogs. For example, viral upper respiratory infections (e.g., canine distemper), including intranasal inoculation with modified-live virus distemper vaccine will cause dysosmia (Myers, 1990). In a survey of field trial participants requesting information about the prevalence of anosmia in their hunting dogs, 85% of owners reported that they currently owned or had owned a dog with some loss of its sense of smell (Holloway, 1961). In another report, only 40% of canine patients presenting with complaints of dysosmia actually had dysosmia. In the remaining 60%, other disorders were interfering with the dogs' ability to hunt, including one dog with hip dysplasia (Myers, 1990).

Drugs can also negatively affect olfaction (**Table 18-8**). For example, corticosteroids reduce olfaction in dogs. The combination of hydrocortisone plus desoxycorticosterone acetate resulted in a reduction of olfactory acuity after 18 days of administration. Dexamethasone administration reduced olfactory acuity in dogs after only one week (Ezeh et al, 1992). These results are not surprising because Cushing's disease results in reduced olfactory acuity and adrenal cortical insufficiency results in increased olfaction (**Table 18-7**). Many hunting dogs receive corticosteroid therapy for skin or musculoskeletal disorders. On the other hand, zinc supplementation is effective in some olfactory disorders (Henkin et al, 1999). In lieu of zinc deficiency, supplemental zinc is not warranted and could be toxic when given at high levels (NRC, 2006).

Cardiopulmonary function is best assessed during routine physical examination by thorough auscultation of the heart and lung fields in a quiet environment. Energy balance can be evaluated by body condition scoring. The body condition score (BCS) is an indication of fat mass. If dietary energy intake is less than energy needs, fat mass declines and BCS decreases. Conversely, if intake exceeds requirement, fat mass and BCS increase. Chapter 1 describes body condition scoring in detail. A BCS of 2.5/5 to 3.5/5 is normal for most pets and for many canine athletes. However, a much leaner body composition is desirable for some canine athletes (e.g., racing greyhounds and sled dogs). Even small excesses of body fat may represent an unnecessary handicap for racing dogs.

The ability of any athlete to excel at a given event depends on that athlete's physical and metabolic characteristics, level of training and drive or desire. Some dogs are not well suited to some activities. Greyhounds make poor sled dogs and sled dogs make poor retrievers. Assessing how well an individual is suited to a particular type of exercise is partly common sense and partly experience; the fine points may take years of careful observation.

It is possible, however, to make some generalizations about characteristics that favor athletic performance. Sprinters tend to be very lean and fine-boned. A study comparing racing greyhounds to other breeds of dogs noted that as a percent of total body mass, greyhounds have more muscle (58% of body mass), the same amount of bone and less fat than other breeds (Gunn, 1978). Maximal muscle mass with no extra weight in the form of fat or excess bone is an obvious advantage for a sprinter. These characteristics benefit greyhounds in oval track racing. Different body types allow other breeds to perform well in various sprint sports. The smaller body of whippets allows for higher performance in the tight turns of lure coursing fields. The body conformation of Border collies allows for high levels of performance in agility competition and herding livestock. Endurance athletes may require more body fat to meet energy needs during long trips.

Laboratory and Other Clinical Information

Laboratory tests are not usually required for the routine assessment of healthy dogs. However, a few factors should be kept in mind when performing laboratory tests. Laboratory tests should address the two major factors of activity or work: anticipation to work and work itself. Anticipation to perform transiently affects the metabolism of dogs bred and trained for specific activities. Exercise can cause transient changes in blood and serum parameters. Concentrations of blood-borne substrates such as glucose and fatty acids may increase or decrease in relation to exercise. Total protein and electrolyte concentrations may increase simply due to fluid shift. As discussed above, contraction of the spleen and fluid shifts may dramatically increase packed cell volume. Lactate may accumulate in the plasma and blood pH may decrease with very intense exercise.

Excitement and conditioning of dogs bred and trained for working and sporting activities produce metabolic states that need to be addressed when performing nutritional studies (Gillette et al, 2006). Anticipation can initiate metabolic changes that result in exercise-related disease processes. An example is exercise-induced collapse in Labrador retrievers, a two-part problem in which event anticipation leads to medical problems.

Changes related to normal exercise physiology may be present to variable degrees up to two hours following exercise. Persistence of these changes may indicate a problem and should be investigated further. Small, persistent increases in concentration of the muscle isoenzyme of creatine phosphokinase (CPK) may occur in response to continuous exercise training. However, grossly elevated values indicate major muscle injury or rhabdomyolysis.

Key Nutritional Factors

The key nutritional factors for foods for working and sporting dogs are summarized in **Table 18-9**. The following section discusses the bases for these key nutritional factors and their recommended levels in foods.

Water

Water is arguably the most essential of all nutrients. It is the solvent for nearly all biologic solutes and a transport medium for nutrients, wastes and heat. Water also absorbs physical shock and lubricates various internal and external body surfaces. Approximately two-thirds of the body's weight is composed of water (Pivarnik, 1994; Houpt, 1984; Swenson, 1984). Total body water is divided into four major compartments. Approximately 62 to 64% of water is located within cells, 22% within interstitial spaces and 7% within the intravascular space in plasma (Wolter, 1985; Ivy et al, 1988). The remaining 7% is present as transcellular fluids such as vitreous and aqueous humor, cerebral spinal fluid, joint fluid and digestive secretions (Pivarnik, 1994; Houpt, 1984). Osmotic, oncotic and hydrostatic pressures as well as the permeability characteristics of individual membranes direct fluid balance between compartments. Dietary water intake and metabolic water production (10 to 16 ml/100 kcal and 3 to 4 ml/g glycogen) on one hand and evaporative, urinary and fecal losses on the other maintain total body water balance (Pivarnik, 1994; Houpt, 1984).

The fluid content of individual tissues and compartments changes with the onset of muscular activity. Cardiac output, partially a function of plasma volume, increases during exercise to meet the muscle's heightened demand for nutrient delivery and waste removal. The increase in blood flow also helps dissipate the heat produced by working muscles. Only about 20 to 30% of the energy consumed within muscle cells during exercise produces work; the remaining 70 to 80% is converted into heat. This is about the same efficiency as a gasoline engine (Serway, 1984). This heat must be dissipated to prevent performance impairments and perhaps life-threatening increases in body temperature (Pivarnik, 1994; Kozlowski et al, 1985; Kruk et al, 1985).

During prolonged periods of exercise in warm and humid environments, heat dissipation leads to a decrease in total body water and plasma volume. Approximately 60% of the heat dissipated during exercise is lost through fluid evaporation from the upper respiratory tract (Young et al, 1959). Water requirements essentially double in dogs when the ambient temperature reaches 45°C (113°F) (NRC, 2006). Exercise in very cold, dry environments also increases evaporative fluid losses. Significant fluid loss during exercise may impair performance. Even mild dehydration can limit exercise performance (Swenson, 1984) and probably negatively affects olfactory performance. Several studies indicate that hydration status is the single most impor-

Table 18-9. Key nutritional factors for foods for working and sporting dogs.

Factors	Sprint activity	Intermediate activity (low/moderate duration and frequency)	Intermediate activity (high duration and frequency)	Endurance activity
Water	Unlimited access except just before a race	Unlimited access	Unlimited access	Unlimited access
Energy density	Use food with 3.5 to 4.0 kcal ME/g DM	Use food with 4.0 to 5.0 kcal ME/g DM	Use food with 4.5 to 5.5 kcal ME/g DM	Use food with >6.0 kcal ME/g DM
Fat	Use food with 8 to 10% DM fat or 20 to 24% of calories from fat	Use food with 15 to 30% DM fat or 30 to 55% of calories from fat	Use food with 25 to 40% DM fat or 45 to 65% of calories from fat	Use food with >50% DM fat or >75% of calories from fat
Unsaturated fatty acids	-	>60% unsaturated fatty acids to optimize olfaction	>60% unsaturated fatty acids to optimize olfaction	-
Digestible carbohydrate	Use food with 55 to 65% DM NFE or 50 to 60% of calories from NFE	Use food with 30 to 55% DM NFE or 20 to 50% of calories from NFE	Use food with 30 to 35% DM NFE or 15 to 30% of calories from NFE	Use food with <15% DM NFE or <10% of calories from NFE
Protein	Use food with 22 to 28% DM protein or 20 to 25% of kcal (ME) from protein	Use food with 22 to 32% DM protein or 20 to 25% of kcal (ME) from protein	Use food with 22 to 32% DM protein or 18 to 25% of kcal (ME) from protein	Use food with 28 to 34% DM protein or 18 to 22% of kcal (ME) from protein
Digestibility	DM digestibility >80%	DM digestibility >80%	DM digestibility >80%	DM digestibility >80%
Antioxidants				
Vitamin E	≥500 IU vitamin E/kg food (DM)	≥500 IU vitamin E/kg food (DM)	≥500 IU vitamin E/kg food (DM)	≥500 IU vitamin E/kg food (DM)
Vitamin C	150 to 250 mg vitamin C/kg food (DM)	150 to 250 mg vitamin C/kg food (DM)	150 to 250 mg vitamin C/kg food (DM)	150 to 250 mg vitamin C/kg food (DM)
Selenium	0.5 to 1.3 mg/kg food (DM)	0.5 to 1.3 mg/kg food (DM)	0.5 to 1.3 mg/kg food (DM)	0.5 to 1.3 mg/kg food (DM)

Key: ME = metabolizable energy, DM = dry matter, NFE = nitrogen-free extract (represents digestible [soluble] carbohydrate fraction).

tant determinant of endurance capacity (Kronfeld and Downey, 1981; Downey et al, 1980; Young et al, 1959a).

There is currently much debate over the best strategy to maintain fluid and electrolyte balance in working dogs. Under most exercise situations, these athletes lose more water than electrolytes, causing a decrease in plasma volume and an increase in plasma osmolality. Efforts to return electrolyte values to normal should thus concentrate on water replacement. Ideally, fresh clean water should be available at all times. There are occasions when such accommodations cannot be made due to the nature of the athletic event or the environmental conditions. Under these conditions, water should be offered at least three times a day and more often if possible. "Baiting" the water with a flavor enhancer such as meat juice can encourage water intake.

Energy

Providing the right amount of energy from the right sources is central to feeding working and sporting dogs. Providing the correct amount of energy is determined by the food's energy density and the amount fed. The energy density can limit the maximum possible caloric intake and a food's overall digestibility. Additionally, the preferred source of energy (fat vs. carbohydrate) depends on exercise type. Energy for exercise comes from three nutrients: fat, carbohydrate and protein. Fats and carbohydrates are the primary energy substrates for exercise. Fat is the preferred substrate for longer duration exercise, whereas sprinters depend more on carbohydrate. Under most conditions, the energy contribution of protein during exercise is small (Hickson and Wolinsky, 1989); however, its contribution will increase in fatigued dogs.

Energy required depends on the intensity, duration and frequency of exercise. The amount of energy required for exercise depends on total work done (intensity x duration x frequency). The preferred source of energy depends mostly on intensity. Greyhounds, even though they work at a very high intensity, have relatively low energy requirements because the duration of their events is so short and frequency is usually only a few times each week. Generally, 1.6 to 2 x resting energy requirement (RER) is adequate for most sprint athletes. Note the daily energy requirement (DER) for most pet dogs is 1.2 to 1.4 x RER. Most pet dogs are minimally active.

For activities of very short duration and high intensity, the energy substrate source is the main determinant of the nutrient profile. Foods for sprint athletes should be high in carbohydrate and lower in fat, with a resulting energy density lower than that of many dog foods. Intensity, duration and frequency of exercise are variable for intermediate athletes; therefore, the energy requirement is highly variable. DER for these athletes ranges from 2 to 5 x RER. Foods with a higher fat content are typically fed to provide adequate dietary energy density. Endurance athletes require more than 5 x RER. For activities of long duration, providing adequate energy is a major determinant in the choice of a nutrient profile for exercising dogs. Foods that are very high in fat are required.

Table 18-9 lists target energy density levels for foods for working and sporting dogs, depending on the type, level and duration of physical activity.

Fat

Fat provides approximately 8.5 kcal (36 kJ) of metabolizable energy (ME) per gram of dry matter (DM) or more than twice the amount provided by protein and carbohydrate. Because of these differences in caloric density, the only practical means of significantly increasing the energy density of a food is to increase its fat concentration. Reasonable increases in fat usually also increase palatability. Energy density and palatability make dietary fat levels an important consideration in the formulation of foods for working and sporting dogs. Increasing dietary fat generally also increases a food's digestibility because fat tends to be more digestible than protein or carbohydrate. Also, when a greater quantity of a lower energy density food is eaten in an attempt to provide adequate calories, there is a more rapid rate of passage through the gastrointestinal (GI) tract, further reducing digestibility and energy intake (Davenport et al, 2001).

Ingesting adequate calories to meet daily energy expenditure is often a serious challenge for working dogs. In extreme cases, sled dogs in long-distance races expend from 6,000 to 10,000 kcal/day (25 to 42 MJ/day), in which case DM intake becomes a performance-limiting factor. Because the total daily DM intake is limited to about 3.5% of body weight,[c] the energy density of a food should be maximized. Under these circumstances, each nonessential gram of protein and carbohydrate ingested potentially robs the dog of 5 kcal (21 kJ). The calorie deficit is paid through mobilization of body fat stores. Overreliance on these depots may lead to catabolism of more functionally crucial energy sources, such as muscle and plasma proteins. In addition to its role as an energy store, adipose tissue also functions as an insulator. Excessive adipose depletion may increase a dog's cost of maintaining its body temperature, especially at rest in cold environments.

Even under the less severe conditions of intermediate exercise, increased dietary fat levels provide needed energy and other valuable benefits. Fatigue and dehydration may decrease appetite. Increasing dietary fat concentration increases energy intake and encourages stressed dogs to ingest more food because the higher fat content improves palatability.

Feeding high levels of fat can positively affect endurance. Training may elevate the carbohydrate threshold, thus increasing the proportion of energy supplied by free fatty acid (FFA) oxidation at all but the highest intensities of exercise. Increasing dietary fat concentration may augment this process by enhancing FFA availability (Kronfeld and Downey, 1981; Kronfeld et al, 1977; Reynolds et al, 1994). Working dogs fed high-fat foods have higher circulating levels of FFA at rest and respond to exercise stimuli by releasing more FFA than those fed isocaloric amounts of a high-carbohydrate food (Kronfeld and Downey, 1981; Kronfeld et al, 1977; Young et al, 1962). This difference in FFA availability may be related to the decreased resting plasma concentration of insulin in animals fed high-fat foods, and the induction of key lipolytic enzymes.

Table 18-10. Effect of nutrient profile on stamina.*

	Food A	Food B	Food C
Nutrient (DM)			
Energy density (kcal/g)	4.7	5.9	6.0
Fat (%)	12.8	28.3	33.1
Protein (%)	22.9	48.7	30.5
Performance			
Time (minutes)	103.7	136.1	137.6
Distance (miles)	15.5	20.4	20.6

Key: DM = dry matter, Food A = grocery brand dry food, Food B = grocery brand moist food, Food C = specialty brand dry food.
*Adapted from: Downey RL, Kronfeld DS, Banta CA. Diet of beagles affects stamina. Journal of the American Animal Hospital Association 1980; 6: 273-277.

The effect of food on insulin levels has also been demonstrated in well-trained human athletes (Gleeson et al, 1986; Martin et al, 1978; Coyle et al, 1985; Yoshida, 1986; Brouns et al, 1989). People eating high-fat foods had significantly lower resting insulin concentrations than those eating high-carbohydrate foods (Maughan et al, 1987). Insulin decreases the release of FFA from peripheral adipose stores through its inhibitory effects on the activity of hormone-sensitive lipase. Dogs rely more heavily on FFA for energy generation at all exercise intensities than people do; therefore, the effect of food on resting insulin levels is a matter of even greater concern for working and sporting dogs (Reynolds et al, 1997). Increased dietary fat (from 25 to 65% of kcal) increases VO_2 max and the maximal rate of fat oxidation by 20 to 30% in well-trained dogs (Reynolds et al, 1995). These increases were associated with a 25 to 30% increase in mitochondrial volume, possibly accounting for the increased oxidative capacity. Protein and total caloric intake were identical between groups. Also, event anticipation can suppress insulin concentrations before and during an event activity (Gillette et al, 2006).

The relationship between fat intake and canine endurance is well established. The time to exhaustion for well-conditioned beagles running on a treadmill was directly related to energy density, digestibility and digestible fat intake (**Table 18-10**) (Downey et al, 1980). Practical applications of this concept are evident in the performance foods currently fed to many successful working and sporting dogs. As the duration of the event performed by a dog increases, so should the dietary fat intake.

Dogs can tolerate high levels of dietary fat if fat is gradually introduced and an adequate intake of non-fat nutrients is maintained. Steatorrhea and a decrease in food palatability are indicators that the fat content of a food has exceeded a dog's fat tolerance. Under conditions of extreme training, sled dogs may ingest up to 60% of their energy as fat. During ultra-endurance events, such as the Iditarod or the Yukon Quest, fat intake may compose 80% of the calories ingested.[d] This "super fat loading" should be attempted only during the most strenuous periods of such events, when it is difficult or impossible for dogs to ingest as much energy as they are expending.

Anemia has been associated with impaired performance in dog teams fed very high-fat foods (i.e., 80% kcal from fat) for prolonged periods (i.e., weeks to months) (Reynolds, 1997).

Table 18-11. Saturated and unsaturated fatty acid content of selected fat sources used in commercial pet foods.*

Ingredient	Saturated fatty acids (%)	Unsaturated fatty acids (%)**
Beef tallow	47.4	52.6
Choice white grease	38.7	61.3
Lard (swine fat)	28.6	71.4
Poultry fat	28.6	71.4
Fish oil (menhaden)	20.2	79.8
Corn oil	12.7	87.3
Flax oil (linseed)	9.4	90.6
Safflower oil	8.6	91.4
Soybean oil	14.2	85.8
Sunflower oil	8.9	91.1

*National Research Council. Nutrient Requirements of Dogs and Cats. Washington, DC: National Academies Press, 2006; 328-329.
**Includes both polyunsaturated and monounsaturated fatty acids; derived by subtracting % saturated fatty acid values from 100.

However, during several long expeditions (including the trans-Antarctica expedition of 1991), Will Steger observed no decrement of performance when dogs were fed food containing 80% fat kcal and 17% protein kcal.[e] Other factors such as environment, training and dietary intake of non-fat nutrients (e.g., protein) may play a role in the development of anemia.

The type of fat used must also be considered in the formulation of foods for working and sporting dogs. Essential fatty acids should make up at least 2% of the DM of a food (Chapter 5). The remainder of the fat may come from any of a number of plant or animal sources. Many greyhound and sled-dog trainers believe that dogs run "hotter" when fed saturated rather than unsaturated fats. No objective evidence supports this theory. However, there is evidence that foods containing high levels of saturated fat (60% of the fatty acids saturated) will reduce olfactory performance in dogs, particularly if they are not physically conditioned (Altom et al, 2003). This may be due to effects of dietary fatty acids on brain function. Membrane composition of the central nervous system can be affected by the dietary fat source. Rats fed food high in saturated fat (beef tallow) showed a deficiency of 18:3 fatty acids in the brain vs. rats fed a food with unsaturated fat (corn oil) (MacDonald et al, 1996). The fatty acid composition of membrane phospholipids dictates membrane fluidity and permeability (Coutre and Hulbert, 1995). Changes in membrane fluidity can affect the functions of membrane enzymes. Sodium-potassium ATPase is one of several major components of the pathway that mediates molecular events of olfaction. Dietary fat can affect brain synaptic membrane sodium-potassium ATPase activity (Gerbi et al, 1994; Altom et al, 2003). In the study above that noted a decrease in olfaction when 60% of the fatty acids were saturated (37% unsaturated), another group of dogs fed a food with only 24.5% saturated fatty acids (72% unsaturated) maintained olfactory performance over time, even if the dogs were not physically fit. Thus, higher levels of unsaturated fatty acids in a food appear to protect against decline of olfaction over time in untrained dogs. Anecdotal reports support the use of supplemental unsaturated fatty acids (corn oil) to improve olfactory performance.[f] If corn oil is added to dry commercial foods to increase the fat and/or unsaturated fatty acid content, 1 tablespoon of corn oil for approximately each pound of dry food will increase the overall fat content by about three percentage points. For example, if two tablespoons of corn oil are added to one pound of dry food that contains 20% fat, the resultant mixture of food and corn oil will contain about 26% fat and would have increased levels of unsaturated fatty acids. However, if commercial foods are properly formulated for active dogs, supplementation with fat sources such as corn oil should not be necessary.

Alternatively, large intakes of unsaturated fatty acids may increase the risk of oxidative damage to membrane lipids (NRC, 1985; Van Vleet, 1980), which can severely damage cell membrane function with potentially disastrous implications for working dogs. Relative to their sedentary colleagues, dogs participating in endurance events are at particular risk for developing oxidative membrane damage because they consume more fat and metabolize more oxygen per unit body weight per day. Feeding only well-stabilized (preserved) unsaturated fatty acids reduces the risk of oxidative damage to tissues. Increasing intake of vitamins E and C and selenium to bolster cellular antioxidant capacity has also been recommended (Kronfeld, 1989) and is discussed below in the Antioxidants section.

Unsaturated fatty acids are an important component in a well-balanced food. As mentioned above, they are largely responsible for membrane fluidity, a property critical to the function of all cell membranes. Unsaturated fatty acids are also required for biosynthesis of many regulatory molecules and maintenance of epidermal integrity. All essential fatty acids are unsaturated. In weighing the biologic significance of unsaturated fatty acids with the possible health risks associated with their overconsumption, balanced amounts of saturated and unsaturated fatty acids may be the best solution. **Table 18-11** shows the percentage of saturated and unsaturated fatty acids in various ingredients used as fat sources for pet foods. For commercial foods, product labels will include ingredient listings in descending order of predominance by weight. By reviewing a product's ingredient list, one can obtain an approximate idea of the levels of saturated and unsaturated fatty acids in the food. If additional unsaturated fat sources are added to a commercial food, adequate vitamin E should be provided. (See Antioxidants discussion, below.)

Certain fatty acids are purported to have ergogenic effects. The omega-3 (n-3) family of fatty acids contained in fish oils has been reported to enhance oxygen uptake (Brilla and Landerholm, 1990). The results reported in this study lacked statistical significance, prompting the need for further investigations. Medium-chain triglyceride (MCT) supplementation reportedly enhances performance (Grandjean and Paragon, 1987; Wolter, 1985). These intermediate length (eight to 12 carbon) fatty acids do not rely on L-carnitine for transport across the inner mitochondrial membrane. Because they bypass this rate-limiting step in fatty acid oxidation, some investigators have theorized that increasing the dietary MCT level may increase the maximal rate of fatty acid oxidation. A study of the effects of MCT supplementation failed to demonstrate an increase in oxygen consumption or FFA oxidation in human athletes (Brilla and Landerholm, 1990). Further research is needed to determine the consequences of MCT supplementation in working dogs.

Sprint exercise depends almost entirely on carbohydrate; therefore, the fat requirement for sprinters is not different than that for other dogs. Total fat content should be 8 to 10% of DM or 20 to 24% of kcal. Dietary fat needs for intermediate athletes are directly proportional to the amount of work done. Part-time athletes during off-season should be fed as other dogs (Chapter 13). Dietary fat content should be increased as the amount of work increases: 15 to 30% DM (30 to 55% fat kcal) for moderate amounts of work and 25 to 40% DM (45 to 65% fat kcal) for large amounts of work. Endurance athletes require very high levels of dietary fat to meet their energy needs, in excess of 50% DM and 75% fat kcal. A balance of saturated and unsaturated fat sources is recommended. **Table 18-9** summarizes recommendations for fat and other nutrients by exercise type. Currently, it is recommended that working and sporting dogs not be fed high-fat meals immediately before or during intense exercise (NRC, 2006).

Digestible Carbohydrate

Provided sufficient gluconeogenic precursors are available, dogs have no dietary requirement for carbohydrates except during gestation and neonatal development (Chapters 15 and 16). Dogs are quite capable of maintaining normal blood glucose and tissue glycogen levels when fed carbohydrate-free foods (Kronfeld et al, 1977; Hammel et al, 1977). Compared with people, dogs are less likely to develop ketosis during long periods of exercise or starvation (Kronfeld et al, 1977; Crandall, 1941). Despite these facts, dogs have great ability to use carbohydrate.

Canine athletes requiring less than twice maintenance levels of energy may derive a significant portion of their kcal from carbohydrate sources. This is an advantage for high-power athletes, such as racing greyhounds that are highly dependent on anaerobic metabolism. Because carbohydrates contain only about 3.5 kcal (15 kJ) ME/g, they cannot be used to increase the energy density of a food. This limitation is an important consideration for endurance athletes that have difficulty ingesting a sufficient volume of food to meet caloric requirements.

Racing greyhounds are highly dependent on carbohydrate stored in muscles as glycogen because they must mobilize energy quickly to run a race. Studies have shown that greyhounds use significant amounts of glycogen during a race; up to 70% of available glycogen in some muscles for an 800-meter race (Dobson et al, 1988; Rose and Bloomberg, 1989). Furthermore, evidence suggests that the rate of glycogen use (and, therefore, energy production) depends on the concentration of glycogen in muscle (Richter and Glabo, 1986). It is logical; therefore, to hypothesize that increasing muscle glycogen will enhance sprint performance. Muscle glycogen content can be increased through a combination of dietary and training protocol changes in some animals (rats, people [Conlee, 1987], horses [Oldham et al, 1989]); these techniques have been used as a means of improving endurance performance (Conlee, 1987; Bergstrom et al, 1967). The possible benefits of increased muscle glycogen on sprint exercise performance of dogs have not been established. It is also unclear if continuous feeding of high-carbohydrate foods to dogs will increase muscle glycogen. For sled dogs, it may be more advantageous to promote glycogen sparing by feeding a high-fat food than increasing pre-exercise glycogen concentrations via ingestion of a high-carbohydrate food. Studies have demonstrated an increase in the amount of muscle glycogen stored and a greater rate of glycogen use in sled dogs fed a high-carbohydrate food (65% of kcal) (Reynolds et al, 1997). When isocaloric amounts of a high-fat food were fed, glycogen was used at a much slower rate, promoting better endurance at all submaximal exercise intensities. In sled dogs, carbohydrate sparing appears to be a more successful strategy than carbohydrate loading.

Two studies have reported the effect of different fat and carbohydrate levels on race time in greyhounds (Toll et al, 1992; Hill et al, 1996). Both studies used seven adult racing greyhounds in a crossover design and used race time in a 5/16-mile (502-m) race as the measure of performance. Investigators in the first study used two foods similar in composition except for fat and carbohydrate content (Toll et al, 1992). The high-carbohydrate food contained 16% DM fat (34% of kcal) and 52% DM carbohydrate (44% of kcal), whereas the low-carbohydrate food contained 56% fat (80% of kcal) and 8% carbohydrate (5% of kcal). No significant difference in race times between the two food groups was detected for the first four weekly measurements. At the end of the fifth week, the dogs fed the high-carbohydrate food ran faster (33.08 ± 0.05 sec) than when they were fed the low-carbohydrate food (33.34 ± 0.05 sec). The results were statistically significant ($p < 0.05$). In this study, dogs performed better when fed a high-carbohydrate/low-fat food than they did when fed a high-fat/low-carbohydrate food. The delay before differences occurred may indicate that some time may be required to adapt to a new food before performance is affected.

The second study compared results of feeding a "high-fat" food (38.2% energy from fat, 23% energy from protein, 38.8% energy from carbohydrate) with those of feeding a "moderate-fat" food (27.6% energy from fat, 20.4% energy from protein, 52.1% energy from carbohydrate) (Hill et al, 1996). Dogs were fed each food for eight weeks. Race times were faster when the dogs were fed the high-fat food than when they were fed the medium-fat food (32.9 ± 0.7 vs. 33.1 ± 0.6 sec at $\alpha .= 0.1$, $\beta .= 0.2$).

Neither of these studies evaluated a truly high-carbohydrate level (60 to 70% of dietary kcal) as is now recommended for glycogen loading in people (Goodyear et al, 1990). Furthermore, although the results of these two studies are mixed, physiologic principles suggest that carbohydrate supplementation should benefit racing greyhounds.

Even endurance athletes may benefit from a low level of dietary carbohydrate. Studies involving sled dogs fed 0 or 17% of their kcal as carbohydrate showed that dogs were more susceptible to developing "stress" diarrhea when fed foods devoid of carbohydrate (Kronfeld, 1973). There are other advantages associated with feeding carbohydrates to sprint athletes. Because these dogs derive more of their energy for exercise from glucose/glycogen, glycogen depletion may play a role in the onset of fatigue for athletes working at or above their anaerobic threshold (Pate and Brunn, 1989; Miller and Massaro, 1989; Keizer et al, 1986; Issekutz, 1981; Burke and Read, 1987).

Carbohydrate availability to working muscles is a limiting factor for prolonged exercise in people and other species. This finding has led to development of strategies for carbohydrate loading or glycogen super-compensation. The classic method (Åstrand method) uses a combination of exhaustive exercise and low-carbohydrate foods (≤10% kcal from carbohydrate) to deplete muscle glycogen. Glycogen depletion is followed by consumption of high-carbohydrate foods (80 to 90% kcal from carbohydrate) and little activity. This method dramatically increases muscle glycogen in people (Bucci, 1993). An alternative carbohydrate-loading method (Sherman/Costill method) simply requires consumption of 60 to 70% of kcal from carbohydrate consistently over time. In people, this method produces results similar to those achieved by the classic method (Bucci, 1993).

Glycogen loading is probably not as beneficial for canine endurance athletes as continuous feeding of foods with high-fat levels. However, high-power athletes (e.g., racing greyhounds) should benefit from glycogen loading. Because racing greyhounds do not have dramatically increased energy needs and cannot use fatty acids effectively during a race lasting less than 60 seconds, there is no benefit to feeding high levels of fat. Additionally, glycogen stores are rapidly mobilized during racing. In one study, greyhounds running an 800-m race in 48 seconds mobilized 50 to 70% of their glycogen stores in specific running muscles (Dobson et al, 1988).

Studies in people have shown that feeding moderate amounts of carbohydrate (2 g glucose/kg body weight) during a brief postexercise time window permits very rapid rates of glycogen resynthesis (Goodyear et al, 1990; Keizer et al, 1986; Ivy et al, 1988). This period begins about 30 minutes postexercise (Kronfeld, 1973). Glucose administered during this window permits up to four times the rate of glycogen resynthesis supported by the same amount of glucose administered after this two-hour window. The form of the glucose (i.e., polymer or simple sugar) does not seem to affect the rate of glycogen repletion (Keizer et al, 1986). Severely hypertonic solutions should be avoided to prevent excessive osmotic movement of fluid into the gut, which may lead to cramping and GI distress (Williams, 1985; Buskirk and Puhl, 1989). This strategy for glycogen repletion is effective in human athletes and dogs. Glucose solutions (from 1.5 to 3 g glucose/kg body weight) given before, during or after exercise have been shown to minimize the exercise-associated decline in blood glucose, promote more rapid repletion of muscle glycogen postexercise and improve thermoregulation (Kruk et al, 1987; Reynolds et al, 1997; Wakschlage et al, 2002). Although only speculation, resultant improvements in exercise performance and thermoregulation might also protect against a reduction in olfactory performance by precluding excessive panting. The carbohydrates used in foods for canine athletes should be highly digestible to limit fecal bulk. Excessive amounts of undigested carbohydrates reaching the colon may increase water loss via the stool, increase colonic gas production and increase overall fecal bulk. These changes in fecal consistency have been proposed to increase an athlete's risk of developing "stress diarrhea," further increasing fecal water losses (Kronfeld, 1973). Bulky stools have also been associated with rectal bleeding during exercise-induced colonic evacuation (Kronfeld, 1973). Excessive fecal bulk is also extra weight that must be carried by the athlete. One study estimated that 150 g of extra stool generated by a racing-sled dog was equal to a 7-kg handicap for a thoroughbred horse (Kronfeld and Downey, 1981).

Metabolic power or a high rate of ATP generation is required for sprint performance. Consequently, anaerobic metabolism of glucose and glycogen is the dominant energy generation pathway. High-carbohydrate foods should be fed to maximize muscle glycogen. Dietary carbohydrates should compose 50 to 70% of total kcal to maximize muscle glycogen levels (based on research done with people).

The dietary carbohydrate recommendation for intermediate athletes is highly variable, depending on the intensity and duration of work. Dogs that perform relatively long bouts of low to moderate intensity work require more dietary energy (higher fat) and relatively low carbohydrate levels (as low as 15% of kcal). Dogs that perform short bursts of higher intensity work should be fed more carbohydrate, up to 50% of kcal.

Endurance athletes require very little carbohydrate. Endurance rations should contain less than 15% of kcal from carbohydrate to achieve the energy density required for the amount of work done by these dogs. Some carbohydrate and/or soluble fiber should be included in the food to avoid loose stools.

Technically, the total carbohydrate portion of a food includes fiber. The digestible (soluble) carbohydrate portion of total carbohydrate consists of starches and sugars, typically referred to simply as "carbohydrate." The digestible carbohydrate fraction of a food is also called the nitrogen-free extract (NFE). The percent digestible carbohydrate is usually not stated on the guaranteed analysis listing of a commercial product's label. Such information should be available from product literature supplied by the manufacturer (e.g., product "keys," websites, etc.). However, percent digestible carbohydrate can also be estimated from the guaranteed analysis listing by subtracting the percent crude protein, fat, crude fiber and ash (mineral) from 100. If fiber and ash are not listed, assume 3% fiber and 9% ash in dry foods and 1% fiber and 6% ash in moist (canned) foods. Another, perhaps simpler means of estimating digestible carbohydrate content is to check if the protein and fat recommendations in **Table 18-9** are close to what is listed on the guaranteed analysis portion of the label of the food in question, if they are, its digestible carbohydrate content should also be close to what is recommended.

Table 18-9 summarizes carbohydrate recommendations for canine athletes by exercise type.

Soluble fiber and resistant starches may provide some benefit to racing dogs, particularly if they are fed raw meat. Rapid fermentation of oligosaccharides may decrease colonic pH and inhibit clostridial growth (Amtsbert et al, 1989). Fructo-oligosaccharides inhibit cecal colonization by *Salmonella* species in chickens and could conceivably do so in dogs (Baily et al, 1991).

Protein

Dietary protein is used to fulfill structural, biochemical and, to a lesser extent, energy requirements. Work increases the requirement for protein. The magnitude of this increase and the best strategy for meeting it are subjects of much debate in canine performance nutrition.

The work-induced elevation in protein requirement is most pronounced when the intensity and/or duration of exercise performed is rapidly increased above an animal's present level of conditioning. These circumstances are encountered at the onset of a training program, when the duration or intensity of training bouts is increased and especially during performances (Zackin, 1990; Hickson and Wolinsky, 1989). A common example would be when a bird dog that is also a minimally active pet is hunted the first time during hunting season with little or no exercise training. The increase in protein demand is due to combined increases in the rates of tissue protein synthesis and catabolism.

Several anabolic processes contribute to the exercise-induced increment in protein requirement. Protein demand is elevated due to an increase in the synthesis of structural and functional proteins. Training induces synthesis of many enzymes and transport proteins in each of the energy-generating pathways (Nadel, 1985; Williams, 1985; Costill et al, 1979, 1979a). Blood volume also expands during aerobic training (Nadel, 1985; Williams, 1985; Zackin, 1990; Hickson and Wolinsky, 1989). Such expansion necessitates an increase in plasma protein synthesis to maintain oncotic and osmotic balance between plasma and interstitial fluids (Pivarnik, 1994). The increase in hematocrit sometimes observed during endurance conditioning programs may reflect an increase in tissue protein synthesis (Nadel, 1985; Williams, 1985; Kronfeld and Downey, 1981). Anaerobic training regimens may also induce muscle hypertrophy (Hickson and Wolinsky, 1989). Amino acids are used in the formation of new muscle tissue and in the repair of damage that may occur to muscle and connective tissue during intensive conditioning programs. In addition to enhancing the rate of tissue protein synthesis, exercise increases the rate of amino acid catabolism. Amino acids may provide between 5 and 15% of the energy used during exercise, depending on the intensity and duration of the task (Young et al, 1962; Zackin, 1990; Hickson and Wolinsky, 1989). Most of this energy comes from the oxidation of branched-chain amino acids (Miller and Massaro, 1989; Blomstrand et al, 1988). All three amino acids belonging to this group (leucine, isoleucine, valine) are "essential" and thus cannot be synthesized from other amino acids in sufficient quantities to meet requirements. The branched-chain amino acids lost through exercise must be replaced through dietary intake.

The proportion of energy supplied by amino acids may be even greater in underfed athletes and those participating in ultra-endurance events in which there is a high risk for depletion of endogenous carbohydrate stores (Zackin, 1990; Miller and Massaro, 1989). In these instances, gluconeogenesis becomes the major pathway for maintaining blood glucose levels (Zackin, 1990; Miller and Massaro, 1989). Because amino acids are the predominant substrate used by the gluconeogenic pathway, their rate of catabolism is increased whenever this pathway is accelerated (Hickson and Wolinsky, 1989; Cahill et al, 1970).

This concept raises an important point: it is disadvantageous for an athlete to rely heavily on endogenous sources of protein for energy. There are no known labile stores of protein in the canine body. All protein sources serve a structural or functional purpose (Cahill et al, 1970). Interestingly, skeletal muscle is readily mobilized. Overuse of this source would have an obvious negative impact on performance. Because the small pool of circulating amino acids is insufficient to meet the amino acid requirements of the anabolic and catabolic processes described above, dietary protein intake must supply the deficit if nitrogen balance is to be maintained (Zackin, 1990).

For endurance athletes, there may be some disadvantages inherent to exploiting dietary protein sources for energy. Protein has only about 3.5 kcal (15 kJ) ME/g DM. Thus, increasing the proportion of protein in the formulation cannot increase the energy density of a ration. The energy density of the food is one of the major determinants of endurance capacity when working dogs have difficulty ingesting as many kcal as they expend (Downey et al, 1980).

Excessive protein intake may predispose an animal to increased amino acid catabolism because dietary amino acids are not stored in labile protein depots, but are deaminated (Hickson and Wolinsky, 1989). The resulting ketoacids are either oxidized for energy directly or converted into fatty acids and/or glucose and then stored as adipose tissue or glycogen. The urea produced from amino acid breakdown is excreted from the body in urine. In healthy animals, the amount of water lost increases with increased urea production.

An optimal food for a working or sporting dog should contain enough high-quality protein to meet the dog's anabolic requirements and enough non-protein energy nutrients to meet its energy requirements. Such a food encourages the use of ingested protein in synthetic rather than energy-generating processes. As non-protein caloric intake increases, less dietary protein is used for energy and more is available for use in anabolic processes. Energy requirements should be met by fat and carbohydrate, leaving the majority of amino acids available for synthetic purposes. During long-duration exercise, DER may increase several-fold whereas protein requirement increases only a few percent. To meet the energy needs of hard-working dogs, either more food must be consumed (increasing both energy and protein intake equally) or a higher energy, lower protein food must be fed (increasing energy intake more than protein intake). Providing sufficient dietary energy by increasing fat content should limit the use of amino acids for energy production. Because the protein requirement is actually a requirement for available amino acids, the digestibility and essential amino acid content of ingested protein will also determine how efficiently amino acids are incorporated into tissue proteins.

Research attempts that define the optimal dietary protein intake for working dogs have been inconclusive. Several field studies performed on racing-sled dogs in the 1970s and early 1980s found that well-conditioned dogs fed a high-fat, high-protein food maintained higher packed cell volumes and serum albumin concentrations than those fed a relatively high-carbohydrate, low-protein food (Kronfeld et al, 1977; Kronfeld, 1977; Adkins and Kronfeld, 1982). The investigators concluded that the high-fat, high-protein food might offer a performance advantage by maintaining better blood volume and oxygen carrying capacity than the other foods tested. These investigators recommended that 30 to 40% of kcal of a performance ration should come from protein.

Another study examined the effects of feeding isocaloric foods (4.5 kcal [19 kJ] ME/g) containing 16, 24, 32 or 40% of their energy as protein on performance and biochemical parameters (Reynolds et al, 1999). During training and racing, dogs fed only 16% of ME as protein suffered significantly more injuries and had a significant decline in VO_2 max when compared with age-, gender- and ability-matched sled dogs fed 24, 32 or 40% of ME as protein. Additionally in people, long-duration exercise leading to glycogen depletion increases protein requirement more than weight lifting. There were no noticeable differences in performance between the dogs fed 24, 32 or 40% of ME as protein, although the dogs fed 40% of ME as protein maintained a significantly higher packed cell volume and total plasma volume. This study indicated that 16% of ME as protein may be insufficient to meet the needs of extremely hard-working dogs and that such animals should ingest a minimum of 24% of their energy requirement as protein.

Work in greyhounds shows a different response to food protein levels. When raced for 500 m twice/week, dogs ran 0.3 km/hr faster and their hematocrits were higher when fed a lower protein (63 g/1,000 kcal, 24% ME), higher carbohydrate (106 g/1,000 kcal, 43% ME) food vs. a higher protein (96 g/1,000 kcal, 37% ME), lower carbohydrate (75 g/1,000 kcal, 30% ME) food (Hill et al, 2001a). The fat content of the foods was similar. Thus, for sprint athletes, a lower level of food protein appears desirable.

The protein requirement for exercise is only mildly increased (5 to 15%) regardless of exercise type. Protein is used for muscle hypertrophy and muscle maintenance/repair. Furthermore, the branched-chain amino acids can contribute to energy production. Dietary protein should be at least 24% of kcal. Because the energy requirement of some endurance athletes is so high (up to 11 x RER), it may not be feasible to feed even this level of protein and provide adequate kcal. For these dogs, 16% of the ME as protein should be viewed as an absolute minimum. Note that for endurance exercise, energy requirement increases up to 11-fold, whereas protein requirements increase much less (5 to 15%). For a given food, as intake increases to meet energy requirements, protein intake increases proportionally. Because of the disparity between the increase in need for energy and protein for exercise, as total dietary energy requirement increases, the percent of the ME as protein of the food can decrease. **Table 18-9** summarizes protein recommendations by exercise type.

Digestibility

DM digestibility of food is important to canine athletes for two reasons. First, exercise may be limited by a dog's ability to obtain sufficient amounts of nutrients (usually energy). Enhanced digestibility increases the maximum possible delivery of nutrients to tissues. Second, lower digestibility means greater fecal bulk, and therefore a greater handicap. Although increased animal size results in greater running efficiency, increased fecal weight creates a greater energetic cost of running with no benefit. Total DM digestibility of any food for canine athletes should exceed 80% (Downey et al, 1980; Lewis et al, 1987). Foods having a higher energy density are likely to have increased DM digestibility.

Antioxidants

There are at least two questions to consider when discussing antioxidants for working and sporting dogs: 1) do supplemental antioxidants provide a health benefit and 2) do they influence performance.

Exercise is associated with an increase in the rate of oxygen consumption. The extent of the increase depends on the intensity of the exercise. Even normal oxidative metabolism results in the production of highly reactive free radical molecules. Proportionate increases in free radical production appear to accompany exercise-associated increases in oxygen consumption (Hinchcliff et al, 2000). Aerobic, anaerobic and mixed exercise cause varying degrees of free radical production. Besides mitochondrial production of free radicals, such as with endurance exercise, anaerobic and mixed exercise result in ischemia reperfusion, acidosis and catecholamine oxidation that further contribute to oxidative stress. The body's typical adaptive response is increased mobilization of a variety of enzymatic and non-enzymatic antioxidant systems. However, with exercise these innate antioxidant capabilities are oftentimes overwhelmed, which leads to oxidative stress. The consequences of prolonged oxidative stress may contribute to and/or exacerbate a wide variety of degenerative diseases (Chapter 7). In human athletes, unchecked oxidative stress seems to be involved in chronic muscular fatigue and may lead to a condition called "overtraining" (Finaud et al, 2006). It is possible that canine athletes experience a similar phenomenon.

Considerable research into the use of supplemental antioxidants to augment the body's antioxidant capacity during exercise has been done in a variety of species. However, because of the complexity of the associated variables, many of the research results are equivocal making it challenging to apply the knowledge to practice (Finaud et al, 2006). These complexities include degree of training, positive effects of free radicals, doses of antioxidant supplements and the number of different antioxidant supplements used.

Oxidative stress can be mitigated to a degree through training. In marathon runners, free radicals generated during exercise up-regulated the expression of antioxidant enzyme systems (Gomez-Cabrera et al, 2006). Also, in other studies, endurance, anaerobic and mixed exercise training programs reduced post-exercise oxidative stress. The positive effects of training are seen in antioxidant enzyme systems in muscle, fat, plasma, liver and heart (Finaud et al, 2006; Aksoy et al, 2006). In one study in minimally trained dogs, the antioxidant mechanisms were insufficient to meet the antioxidant needs associated with repetitive endurance exercise (Hinchcliff et al, 2000). Not surprisingly, training matters. Many hunting dogs have a leisurely lifestyle for most of the year, associated with being the family pet. However, on the opening day of hunting season, they are expected to function at peak athletic and olfactory performance. Such dogs should have adequate levels of antioxidants in their food. Better yet, combine that recommendation with a preseason exercise-training program. It should be noted that free radicals appear to also have a physiologic function and total mitigation of reactive oxygen molecules can negatively affect certain types of exercise performance. In human subjects, free radicals have been shown to have a regulatory function at the vascular level, causing vasodilatation (Richardson et al, 2006). Excessive doses of antioxidants have been shown to impair muscle force production (Stone and Yang, 2006). When racing greyhounds were supplemented with high doses (1 g/day) of vitamin C, they ran slower (Marshall et al, 2002). Racing greyhounds also ran slower when supplemented with high doses of vitamin E (1,000 IU/day) but not lower doses (100 IU/day) (Hill et al, 2001).

Besides interfering with normal redox signaling, high doses of antioxidants, particularly of individual antioxidant supplements, can be counterproductive in a different way. Single antioxidant supplementation can have a pro-oxidant effect. For example, as part of its antioxidant function, vitamin E temporarily becomes a radical species known as the α-tocopherol radical. Normally, co-antioxidants, such as vitamin C, reduce the α-tocopherol radical back to α-tocopherol. If co-antioxidants are absent or decreased, the α-tocopherol radical can exhibit pro-oxidant activity (McNaulty et al, 2005). Antioxidant balance is important because supplementation with large amounts of a single antioxidant may change the balance to one of a pro-oxidative state. High doses of vitamin C and selenium may act as pro-oxidants (Atalay et al, 2006). Multi-nutrient antioxidant supplementation using lower doses is a better approach.

Commonly supplemented food-source antioxidants include vitamins E and C, β-carotene and other carotenoids, selenium and thiols. Fruits and vegetables are good sources of flavonoids, polyphenols and anthocyanidins. The following recommendations, however, will focus on vitamins E and C and selenium as antioxidant key nutritional factors because: 1) they are biologically important, 2) they act synergistically and 3) there is published information regarding safety and inclusion levels.

VITAMIN E

Vitamin E is the primary lipid-soluble antioxidant in plasma, erythrocytes and tissues (NRC, 2006). It is transported in plasma proteins and partitions into membranes and fat storage sites where it is one of the most effective antioxidants for protecting polyunsaturated fatty acids from oxidation. The minimum DM requirement for vitamin E for foods for adult dogs is 30 mg/kg (NRC, 2006). Research indicates that a higher level of vitamin E confers specific biologic benefits. In minimally trained sled dogs, 136 IU of vitamin E/kg was not enough to maintain normal vitamin E levels in plasma after three successive 58-km exercise runs (Hinchcliff et al, 2000). In another sled dog study, 400 IU vitamin E/day in conjunction with β-carotene and lutein resulted in increased plasma concentrations of antioxidants and decreased DNA and lipoprotein oxidation (Baskin et al, 2000). In a study that measured plasma vitamin E concentrations in racing-sled dogs during the 1998 Iditarod Race, dogs that had high pre-race vitamin E concentrations were almost twice as likely to finish the race (Piercy et al, 2000). These results could reflect a higher vitamin E intake and/or better fitness and a resultant higher anaerobic threshold. As noted above, unchecked oxidative stress can result in muscle fatigue. Endurance exercise in sled dogs results in considerable oxidative stress (Hinchcliff et al, 2000). Trained subjects present a higher vitamin E status whereas overreaching seems to decrease it (Finaud et al, 2006).

Based on antioxidant biomarker studies in non-exercising dogs, for improved antioxidant performance, dog foods should contain at least 500 IU/kg of DM vitamin E (Jewell et al, 2000). For a 25-kg dog engaged in moderate exercise for several hours/day, this would amount to approximately 250 IU/day. Compared to the amounts in the studies mentioned above, this is not an excessive amount.

VITAMIN C

Vitamin C is the most powerful reducing agent available to cells. As mentioned above, it is an important co-antioxidant because it regenerates oxidized vitamin E. Besides regenerating vitamin E, vitamin C also: 1) regenerates glutathione and flavonoids, 2) quenches free radicals both intra- and extracellularly, 3) protects against free radical-mediated protein inactivation associated with oxidative bursts of neutrophils, 4) maintains transition metals in reduced form and 5) may quench free radical intermediates of carcinogen metabolism.

Dogs can synthesize amounts of vitamin C required for maintenance (Innes, 1931; Naismith, 1958; Chatterjee et al, 1975) and they can rapidly absorb supplemental vitamin C (Wang et al, 2001). However, in-vitro studies indicated that dogs (and cats) have from one-quarter to one-tenth the ability to synthesize vitamin C as other mammals (Chatterjee et al, 1975). Whether or not this translates to a reduced ability in vivo is unknown.

Studies in exercising people and horses have shown improvements in indicators of oxidative stress associated with exercise

Box 18-6. Vitamins, Minerals and Exercise.

Although vitamins and minerals are obviously important for exercise, it is unclear if exercise alters the requirements for these nutrients. Additionally, some vitamins and minerals are believed to be beneficial as ergogenic aids. Unfortunately, little well controlled research has been conducted in this area and current results are conflicting.

Exercise-induced increases in demand have been suggested for nearly all of the B-complex vitamins. Many of these compounds are used as cofactors in key enzymes of energy-generating pathways; others function in tissue synthesis and repair initiated by exercise. Likewise, the demand for vitamin C has been postulated to increase due to its role in L-carnitine and collagen synthesis and its antioxidant functions. Exercise may also hasten the excretion of water-soluble vitamins because exercise increases total body water turnover. Five to 10 times maintenance levels of the water-soluble vitamins have been safely fed to working dogs.

High consumption of polyunsaturated fatty acids (PUFA) and increased oxygen metabolism may also increase a working or sporting dog's risk for oxidative damage of cell membranes. Such damage may induce myodystrophy and decrease endurance. Increased intake of antioxidants is recommended for prophylaxis. At present, there is no evidence to indicate that exercise increases dietary requirements for vitamins D and K.

Metabolic acidosis induced by lactic acidosis associated with strenuous work may increase excretion of calcium, magnesium and potassium. Foods containing low levels of magnesium (but at levels above the minimum Association of American Feed Control Official's allowance) resulted in clinical signs of magnesium deficiency in greyhound dogs. These signs were alleviated when foods containing magnesium at 0.12% of the dry matter (DM) were fed.

Canine athletes fed high-fat foods or those whose food is supplemented with meat (as is common with greyhounds and sled dogs) may require additional calcium. The high level of fat in performance foods enhances the formation of insoluble calcium soaps, thus rendering a portion of the ingested calcium unavailable. Additionally, red meat is rich in phosphorus and nearly devoid of calcium. Meat supplementation may thus require calcium supplementation to maintain a normal calcium content and calcium-phosphorus ratio in the diet. Dietary calcium levels of 1.2 to 2.0% of a food's DM have been successfully fed to working dogs. Very high-fat foods with lower calcium concentrations may be deficient in available calcium. Excessive calcium supplementation may also predispose a dog to zinc deficiency by inhibiting absorption of this nutrient (Chapter 32).

The requirement for iron is also thought to increase with exercise. Commercial performance foods and foods supplemented with substantial quantities of red meat should easily meet this increased demand. In such instances, iron supplementation is contraindicated because it may irritate the lower gastrointestinal tract and predispose canine athletes to develop bloody diarrhea.

Large doses of vitamins and minerals individually or in combination have not been demonstrated to increase the physical capabilities of human or canine athletes. Dietary intake of these nutrients should be aimed at meeting increased physiologic requirements rather than attempting to produce an unproved pharmacologic enhancement of performance.

Several considerations must be weighed when determining the optimal vitamin and mineral content of a performance food. One must estimate the availability and the tolerance levels of these nutrients as well as possible nutrient interactions. For example, iron and zinc must be present in proper proportions; an excess of one may lead to a relative deficiency of the other because they share a common mechanism of absorption. Similarly, a disproportionate supplementation of one fat-soluble vitamin may inhibit absorption of the others. The concentrations and types of energy-producing nutrients in the food can also influence vitamin and mineral requirements. As mentioned, PUFA intake can alter the demand for vitamin E and selenium.

Although dogs have no known dietary vitamin C and L-carnitine requirement, some researchers argue that canine athletes may be unable to synthesize adequate quantities of these nutrients to meet the metabolic demands of extremely hard work. It is also unclear whether requirements for vitamins and minerals increase in proportion to caloric intake or whether they approach an asymptote. Further research is needed to resolve these issues.

Those wishing to supplement with vitamins and minerals are advised to do so carefully. Such supplementation should only be undertaken with knowledge of nutrient availability, interactions and tolerance levels because dietary overcompensation of these nutrients may be as detrimental to performance as dietary deficiencies. One report noted that a mineral mixture solution containing potassium, phosphorus, sodium, magnesium, copper and iron given free-choice to exercising dogs caused diarrhea.

The Bibliography for **Box 18-6** can be found at www.markmorris.org.

as a result of vitamin C supplementation (Goldfarb et al, 2005; White et al, 2001). However, as mentioned above, a study in greyhounds that were supplemented with high doses of vitamin C resulted in slower racing times. As mentioned previously, multi-nutrient antioxidant supplementation using lower doses is a better approach than using high doses of a single antioxidant supplement. To augment antioxidant protection, in conjunction with recommended levels of vitamin E above, improved antioxidant performance foods for working and sporting dogs should contain between 150 to 250 mg of vitamin C/kg (DM). The upper end of this range would be about 70 to 100 mg/day for a 30-kg dog. This is about 7 to 10% of the amount (1 g/day) that slowed race times in the greyhound study described above.

SELENIUM

Glutathione-peroxidase is a selenium-containing antioxidant enzyme that defends tissues against oxidative stress by catalyzing the reduction of H_2O_2 and organic hydroperoxides and by sparing vitamin E. In people, following eccentric exercise-

Box 18-7. Electrolytes and Exercise.

Electrolytes are integral components of nearly all chemical reactions and transmembrane transport systems. About one-third of basal energy requirement is expended to maintain electrolyte concentration gradients across cellular membranes. The narrow range within which these concentrations are regulated and the high cost of achieving this regulation is evidence of their biologic significance. The electrolytes sodium, potassium and chloride are involved in control of fluid balance, maintenance of normal muscle and nerve excitability and acid-base status.

The electrolytes (primarily sodium) play a major role in regulation of total body water. Hyperosmolality stimulates thirst and causes the kidneys to conserve water. In cases of electrolyte depletion, aldosterone may reduce renal losses by stimulating tubular reabsorption of sodium and water. Sodium depletion occurs commonly in horses, people and other mammals that sweat; however, exercise-related loss of sodium may also be significant in canine athletes. The amount of sodium lost via saliva in exercising dogs depends on salivary flow rate. As salivary flow increases, the osmotic concentration of the initially hypotonic saliva increases; saliva approaches isotonicity with plasma at maximum flow rates. Warm or humid conditions that elicit increased salivary flow rates during exercise may also significantly increase sodium, bicarbonate and chloride losses.

Abnormal electrolyte concentrations impair physical performance by altering membrane potentials across muscle and nerve cells, and altering the functions of catalytic and contractile proteins. These changes hinder performance by diminishing the rate of energy and force generation. They also interfere with heat dissipation, which is particularly impaired by increases in plasma osmolarity.

Either water or an electrolyte solution may be used to maintain or replace fluid-electrolyte losses during and after exercise. Electrolyte solutions, while popular, are of limited value for most dogs eating a balanced food. Additionally, there is much debate about the proper concentration of these solutions. Hypertonic and even isotonic solutions administered orally may not return postexercise plasma osmolarity to normal. These solutions may encourage water transfer into cells if they are more hypertonic than the fluid of the interstitial spaces. Such fluids may lead to gastrointestinal cramping, vomiting and diarrhea and thus exacerbate dehydration. Anecdotally, even isotonic solutions administered before exercise have been associated with snow “dipping” or ingesting snow during sled-dog races. This phenomenon may be caused by the effect of the electrolyte solution on plasma osmolarity and thus thirst. Snow dipping is considered undesirable in racing dogs because it disturbs the rhythm and speed of the team.

Proponents of electrolyte supplementation note that in proper concentrations, such solutions increase fluid palatability and the rate of fluid absorption from the gut. Some argue these solutions may help maintain plasma volume during exercise and may aid in its restoration in the postexercise period. Because diarrhea is a common disorder among working dogs, the use of electrolyte replacement solutions may play a role in the clinical management of these cases.

Clearly, more research is needed before recommendations can confidently be given about the administration of electrolyte solutions to canine athletes before, during and after exercise. Under nearly all conditions, it is more important to replace water losses. Under conditions where electrolyte administration is deemed beneficial, it is safer to err on the side of hypotonic rather than hypertonic oral supplementation.

The Bibliography for **Box 18-7** can be found at www.markmorris.org.

induced muscle injury, suboptimal selenium status worsens muscle functional decrements (Milias et al, 2006). The minimum requirement for selenium in foods for dogs is 0.10 mg/kg (DM) (Wedekind et al, 2002). Animal studies and clinical intervention trials in people have shown selenium to be anticarcinogenic at much higher levels (five to 10 times) than the human recommended allowance or minimal requirement (Combs, 2001; Neve, 2002). Several mechanisms have been proposed for this effect, including enhanced antioxidant activity via glutathione peroxidase (Neve, 2002). Therefore, for increased antioxidant benefits, the recommended range of selenium for dog foods is 0.5 to 1.3 mg/kg (DM). There are no data to base a safe upper limit of selenium for dogs or cats, but for regulatory purposes, a maximum standard of 2.0 mg/kg (DM) has been set for dog foods in the United States (AAFCO, 2007).

Other Nutritional Factors

Vitamins, minerals and electrolytes play important roles in maintaining homeostasis and chemical reactions during exercise (**Boxes 18-6** and **18-7**). However, they are of secondary concern when feeding canine athletes and are found in adequate amounts in most commercial foods. Likewise, the acid-base composition of the food and base loading may also affect performance (**Box 18-8**); however, these effects are poorly understood in canine athletes. Deficiencies of vitamin A, iodine and zinc have been associated with disturbances of smell in people (Mattes, 1999) but are not of practical concern in dogs being fed commercial foods.

FEEDING PLAN

The feeding plan should be formulated based on realistic and quantifiable nutritional objectives after the patient, food and feeding method have been assessed. The feeding plan guides the selection of foods and feeding methods.

Assess and Select the Food

Although the working or sporting dog’s nutritional needs could conceivably be met by many different dietary approaches, all foods for canine athletes (performance foods) should share a few important characteristics. First, the food should be calori-

Box 18-8. Acid-Base Balance and Exercise.

Muscle contraction produces metabolic acid (CO_2 and/or lactate), which decreases the intracellular pH of muscles. Changes in intracellular pH can affect the function of muscle enzymes responsible for ATP generation and contraction. The mechanisms that act to blunt the detrimental effects of acid production within muscles include: 1) intracellular buffering and 2) removal of acids by the bloodstream.

In equine athletes, two approaches have been used to help counteract exercise-induced acidosis to improve athletic performance. The first is to base load the horse via stomach tube several hours before exercise. Sodium bicarbonate in water is the base used most often. This solution is frequently called a "milkshake" due to its milky white appearance. This approach can effectively alter resting acid-base status, but hasn't been proven to alter performance. The second approach is to alter the ionic composition of food to change the acid-base status of the animal. Investigators have been able to alter resting acid-base status by altering the dietary cation-anion balance of the food, but again it is unclear if this alteration affects performance. Alteration of acid-base status by dietary or supplementation means has not been investigated extensively in dogs; however, the basic principles investigated in horses should apply to dogs.

The Bibliography for **Box 18-8** can be found at www.markmorris.org.

cally dense so that canine athletes can consume enough food to meet their energy requirements. Second, the food must be acceptable and highly digestible. DM digestibility should exceed 80% (Downey et al, 1980; Lewis et al, 1987). High digestibility reduces fecal bulk and fecal water loss and may decrease the risk of developing stress diarrhea (Houpt, 1984; Downey et al, 1980). Finally, the food should be practical. Factors such as the cost of the food, the form of the food, the environment in which the food is stored and fed and the number of dogs being fed are all important considerations. What is practical for a single hunting dog at home may not be practical for a team of sled dogs hundreds of miles from civilization, agility dogs at an out-of-town competition or racing greyhounds at a track.

Because the greatest nutritional demand of exercise is for energy, foods for canine athletes must provide sufficient kcal from the right sources. Increasing the fat content of the food usually enhances energy density. The appropriate fat content is dictated by energy need and exercise intensity. Dogs participating in short-duration, maximal exercise may benefit from lower fat, higher carbohydrate foods.

Assessment of the food includes: 1) physical evaluation of the food, 2) evaluation of the product label for commercial foods and 3) evaluation of the food's nutritional content relative to the animal's needs (key nutritional factors) (Chapter 1).

Working and sporting dogs are fed a wide variety of foods and supplements. When assessing the overall ration, it is important to assess all foods and supplements fed. The nutrient profile of the total daily ration should be evaluated for the key nutritional factors based on the type and amount of exercise performed by each dog.

Most intermediate athletes are fed commercial foods, whereas many elite sprint and endurance athletes (racing dogs) are fed homemade foods or more commonly a mixture of commercial food and other ingredients. The use of supplements is prevalent with working and sporting dogs of all types.

Comparing the nutritional content of the current food to the key nutritional factors allows decisions to be made about the adequacy of the food for individual dogs. If the current food is appropriate (key nutritional factors in balance with the dog's needs) then that food can continue to be fed. If discrepancies exist between the key nutritional factors for the dog and the content of the food, the food should be changed or "balanced" to meet the dog's needs.

Commercial Foods

Table 18-12 lists the key nutritional factors for working and sporting dogs and compares them to the key nutritional factor content of selected commercial foods formulated for these dogs. For those commercial foods not found in **Table 18-12**, minimum fat and protein levels are listed in the guaranteed or typical analysis on the pet food label. (See Chapter 1 for limitations of this information.) The carbohydrate portion of a food can also be estimated as described above under "Carbohydrates" in the "Key Nutritional Factors" section or in Chapter 5. Digestibility information is usually only available from the manufacturer. The energy density of most commercial foods is not high enough for dogs engaged in true endurance activity. **Table 18-12** provides energy density information for commercial foods supplemented with vegetable oil in order to meet the energy density needs for endurance athletes.

Homemade Foods

Homemade foods can be very complicated mixtures of many ingredients. Chapter 10 discusses assessment of homemade foods in detail. Fortunately, most recipes for homemade foods for working and sporting dogs use a commercial dry dog food as a base. Many racing greyhound food regimens contain dry dog food mixed with either raw or cooked meat, water, vitamin-mineral supplements and a variety of other ingredients. Likewise, many sled-dog mushers mix animal fat or both meat and fat with dry dog food and other ingredients. If the commercial dry food constitutes 50 to 75% of the mixture on a weight basis and most of the added ingredients are wet ingredients or fat, it is unlikely that vitamin and mineral deficiencies will occur.

Because many elite canine athletes (racing greyhounds and sled dogs) are fed homemade foods containing meat and animal by-products of variable quality, the safety of these foods should always be evaluated. Some raw meat sources contain abundant bacteria and bacterial toxins (Case 11-1). Raw foods may pose a health hazard for people who care for these dogs and for the dogs themselves. Chapter 11 discusses food safety.

Supplements

Feeding glucose solutions minimizes the exercise-associated decline in blood glucose, promotes more rapid repletion of muscle glycogen postexercise and improves thermoregulation. However, when such solutions are fed is important. Glucose solutions (from 1.5- to as much as 5-g glucose/kg body weight) have been used (Kruk et al, 1987; Reynolds et al, 1997; Wakshlag et al, 2002; NRC, 2006). As an option to a glucose solution, an anecdotal report recommends using up to one 8-oz. measuring cup of sucrose per quart of water (~240 g/l).[f] To receive an amount of sucrose equal to the upper end of the previously recommended range for glucose (5 g/kg body weight), a 35-kg dog would have to ingest approximately three-fourths of a quart of the sucrose-water solution.

Several commercial products are available to support energy levels during exercise. These products are available as powders to be added to drinking water (so called "canine sports drinks") or dry snacks. They can be found online or at pet or sporting goods stores. Small amounts of a high-carbohydrate low-fat commercial dog food could also be used for this purpose.

Vegetable oils (plant-source edible oils, e.g., corn oil and soybean oil) can be used to increase the unsaturated fatty acid content of a commercial food for improving olfaction (see "Fat" under Key Nutritional Factors discussion) and for increasing the energy density of a commercial food. If corn oil is added to dry commercial foods to increase the fat and/or unsaturated fatty acid content, 1 tablespoon of corn oil for approximately each pound of dry food will increase the overall fat content by about three to four percentage points. For example, if two tablespoons of corn oil are added to one pound of dry food that contains 20% fat, the resultant mixture of food and corn oil will contain about 27% fat and would have increased levels of unsaturated fatty acids. Corn and vegetable oils provide about 125 kcal ME/tablespoon (14 g). **Table 18-12** provides energy density information for commercial foods. The foods listed would need to be supplemented with vegetable oil to increase energy density to a level to support needs for dogs engaged in endurance activity. Dogs can tolerate high levels of dietary fat if the fat is gradually introduced and an adequate intake of nonfat nutrients is maintained. Steatorrhea and a decrease in food palatability are indicators that the fat intake of a food has exceeded an individual dog's fat tolerance.

Assess and Determine the Feeding Method

Performance can be influenced by the composition of the food and how it is fed. It is possible to feed the right food in the wrong way and vice versa. Items to be assessed should include amount fed, frequency of feeding and timing of meals in relation to exercise, food adaptation, access to water and the use of supplements. All of these factors should be matched to the individual athlete and the type of exercise performed (intensity, duration, frequency and season). If the current feeding method matches the individual's needs based on the assessment, no changes are necessary. Changes should be made if the assessment reveals discrepancies in the feeding method. If the animal is in appropriate body condition and hydration status, it is likely that the amount of food and water consumed is appropriate.

The amount of a new food to feed can be estimated several ways. Feeding guidelines from the manufacturer and those on pet food labels are seldom correct for active working and sporting dogs. Energy needs and food doses usually must be calculated. If the amount of the previous food was correct (i.e., appropriate body condition was maintained) and the energy density of the food is known, simply feed the same amount of the new food to supply the same energy intake. If this method isn't feasible, the food dose should be calculated based on the dog's needs as shown above. In all cases, the dog should be assessed frequently and adjustments should be made to maintain correct body condition.

Timing of feeding and timing of food changes are important for working and sporting dogs. Timing of feeding in relation to exercise influences hormonal status, substrate availability and performance. When changing foods, adequate time must be allowed for the dog to adapt to the new food type to take full advantage of its nutrient profile.

Amount to Feed

An increase in energy requirement is the hallmark of exercise. The wide variation in the intensity and duration of exercise and therefore energy requirement of different types of working and sporting dogs emphasizes the need for food dose calculations. The basics of energy requirement and food dose calculation are covered in Chapter 1.

The dog's DER is the product of its RER and a factor that accounts for activity. For the average neutered, minimally active adult dog, DER is 1.2 to 1.4 RER (Chapters 1 and 13). DER for exercising dogs has a wide range of values from 1.6 x RER to 11 x RER, depending on the intensity and duration of exercise. The DER range for sprint dogs is 1.6 to 2 x RER, for intermediate (mixed) type activity the DER range is 2 to 5 x RER, for endurance-type activity the DER is more than 5 x RER. As discussed earlier, the caloric cost of running is determined by the size of the animal (body weight), weight carried or pulled and distance traveled.

Energy is also used to maintain body temperature. Extreme arctic and tropical temperatures increase a dog's RER (Lewis et al, 1987; Young et al, 1959). Dogs working in cold climates may require less energy than the sum of those determined for work and thermoregulation because exercise generates significant quantities of heat. RER for nonworking dogs in hot environments increases only marginally as a result of increased work of the respiratory muscles (panting) (Chapter 13). Working dogs already have increased respiratory rates, thus, additional energy for thermoregulation during exercise in hot climates should be negligible. Total DER is the sum of the needs for rest (RER), exercise (EER) and thermoregulation (ET) (i.e., DER for canine athletes = RER + EER + ET).

Most working dogs expending fewer kcal than 3 x RER can adequately fulfill their energy needs by eating a commercial

Table 18-12. Levels of key nutritional factors (DM) in selected dry commercial foods used for working and sporting dogs compared to recommended key nutritional factor values.*

Recommended levels for sprint activity

Foods	Energy density (kcal/cup)**	Energy density (kcal ME/g)***	Fat (%)	Carbohydrate (%)	Protein (%)	Vitamin E (IU/kg)	Vitamin C (mg/kg)	Selenium (mg/kg)
	-	3.5-4.0	8-10	55-65	22-28	≥500	150-250	0.5-1.3
Hill's Science Diet Adult Lamb Meal & Rice Recipe	364	4.0	16.0	52.9	23.0	582	174	0.54
Hill's Science Diet Adult Active	560	5.0	27.2	35.4	29.8	556	152	0.54
Iams Eukanuba Premium Performance Sporting Dog Food	431	4.8	22.2	33.8	33.3	na	na	na
Iams Proactive Health Lamb Meal & Rice Formula	330	4.0	14.2	46.3	25.1	123	52	0.37
Nutro Natural Choice High Energy	396	4.3	23.1	32.4	34.1	na	66	0.33
Nutro Natural Choice Lamb Meal & Rice Formula	342	3.8	14.3	50.0	24.2	220	66	0.77
Pedigree Small Crunchy Bites Dog Food	290	3.8	13.7	48.1	26.0	256	80	na
Purina Dog Chow	430	4.2	11.4	51.9	23.9	144	na	0.64
Purina Pro Plan Performance Formula	493	4.8	23.2	31.3	35.0	na	na	na
Royal Canin Energy 4800	591	5.2	33.3	15.8	35.6	856	389	0.28
Royal Canin Maxi German Shepherd 24	314	4.5	21.2	37.0	26.8	670	na	0.22
Royal Canin Maxi Golden Retriever 25	412	4.1	14.7	38.7	27.5	769	na	0.20
Royal Canin Maxi Labrador Retriever 30	321	4.1	14.3	35.3	33.0	659	na	0.18
Royal Canin Medium Active Special 25	349	4.6	18.9	na	27.8	667	333	0.16

Recommended levels for intermediate activity (low/moderate duration and frequency)

Foods	Energy density (kcal/cup)**	Energy density (kcal ME/g)***	Fat (%)	Carbohydrate (%)	Protein (%)	Vitamin E (IU/kg)	Vitamin C (mg/kg)	Selenium (mg/kg)
	-	4.0-5.0	15-30 (>60% unsaturated)†	30-55	22-32	≥500	150-250	0.5-1.3
Hill's Science Diet Adult Lamb Meal & Rice Recipe	364	4.0	16.0 (na)	52.9	23.0	582	174	0.54
Hill's Science Diet Adult Active	560	5.0	27.2 (64% unsaturated)	35.4	29.8	556	152	0.54
Iams Eukanuba Premium Performance Sporting Dog Food	431	4.8	22.2 (na)	33.8	33.3	na	na	na
Iams Proactive Health Lamb Meal & Rice Formula	330	4.0	14.2 (na)	46.3	25.1	123	52	0.37
Nutro Natural Choice High Energy	396	4.3	23.1 (na)	32.4	34.1	na	66	0.33
Nutro Natural Choice Lamb Meal & Rice Formula	342	3.8	14.3 (na)	50.0	24.2	220	66	0.77
Pedigree Small Crunchy Bites Dog Food	290	3.8	13.7 (na)	48.1	26.0	256	80	na
Purina Dog Chow	430	4.2	11.4 (na)	51.9	23.9	144	na	0.64
Purina Pro Plan Performance Formula	493	4.8	23.2 (na)	31.3	35.0	na	na	na
Royal Canin Energy 4800	591	5.2	33.3 (na)	15.8	35.6	856	389	0.28
Royal Canin Maxi German Shepherd 24	314	4.5	21.2 (na)	37.0	26.8	670	na	0.22
Royal Canin Maxi Golden Retriever 25	412	4.1	14.7 (na)	38.7	27.5	769	na	0.20
Royal Canin Maxi Labrador Retriever 30	321	4.1	14.3 (na)	35.3	33.0	659	na	0.18
Royal Canin Medium Active Special 25	349	4.6	18.9 (na)	na	27.8	667	333	0.16

food formulated for performance (**Table 18-12**). These foods are palatable, complete/balanced and convenient in most situations. Working and sporting dogs exercising in extremely warm or extremely cold environments or those working for several hours a day for several consecutive days may expend more calories than 3 x RER. DM intake is limited to about 3.5% of body weight under most physiologic conditions.[c] A performance food containing these amounts (30% DM protein, 20% DM

Recommended levels for intermediate activity (high duration and frequency)

Foods	Energy density (kcal/cup)**	Energy density (kcal ME/g)***	Fat (%)	Carbohydrate (%)	Protein (%)	Vitamin E (IU/kg)	Vitamin C (mg/kg)	Selenium (mg/kg)
Foods	**-**	**4.5-5.5**	**25-40 (>60% unsaturated)†**	**30-35**	**22-32**	**≥500**	**150-250**	**0.5-1.3**
Hill's Science Diet Adult Active	560	5.0	27.2 (64% unsaturated)	35.4	29.8	556	152	0.54
Iams Eukanuba Premium Performance Sporting Dog Food	431	4.8	22.2 (na)	33.8	33.3	na	na	na
Iams Proactive Health Lamb Meal & Rice Formula	330	4.0	14.2 (na)	46.3	25.1	123	52	0.37
Nutro Natural Choice High Energy	396	4.3	23.1 (na)	32.4	34.1	na	66	0.33
Nutro Natural Choice Lamb Meal & Rice Formula	342	3.8	14.3 (na)	50.0	24.2	220	66	0.77
Pedigree Small Crunchy Bites Dog Food	290	3.8	13.7 (na)	48.1	26.0	256	80	na
Purina Dog Chow	430	4.2	11.4 (na)	51.9	23.9	144	na	0.64
Purina Pro Plan Performance Formula	493	4.8	23.2 (na)	31.3	35.0	na	na	na
Royal Canin Energy 4800	591	5.2	33.3 (na)	15.8	35.6	856	389	0.28
Royal Canin Maxi German Shepherd 24	314	4.5	21.2 (na)	37.0	26.8	670	na	0.22
Royal Canin Maxi Golden Retriever 25	412	4.1	14.7 (na)	38.7	27.5	769	na	0.20
Royal Canin Maxi Labrador Retriever 30	321	4.1	14.3 (na)	35.3	33.0	659	na	0.18
Royal Canin Medium Active Special 25	349	4.6	18.9 (na)	na	27.8	667	333	0.16

Recommended levels for endurance activity

Foods	Energy density (kcal/cup)**	Energy density (kcal ME/g)***	Fat (%)	Carbohydrate (%)	Protein (%)	Vitamin E (IU/kg)	Vitamin C (mg/kg)	Selenium (mg/kg)
Foods	**-**	**>6**	**>50††**	**<15**	**28-34**	**≥500**	**150-250**	**0.5-1.3**
Hill's Science Diet Adult Active	560	5.0	27.2	35.4	29.8	556	152	0.54
Iams Eukanuba Premium Performance Sporting Dog Food	431	4.8	22.2	33.8	33.3	na	na	na
Nutro Natural Choice High Energy	396	4.3	23.1	32.4	34.1	na	66	0.33
Purina Pro Plan Performance Formula	493	4.8	23.2	31.3	35	na	na	na
Royal Canin Energy 4800	591	5.2	33.3	15.8	35.6	856	389	0.28

Key: DM = dry matter, ME = metabolizable energy, na = not available from manufacturer.

*This table lists selected products for which manufacturers' published information is available. **Table 18-1** provides examples of types of activities conducted by working and sporting dogs.

**Energy density values are listed on an as-fed basis and are useful for determining the amount to feed; cup = 8-oz. measuring cup. To convert to kJ, multiply kcal x 4.184.

***Foods higher in energy density are generally more digestible.

†For improved olfaction, fat sources should provide >60% total unsaturated fatty acids (**Table 18-11**).

††To increase fat content and energy density, adding two tablespoons of vegetable oil per pound (454 g) of food would increase fat content by approximately 6 percentage points; one tablespoonful of vegetable oil = 125 kcal ME; adding vegetable oil to dry commercial foods intended to support endurance activity is recommended.

fat, 40% DM carbohydrate and >80% DM digestibility) provides a maximum of 5 x RER for a 25-kg dog.

Because true endurance athletes have a DER greater than 5 x RER, providing sufficient dietary energy becomes the focus of feeding these athletes. Long-distance sled-dog drivers frequently encounter situations in which their 25- to 30-kg dogs require 6,000 to 10,000 kcal/day (25 to 42 MJ/day) (7 to 11 x RER). Under these extreme circumstances, dogs are fed 1,500

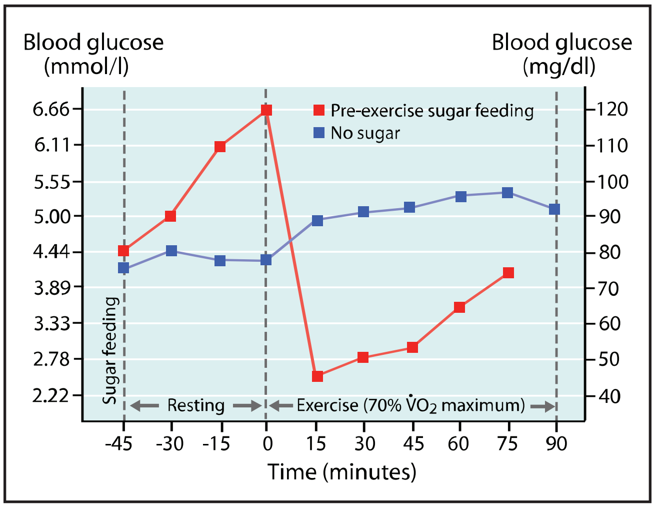

Figure 18-5. Differences in blood glucose concentrations between people exercising on a bicycle ergometer following administration of a glucose drink or placebo. (Adapted from Costill DL, Miller JM. Nutrition for endurance sport: Carbohydrate and fluid balance. International Journal of Sports Medicine 1980; 1: 2-14.)

to 2,500 kcal (6 to 11 MJ) of a dry commercial food in an attempt to fulfill protein, carbohydrate, vitamin and mineral requirements. Fulfilling the rest of the dog's DM intake with fat or fatty meat then maximizes energy intake. Strategies that maximize fat intake have been successfully used in virtually all of the recent Iditarod, Quest and Alpirod victories and in sled-dog expeditions to both poles.[d,e,g,h] These extremely high-fat foods, which derive up to 80% of their kcal from lipid sources, should be fed only to dogs previously acclimated to high-fat intake (i.e., 30 to 60% fat kcal), through feeding and training. Also, there may be a limited amount of time that dogs can be maintained on such a food or at such a level of stress.

Another strategy used by sled-dog mushers is to feed their dogs so they begin a long-distance race with 1.36 to 2.3 kg of extra adipose tissue. This gives the dogs a reserve to draw upon when caloric intake cannot meet energy expenditure. The additional insulation may also help dogs reduce heat loss during rest periods.

Feeding to Maintain Proper Body Condition

Food-dose calculations are based on average energy needs for a population of dogs and therefore will not be accurate for all dogs in various circumstances. Variation in individual metabolic rate, environmental temperature and exercise affect energy requirement and food dose. Repeated or continual body condition assessment is clearly the best clinical measure of energy balance. Body condition scoring is primarily a measure of body fat. Increasing body fat indicates positive energy balance; therefore, food dosage should be decreased. If body fat falls below optimal, energy balance is negative and food dosage should be increased to ensure adequate energy for maximal performance. One method of body condition scoring is presented in Chapter 1. A BCS of 2/5 to 3/5 is normal for most working and sporting dogs, with a bias towards the lean side of this range. Hunting dogs' BCS should be in the range of 2.5/5 to 3.5/5. Unfortunately, some of these dogs will have BCS greater than 3.5/5 because they are pet dogs and thus are more prone to being overweight.

Because fat in excess of what is needed for energy reserves during racing adds weight and may affect performance, many sight hounds are kept very lean (BCS 1/5 to 2/5). Most racing greyhounds normally have a BCS of 1/5. Being very lean may be an important physical characteristic for maximal sprint performance plus the fact that greyhounds have a very limited ability to use fat as an energy source for sprinting. Racing sled dogs should have a BCS of 2.5/5 (Reynolds et al, 1999).

When to Feed

To gain maximum benefit from a specific food, meals must be fed at the right time in relation to exercise and ample time must be allowed for metabolism to adapt to a new food type when changing foods.

After the amount to feed has been determined, an appropriate feeding schedule should be used. The temporal relationship between food intake and exercise greatly affects nutrient use. In one study, dogs fed within six hours of exercise developed a higher working body temperature than those fed 17 hours before exercise (Young et al, 1962). The elevated body temperatures in dogs fed closer to the onset of exercise may have been caused by heat released by the digestive process (specific dynamic action of food), and by vasodilatation of the splanchnic vessels. Such shunting may decrease cutaneous circulation and thus diminish heat dissipation. In performing the same task, dogs fed within six hours of exercise used more glucose and less fat than postabsorptive dogs (Young et al, 1962, 1959a; Young, 1959). Higher circulating insulin levels in the more recently fed dogs may cause this alteration in substrate use (Pate and Brunn, 1989). Because insulin tends to decrease free fatty acid mobilization from peripheral adipose depots, feeding too close to exercise may impair endurance by encouraging use and thus depletion of limited carbohydrate (glycogen) stores (Pate and Brunn, 1989).

The importance of the temporal relationship between feeding and exercise is seen in the poorly documented syndrome known as hunting dog hypoglycemia. The exact etiology of this syndrome is unknown. It is often associated with hyperactive, under-conditioned hunting dogs. Elevated ambient temperature has also been implicated as a risk factor (Lewis et al, 1987). Dogs experiencing this syndrome begin working normally and then develop signs of weakness and tremors that may progress to seizures and even death. Their purported inability to maintain normoglycemia has been attributed to inadequate glycogen mobilization (due to a lack of a glycogen debranching enzyme), excessive rates of glycogen mobilization or a combination of the two (Lewis et al, 1987). Feeding these dogs several hours (≥4) before the onset of exercise may help decrease insulin levels at the onset of exercise. Exercise also dampens the insulin response to ingested carbohydrate (Pate and Brunn, 1989). Providing exogenous carbohydrate via small amounts of food offered at the onset of, and periodically during, exercise may aid blood glucose homeostasis in these dogs (Lewis et al, 1987). It is best if this food is not high in fat (NRC, 2006). As mentioned above (Supplements), glucose or sucrose solutions can also be used (Kruk et al, 1987; Reynolds et al, 1997; Wakshlag et al, 2002; NRC, 2006). Such solutions can be given immediately before, during or after exercise and have been shown to minimize the exercise-associated decline in blood glucose, promote more rapid repletion of muscle glycogen postexercise and improve thermoregulation. The same timing of feeding is recommended for the several commercial products that are marketed to support energy levels during exercise (specific-purpose hydratable powders and dry snacks).

Figure 18-5 shows blood glucose results from a study that examined the effect of feeding time on blood glucose concentration during exercise in people riding a stationary bicycle (Costill and Miller, 1980). One group was given a drink containing glucose 45 minutes before the onset of exercise, whereas the other group received a placebo drink. Blood glucose levels remained constant in the non-fed group, whereas people ingesting the glucose drink had a normal postprandial increase in blood glucose followed by a severe drop at the onset of exercise.

Feeding long before exercise (more than four hours) may also aid endurance by allowing the dog to evacuate its bowels before it begins work. This decreases the weight carried by the dog and may decrease its risk of developing stress diarrhea. Although the cause of loose stools postexercise has not been determined, some researchers have attributed it to the presence of stool in the colon at the onset of exercise.[h] As with pre-exercise feedings, the timing of postexercise meals also influences nutrient use. Glycogen synthesis postexercise occurs much more rapidly in human athletes given exogenous substrates within 30 minutes to two hours postexercise. Feeding within this time frame may aid repletion of glycogen stores in athletes who must perform strenuous exercise on several consecutive days.

The practical application of the above information is feed: 1) more than four hours before exercise, 2) within two hours after exercise and 3) small amounts of food during exercise. Feeding must be done during exercise or during short breaks. Feeding a hunting dog that has hypoglycemic tendencies at the beginning of a 45-minute lunch break may contribute to exercise-induced hypoglycemia (**Figure 18-5**).

Because large volumes of urine represent additional weight and a possible time handicap for racing dogs, many handlers will not water an animal closer than two hours before a competition. The dog is then confined for one and one-half to two hours after drinking and will usually empty its bladder upon being released from the cage. Water should be offered as soon as is practicably possible after exercise. Cooler fluids seem to be absorbed most rapidly (Bucci, 1993). Canine athletes may become significantly dehydrated after prolonged exercise and under relatively warm or humid conditions. Attempts should not be made to replace the entire fluid deficit orally or at once. Gradual oral replacement can be supplemented with subcutaneous (or in severe cases intravenous) isotonic solutions. Body temperature should be monitored because dehydrated animals are less capable of regulating this parameter (Greenleaf et al, 1976).

Table 18-13. Feeding plan summary for working and sporting dogs.

Sprint activity
1. Feed a food with the appropriate amounts of key nutritional factors for this type of activity (**Table 18-12**).
2. Feed the right amount of food (DER = 1.6 to 2 x RER).
3. Check body condition frequently to assess energy balance and food dose.
4. Time meals and snacks correctly. Provide food or snack >four hours before activity; offer high-carbohydrate snack within 30 minutes after racing to enhance glycogen repletion.
5. Allow free access to water except just before racing.
6. Monitor hydration status frequently.

Intermediate activity (working/hunting)
1. Feed a food with the appropriate amounts of key nutritional factors for this type of activity (**Table 18-12**).
2. Feed the right amount of food. The food dose will be highly variable depending on duration and frequency of exercise (DER = 2 to 5 x RER) and should be calculated after assessing the amount of exercise performed.
3. Check body condition frequently to assess energy balance and food dose.
4. Time meals and snacks correctly. Feed after exercise or >four hours before exercise. Snacks should be given during exercise or at the end of breaks <15 minutes before resuming exercise.
5. Allow free access to water.
6. Monitor hydration status frequently.

Intermediate athletes (training)
1. Feed the same as for work (See above).
2. Allow adequate time to adapt to new food (>six weeks) before seasonal work.
3. Begin training and new food at least six weeks before seasonal work begins.
4. Allow free access to water.

Intermediate athletes (idle)
1. Feed as typical adult dog (Chapter 13).
2. Feed a performance food (smaller amount) or typical adult maintenance food as needed to maintain optimal body condition.
3. Allow free access to water.

Endurance athletes
1. Feed a food with the appropriate amounts of key nutritional factors for this type of activity (**Table 18-12**).
2. Feed the right amount of food. The food dose will be highly variable depending on duration and frequency of exercise (DER = 5 to 11 x RER) and should be calculated after assessing amount of exercise performed.
3. Check body condition frequently to assess energy balance and food dose.
4. Time meals and snacks correctly. Feed after exercise or >four hours before exercise. If snacks are used they should be given during or after exercise.
5. Allow free access to water.
6. Monitor hydration status frequently.

Key: DER = daily energy requirement, RER = resting energy requirement.

Table 18-13 summarizes the feeding plans for sprint-, intermediate- and endurance-type activities.

Food Adaptation

Dogs require some time to adapt to a new food whenever a dietary change is made. When dramatic changes in proportion of fat and carbohydrate are made, GI and metabolic adaptations occur. The GI adjustments usually happen in a few days provided the transition to the new food is gradual. The metabolic changes generally take more time. Muscle glycogen responds to feeding a high-carbohydrate food in a few days to a few weeks (Reynolds et al, 1995). Changes in muscle enzymes and oxidative capacity occur in response to high-fat rations in six to eight weeks. Allowing appropriate time for these adaptations to occur is especially important for seasonal athletes that may be fed a high-fat performance food only part of the year and a maintenance food the remainder of the year (Reynolds et al, 1994). Both training and dietary change should occur six weeks before exercise season (e.g., hunting season).

REASSESSMENT

After the feeding plan has been implemented, the dog should be monitored to evaluate the appropriateness of the feeding plan. This process is identical to the original assessment of the dog. Frequent physical examinations are important for early detection of injuries or illnesses. Daily monitoring of food consumption is an early indicator of problems. Frequent evaluation of stool quality may indicate how well the dog is tolerating the food. Weekly measurements of body condition and weight allow assessment of energy balance (i.e., whether food intake matches energy expenditure). Appropriate body condition is also important for optimal performance. Excess fat represents an unneeded handicap, whereas excessively lean dogs may not have sufficient energy stores.

Hydration status should be monitored frequently. Water plays a vital role in supporting cardiovascular function, transport of metabolic substrates and wastes and thermoregulation. Respiratory water losses can be large, particularly during lengthy exercise or under hot or cold environmental conditions.

Ultimately, assessing both exercise and olfactory performance is the best means of monitoring the feeding plan for working and sporting dogs. Generally, what is good for exercise performance is good for olfaction.

ACKNOWLEDGMENT

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CASE 18-1

Poor Performance in Racing Greyhounds

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Patient Assessment

A litter of 14-month-old greyhound dogs (four males, two females) was examined for poor performance. The dogs were owned by a rural mail carrier who recently started a small greyhound farm. This litter of dogs was currently in training and was to begin racing within 60 days. The dogs were being schooled by racing 3/16 mile twice a week at a local training track; however, their performance was not up to the owner's expectations.

The physical examination of all dogs was normal except for a profound overbite (brachygnathia) in two males and one female. All dogs had body condition scores (BCS) of 1/5 and weighed approximately 30 kg each. Fecal examination (composite sample) was negative for parasites. Results of complete blood counts and serum biochemistry profiles from samples obtained from two of the dogs were normal.

Assess the Food and Feeding Method

The dogs were fed individually once daily. They received a ration composed of the following:
2 cups dry puppy food
1 lb raw meat (90% lean)
1 tbs bone meal
1 tbs dry vitamin supplement
1 cup milk

A trainer at a neighboring greyhound farm suggested feeding more meat and adding one-fourth cup vinegar to the ration.

Questions

1. What are the key nutritional factors and dietary recommendations for sprint athletes?
2. What additional information is necessary to fully assess the food and feeding method for these dogs?
3. What recommendations should be made about the food recipe for these dogs?
4. What is an appropriate feeding method?

Answers and Discussion

1. The key nutritional factors for sprint athletes include energy density, fat, digestible carbohydrate, protein, water and food digestibility. The ideal food or ration for sprint athletes should have an energy density between 3.5 to 4.0 kcal (15 to 17 kJ) metabolizable energy (ME)/g dry matter (DM) and contain these levels of nutrients: fat 8 to 10% DM, digestible carbohydrate 55 to 65% DM, protein 22 to 28% DM and DM digestibility greater than 80%. Water should be available at all times except just before a race.
2. Further assessment should include the following: 1) Nutrient levels in the final ration are needed. **Table 1** estimates the key nutrient levels for the current ration. 2) Amount of food fed to each dog and the timing of feeding in relationship to exercise (training). 3) Food safety issues must be addressed for animals that are fed a homemade ration containing raw meat. Greyhounds are frequently fed raw meat that may contain large numbers of bacteria and toxins. Information is needed about how the meat is stored, thawed and handled.
3. The current ration is a typical food for racing greyhounds. The recommendation from the other trainer to increase the meat fraction will increase the protein and fat content of the ration. Although most greyhound trainers believe that meat is essential for optimal performance, the protein and fat content of this recipe is already more than adequate. The appropriate recommendation is to increase the carbohydrate content of the ration by increasing the amount of a balanced commercial dry dog food. This food should be a commercial dry food formulated for adult dogs (lower in fat and protein and higher in carbohydrate than the puppy food). Vitamin and micronutrient deficiencies are unlikely to occur if a balanced commercial dry food makes up at least 50% of the recipe on an as fed weight basis. Cooking raw meat is recommended for homemade dog foods although many greyhound trainers believe that raw meat is vital for optimal performance. Therefore, efforts should focus on meat quality, storage, handling and sanitation (Chapter 11). Food storage and preparation should emphasize sanitation and minimize the opportunity for bacterial growth in the food mixture. Meat should be kept frozen until near the time of use and be cooked to kill bacteria and decrease quantities of heat-labile toxins. Greyhound trainers often use and recommend a wide variety of unusual dietary supplements. However, most of these supplements are unnecessary and no data exist to support their use. Because greyhounds produce large amounts of metabolic acid when racing, adding an acid such as vinegar to the ration is inappropriate.
4. Meals should be fed more than four hours before training or racing. Water should be available at all times except just before racing. Food dose should be adjusted to maintain proper body condition (usually 1/5 or 2/5 for racing greyhounds).

Progress Notes

The recipe was changed to the following:
3 cups dry adult food
0.5 lb meat
1 cup milk
1 tbs vitamin supplement

The recommendations decreased the protein and fat levels and increased the digestible carbohydrate levels of the ration while not markedly changing the overall feeding regimen. Nutritionally speaking, this was not an ideal ration, but rather a compromise between the need to improve the nutrient profile, while maintaining the owner's desire to continue feeding raw meat. **Table 2** lists the key nutrient levels. The owner was pleased with these suggestions and they were implemented as part of the training program.

Table 1. Nutrient levels in the current ration for greyhounds during training.

	Dry puppy food (as fed)	Meat (as fed)	Milk (as fed)	Total ration (as fed)	Total ration (DM)
Moisture (%)	8	68	87	58.3	0
Energy (kcal/g)*	3.95	1.79	0.65	1.87	4.44
Protein (%)	27	21	3.5	17.9	42.8
Fat (%)	18	10	3.5	10.2	24.6
NFE (%)	39	0	4.9	10.9	26
Amount (g)	226	454	244	924	na

Key: DM = dry matter, NFE = nitrogen-free extract (digestible carbohydrate), na = not applicable.
*To calculate kJ, multiply kcal x 4.184.

Table 2. Nutrient levels in the recommended ration for greyhounds during training.

	Dry adult food (as fed)	Meat (as fed)	Milk (as fed)	Total ration (as fed)	Total ration (DM)
Moisture (%)	8	68	87	48.6	0
Energy (kcal/g)*	3.4	1.79	0.65	1.72	3.37
Protein (%)	23	21	3.5	16.6	32.2
Fat (%)	14	10	3.5	9.7	18.9
NFE (%)	49	0	4.9	22	42.8
Amount (g)	340	227	244	811	na

Key: DM = dry matter, NFE = nitrogen-free extract (digestible carbohydrate), na = not applicable.
*To calculate kJ, multiply kcal x 4.184.

Bibliography

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Toll PW. Racing greyhound nutrition: Metabolic considerations. In: Proceedings. Eighth International Racing Greyhound Symposium, Orlando, FL, 1992: 19-21.

CASE 18-2

Weight Loss in a Cattle Dog

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Patient Assessment

A 14-month-old, intact male Australian cattle dog cross that weighed 20 kg was examined for weight loss. A cowboy who worked on a 10,000-acre ranch in the western United States owned the dog. According to the owner, the dog had always been thin but had recently lost weight and was having trouble keeping up when the owner checked cattle on horseback. The owner estimated that the daily ride was about 15 to 20 miles. The dog had been kicked by horses several times in the past and was treated for rattlesnake envenomation three months earlier. There were no apparent long-term health effects from these problems.

The results of a physical examination were unremarkable except for one testicle in the scrotum and a body condition score (BCS) of 1/5. Ideal body weight was estimated to be 25 kg. Fecal examination and heartworm test results were negative. Complete blood count, serum biochemistry profile and urinalysis results were normal.

Assess the Food and Feeding Method

The dog was fed a generic, "high-protein" dry dog food produced at a local feed mill. The food was offered free choice, but the dog usually ate in the morning and evening. The guaranteed analysis on the food bag was as follows: Crude protein, not less than 32%; Crude fat, not less than 11%; Crude fiber, not more than 4%; Moisture, not more than 12%; Calcium, not less than 1.2%; Phosphorus, not less than 0.9%. The ingredient list was as follows: corn, corn gluten meal, rice, meat and bone meal, soybean meal, animal fat, wheat, vitamins and minerals. The nutritional adequacy statement read "provides complete and balanced nutrition for adult dogs as established by the AAFCO Dog Food Nutrient Profiles."

Questions

1. What additional dietary history would be important to obtain for this patient?
2. Outline an appropriate feeding plan (food and feeding method) for this dog, assuming there are no underlying metabolic or medical problems contributing to the weight loss.
3. What client education is appropriate about the feeding plan?

Answers and Discussion

1. The normal physical examination and laboratory database in an otherwise healthy young dog rules out many causes of chronic weight loss. The weight loss could be due to insufficient food intake in the face of strenuous exercise. The actual amount of food that is being offered free choice and the actual amount being consumed by the dog should be documented. This result can be compared with the daily energy requirement (DER) calculated in Answer 2 below.
2. The food for this dog should provide the nutrient levels outlined for intermediate athletic dogs (high duration and frequency) in **Table 18-9**. In general, the food should have moderate protein and carbohydrate levels, high fat levels, high energy density and above average digestibility.

   The estimated DER should include energy for maintenance of young, intact adult dogs (1.8 x resting energy requirement [RER]) plus energy for additional running. RER at an ideal weight of 25 kg = 820 kcal x 1.8 = 1,476 kcal/day (3.4 MJ x 1.8 = 6.2 MJ) for adult maintenance activities. Energy required for a 25-kg dog running 20 miles (33 km)/day = 33 km x 30 kcal/km = 990 kcal/day (4.1 MJ). The added energy cost of running increases the DER to 2,460 kcal (10.3 MJ) (3 x RER). The amount of food to achieve the estimated DER should be divided into two to three meals.
3. The owner should be told that hard work dramatically increases the requirement for calories. By comparison, the need for protein and other nutrients increases only slightly with increasing workload. The idea that athletic dogs require markedly more protein than nonworking dogs is inaccurate. The energy density of the current food is probably less than 3.5 kcal metabolizable energy (ME)/g dry matter (DM), which will not provide enough kcal in the amount of food the dog normally consumes. Using a food with higher fat levels will ensure a higher energy density. A food with 25 to 30% DM fat is recommended. The current food has 12 to 13% DM fat (estimated from the guaranteed analysis).

   The food should also have above average digestibility to ensure that the energy and nutrients are readily available to the dog. The nutritional adequacy statement shows that the food has not undergone feeding trials, which suggests that the digestibility of the food is unknown.

   Routine body condition scoring is the best way to assess whether the appropriate food is being fed in the correct amounts. A food with a higher fat content and higher energy density should be fed free choice until the dog achieves an ideal body condition (BCS 3/5). Then the amount should be adjusted to maintain that weight and body condition.

Progress Notes

The dog was eating 5 cups of the current food per day, which was estimated to provide 1,700 kcal/day (7.1 MJ/day). This caloric intake was clearly inadequate to provide the estimated DER with the added cost of running. The food was changed to a dry commercial specialty brand food (Science Diet Canine Active[a]) with 30.5% DM protein, 26.2% DM fat, 4.4 kcal ME/g DM and DM digestibility exceeding 85%. The new food was gradually exchanged for the old food over several days. The new food was offered free choice until a BCS of 3/5 was achieved, and the daily amount was then stabilized at 2,500 kcal (10.5 MJ) (5 cups) when the dog was working cattle. The amount was decreased to approximately 1,500 kcal (6.3 MJ) (3 cups) on days the dog was not working.

Endnote

a. Hill's Pet Nutrition, Inc., Topeka, KS, USA. This product is currently available as Hill's Science Diet Canine Adult Active Formula.

CASE 18-3

Poor Performance in a Hunting Dog

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Patient Assessment

A five-year-old neutered female golden retriever was examined for collapsing during a game bird hunting trip. The dog was a sedentary house pet for most of the year, but was used as a retriever for game bird hunting each fall. The dog's general health had always been good but its retrieving ability was considered only fair. The dog had received routine heartworm preventive medication since it was a puppy.

On the opening day of hunting season, the dog was fed at 5:30 a.m., loaded in the truck about 6:00 a.m. and began hunting at 7:00 a.m. The dog worked hard through the morning and covered about 10 miles. The weather was unseasonably warm (23.8˚C; 75˚F) for the fall season in the upper Great Plains region of the United States. The hunters and dog took a lunch break from 11:00 a.m. to noon. The dog was given 1 cup of food and water at 11:00 a.m. and snacked on a small bag of potato chips around 11:30 a.m. The dog rested peacefully until noon when hunting resumed. Half an hour after hunting resumed, the dog began to falter, became ataxic and then collapsed. The dog never appeared to lose consciousness or develop seizures.

The dog was carried back to the truck and taken immediately to a veterinary hospital. During the trip to the hospital the dog seemed to improve. The physical examination was normal. The dog weighed 30 kg and had a body condition score of 3/5. Heart rate and heart sounds were normal with no pulse deficits. Hydration status was normal. Packed cell volume and serum glucose concentration were normal. A heartworm test was negative.

Assess the Food and Feeding Method

The dog was fed a commercial private label brand dry food formulated for adult dogs. The owners fed the dog one meal daily (1,500 kcal [6.3 MJ]; 4.5 cups) at 7:00 a.m. before they went to work. The dog received several biscuit treats in the evening and occasionally leftover food from family meals.

Questions

1. What are possible causes of the dog's collapse during the hunting trip?
2. What education should be provided to the owner about management of the dog?
3. What food should be recommended for this dog during the hunting season?
4. What feeding methods should be used during the hunting season?

Answers and Discussion

1. Causes of sudden collapse of a healthy appearing dog while hunting include hyperthermia, dehydration, hypoglycemia, heartworm disease, cardiac dysrhythmia and/or muscle cramping. Heartworm disease is unlikely based on the history of a good preventive medication program and negative heartworm test. A cardiac dysrhythmia may have occurred in the field and spontaneously resolved during travel to the veterinarian. Dehydration is unlikely because the dog received water during the lunch break and no clinical evidence of dehydration was found. Hyperthermia may have occurred due to excessive work in a warm environment, but the dog's rectal temperature was not elevated at the hospital. Transient hypoglycemia may have occurred. Muscle cramping may accompany electrolyte abnormalities, dehydration and poor training and conditioning.
2. The dog was poorly trained and went from being a sedentary house pet to working dog very abruptly. Physical training should begin about six weeks before hunting season for part-time athletes such as this dog. One hour of brisk walking each day is a good starting point. The dog should work for several hours at an intensity level similar to what is expected in the field during the last two weeks of training. Besides improving exercise tolerance, such a training program would likely improve olfactory ability. Preseason exercise is also recommended to prepare the dog's footpads for the work in the field.
3. A performance-type food (**Table 18-12**) should be recommended if the dog is to be used frequently for long periods of time during the hunting season. Performance foods are usually higher in fat, the preferred muscle fuel for longer lasting exercise and improved olfaction. Olfaction is further enhanced if the fat contains a significant amount of unsaturated fatty acids. Also, higher fat levels increase a food's energy density, which is needed for additional work in the field. A 30-kg dog traveling 10 miles requires 480 kcal (2.0 MJ). The food should be changed well before hunting season (preferably six weeks before) to allow for metabolic adaptation. Adaptation allows a dog to take full advantage of the higher dietary fat content.
4. Timing of feeding is also important. Working dogs should be fed four or more hours before exercise to allow some time for food assimilation and for blood glucose and insulin concentrations to return to normal. Snacks during exercise are helpful. However,

they should be spaced throughout the day and each snack should compose no more than 10% of the normal daily food amount. Feeding at the end of a break will cause less blood glucose disturbance.

Progress Notes

The food was changed to a commercial specialty brand dry food that was higher in fat, energy density and digestibility (Science Diet Canine Active[a]) than the previous food. The owner reported that the dog performed well through the rest of the hunting season with no further collapsing episodes. In addition to the change in feeding plan, the dog now runs four to five miles several times weekly with the owner's daughter.

Endnote

a. Hill's Pet Nutrition, Inc., Topeka, KS, USA. This product is currently available as Hill's Science Diet Canine Adult Active Formula.

CASE 18-4

Diarrhea in a Team of Sled Dogs

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Patient Assessment

A team of Alaskan husky-type dogs was examined for recurrent bouts of hemorrhagic diarrhea during exercise. The owner was a neophyte musher from upstate New York and noted that the dogs were eating well and eager to work. However, they would defecate loose feces during and immediately after each training run. Sometimes the feces were flecked with bright red blood. At other times during the day, the feces were of normal consistency without blood. At the time they were examined, the dogs were running four 10-mile training sessions each week.

Physical examination revealed a group of bright, alert, well-hydrated dogs with an average body weight of 20 kg. Muscle tone and mass were slightly greater than is usual for sedentary dogs. Their body condition score (BCS) was 2/5. Their overall condition was judged to be normal for this breed at this stage of training. The only abnormality noted on physical examination was mild brown staining of the hair on the ventral aspects of the tail and caudal aspects of both hind limbs.

The results from fecal smears and flotation tests for parasite ova, blood and abnormal bacteria were negative. Manual rectal palpation results, hematocrit and total solids measurement were normal.

Assess the Food and Feeding Method

The owner was feeding a dry commercial dog food with the following guaranteed analysis: Crude protein, not less than 26%; Crude fat, not less than 12%; Crude fiber, not more than 9%; Moisture, not more than 10%; Ash, not more than 8%. The dogs did quite well on this food during the summer and early fall training. By November, with the cold, wet climate and increased training mileage, the owner was feeding twice the volume of food he fed during the summer. Each 20-kg dog was receiving 800 g of food per day to maintain body weight. The dogs were fed half that amount in the morning (8:00 a.m.) and half in the evening (8:00 p.m.). The training runs usually occurred around noon.

Questions

1. What is the most likely cause of the diarrhea observed in these dogs?
2. What characteristics of the food and feeding method might have contributed to the diarrhea?
3. What recommendations should be made to the owner to prevent this problem from continuing?

Answers and Discussion

1. The observation that the dogs had normal feces except during and immediately after running suggests that stress or physiologic diarrhea is the most likely diagnosis. This problem is usually observed when exercise takes place while feces remain in the lower gastrointestinal tract.
2. The food is relatively low in fat and energy density for a performance ration; therefore, a large volume of food must be fed to meet the increased energy requirements associated with intense training and cold environmental temperatures. Feeding a large volume of food and feeding close to the time of exercise increases the fecal volume present during exercise. One theory is that the constant concussion between feces and colonic mucosa, termed "cecal slap," may irritate the colonic mucosa and alter colonic

motility, thereby inducing diarrhea during and immediately after exercise.

3. The musher should switch to a commercial food with a higher fat content and energy density so that a smaller volume can be fed (**Table 18-12**). For sled dogs exercising once a day, a single meal given within two hours after exercise will give maximal time for ingesta to pass completely through the gastrointestinal tract before the next exercise session.

Progress Notes

The dogs' food was changed to commercial performance ration (Eukanuba Original[a]) containing 32% protein and 20% fat (as fed). Each day, the dogs were fed approximately 500 g of the commercial food and 2 oz. of a fat supplement (poultry fat, beef tallow or corn oil) within two hours postexercise. Within two weeks, the problem had resolved in all dogs and defecation during performance was nearly eliminated.

Endnote

a. The Iams Co., Dayton, OH, USA.