Abstract

Sallander, M. 2001. *Diet and activity in Swedish dogs.* Doctor's dissertation.
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In this thesis the demographics, diet and activity in a defined population of 460 insured Swedish dogs between 1 and 3 years was presented. The data was collected by using a mail and telephone questionnaire. The repeatability (the questionnaire repeated to the same dog owners) and validity (questionnaire compared to 7-day weighed registration of dietary intake and recording of activity) of the questionnaire were examined, and shown to be good to excellent for most of the parameters measured. Also, the most commonly used commercial dog feeds were analysed, and the results were compared to the declared values and to the recommended nutrient profiles.

The insured dogs were shown to be representative for all Swedish dogs of the same age. A typical Swedish dog consumed 75% of the energy intake from commercial feeds, and a smaller part as table foods, but with large variations between individuals. Most of the dogs were fed total diets supplying adequate amounts of the nutrients compared to the recommended nutrient profiles. Total diets that did cause deviations from recommended levels were most commonly those consisting of only table foods (too low levels of vitamins and minerals) or commercial feeds supplied with extra vitamin and mineral supplements (too high levels of vitamins and minerals). The total energy intakes were comparable to previously published studies on maintenance energy requirements of adult dogs, but varied due to sex, breed and weight.

Three quarters of the dogs performed some type of activity for one hour or more per day, but although substantial variations were recorded, there was no significant difference in energy intake that could be related to the amount of activity recorded. There was a tendency (P=0.07) that the general temperament of the dog had an influence on the energy intake.

The analysed protein and fat content in commercial feeds was on average highly correlated with the declared values and with the recommended nutrient profiles. However, especially the calcium but also other minerals of commercial dog feeds often deviated from declared values, and did not always meet the AAFCO (2000) nutrient profiles. More expensive feeds had the same magnitude of deviation from declared energy and nutrient values as did feeds of a lower cost.

This validated questionnaire could be used to collect data on dietary intake and activity in future epidemiological studies in order to quantify the influence of these factors of the effects on health and disease in defined populations of dogs.

Key words: *Dog, canine, population, insured, demographics, telephone, questionnaire, survey, weighed record, Sweden, validity, repeatability, diet, feed, food, energy, protein, fat, carbohydrate, vitamin, mineral, activity, exercise, training, health, epidemiology.*

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Sammanfattning

Sallander, M. 2001. Svenska hundars kost och motionsvanor. Doktorsavhandling.
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I denna avhandling presenteras demografiska data för 460 försäkrade svenska hundar mellan ett och tre år, deras matvanor samt levnads- och aktivitetsmönster. För att undersöka dessa parametrar har en kombinerad post- och telefonenkät använts. Tillförlitligheten på de svar som angivits i enkäten har undersökts genom att såväl reproducerbarhet (enkäten upprepad till samma hundägare) som validitet (enkät jämförd med 7-dagars vägd registrering av födointag och registrering av aktivitet) utförts. Enkäten hade medelhög till mycket hög reproducerbarhet, och speglade väl det födointag som angivits i den vägda registreringen. De i enkäten mest använda hundfodren analyserades, och resultaten jämfördes med deklarerade näringsvärden och med hundars näringsbehov.

De försäkrade hundarna visade sig vara representativa för alla svenska hundar i samma ålder. Den typiska svenska hunden konsumerade 75% av det totala energiintaget från kommersiella hundfoder, men andelen varierade mycket mellan individer. De flesta hundar åt en kost som innehöll de undersökta näringsämnena i rätta proportioner. De individer som avvek från detta mönster var oftast de som åt enbart matrester (för låga nivåer av vitaminer och mineraler) eller de som åt kommersiella helfoder kompletterade med extra vitaminer eller mineraler (för höga nivåer av vitaminer och mineraler). Energiintaget för hundarna i denna studie var jämförbart med tidigare publicerade studier av vuxna hundars underhållsbehov, men varierade med kön, ras och vikt.

Tre fjärdedelar av hundarna motionerades eller tränades minst en timme per dag, men trots att en stor variation registrerades mellan individer, kunde inget signifikant samband mellan energiintag och aktivitet påvisas. Däremot fanns det en tendens (P=0.07) att hundens generella temperament hade betydelse för energiintaget.

Analyserade värden för protein och fett i kommersiella hundfoder stämde generellt sett väl med deklarerade värden och med hundens näringsbehov. För mineraler, speciellt kalcium, avvek dock många foder från uppgivna värden och ibland dessutom från rekommenderade näringsbehov. Dyrare foder avvek i samma utsträckning som billigare foder ifrån deklarerade värden och ifrån näringsnormen.

Den validerade enkät som utvecklats inom ramen för denna avhandling kan i framtida epidemiologiska studier användas för att undersöka kostens och aktivitetens betydelse för hälsa och sjukdom i en väldefinierad hundpopulation.

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"Tell me what you eat and I'll tell you what you are"
Anthelme Brillat-Savarin, 1825

To my family

Contents

Appendix

Papers I-V

The thesis is based on the following papers that will be referred to in the text by Roman numerals:

I. Sallander, M., Hedhammar, Å., Rundgren, M. & Lindberg, J. E. 2001. Demographic data of a population of insured Swedish dogs measured in a questionnaire study. *Acta Veterinaria Scandinavica 42*, 41-50.

II. Sallander, M., Hedhammar, Å., Rundgren, M. & Lindberg, J. E. 2001. Repeatability and validity of a combined mail and telephone questionnaire on demographics, diet, exercise and health status in an insured-dog population. *Preventive Veterinary Medicine 50 (1-2),* 35-51.

III. Sallander, M., Hedhammar, Å., Rundgren, M. & Lindberg, J. E. 2001. Dietary Intake in a Dog Population Measured by a Validated Questionnaire. *Submitted to the Journal of Animal Physiology and Animal Nutrition.*

IV. Sallander M, Hagberg M, Hedhammar Å, Rundgren M & Lindberg J E. 2001. Energy intake and activity in a population of dogs. *Submitted to the Journal of Animal Physiology and Animal Nutrition.*

V. Sallander M, Hedhammar Å, Rundgren M, Lindberg J E. 2001. A study of the nutrient and energy content of commercial dog feeds. *In manuscript.*

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Background

Most people are aware of the fact that pets play an important role in society, and that they have an impact on humans, both socially, physically, psychologically and economically. In Sweden, there are approximately 800,000 dogs, and 16% of the Swedish households own at least one dog. Today, most Swedish dogs are considered as family members, and based on data presented by Manimalis (2000), approximately 2.5 million people are involved in dog ownership.

Beside the owners of dogs, many others are economically involved in the pet sector, i. e. breeders, feed manufacturers, insurance companies, dog organisations and companies, dog trainers and veterinarians. For example, the Swedish Kennel Club and the associated organisations had an annual turnover of over 200 million Swedish Crowns (SEK), engaging 270,000 members (SKC, 2001). Moreover, dogs are the fourth largest consumer of animal feed in Sweden, and the turnover of dog and cat food is estimated at approximately 2.5 billion SEK per year (Henrik Jansson, DLF, *personal communication*, 2001). The whole pet sector in Sweden has an annual total turnover of 5.5 billion SEK (Manimalis, 2000).

In Sweden, 87% of the dogs are pure-bred and the Swedish Kennel Club registers three fourths of these individuals. Dachshunds (7.4%), German shepherds (7.0%), Golden retrievers (5.0%) and Labrador retrievers (4.9%) are currently the most common breeds in Sweden. Dogs are mainly kept for company, hunting, guarding, and for various types of competition and breeding (Egenvall *et al*., 1999). Moreover, two thirds of all Swedish dogs are enrolled in health insurance schemes, providing data suitable for epidemiological investigations of the Swedish dog population (Egenvall *et al*., 1999). In Sweden, there have been efforts to register certain health parameters of pure-breed dogs for more than 20 years. Data on morbidity, mortality (Bonnet *et al*., 1997; Egenvall *et al*., 1997, 2000; Egenvall, 1999) and the genetic background to some diseases (Swenson *et al*., 1996; Swenson *et al*., 1997a, 1997b; Swenson, 2001) have been published. However, national baseline data on important environmental factors, such as diet and exercise, have so far been limited. Such data are crucial in order to be able to identify and study factors that might have an influence on the health and disease in the Swedish canine population.

Introduction

The digestive system of the dog

Being something between a carnivore and an omnivore, the digestive system of the dog differs somewhat from the traditional farm animals (Fig. 1). The jaw of a dog is formed as a predator's, with the first molar teeth in the lower jaw cutting the feed into pieces, and possibly crushing bones. With the exception of bones, the dog often chews food poorly (Meyer, 1990).

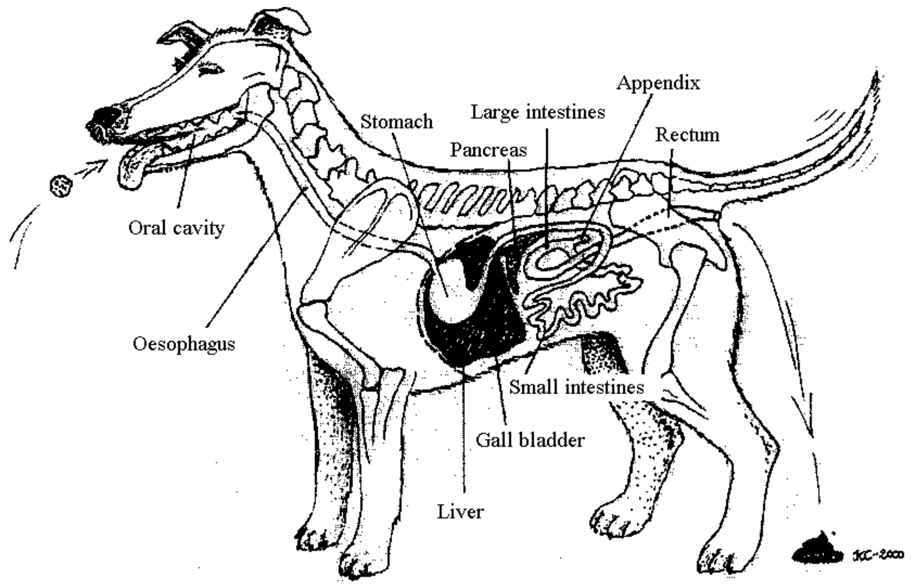

Figure 1. The digestive system of the dog. Drawing by Katarina Cvek-Hopkins.

The dog has a capacity to consume large quantities of food at once. As the stomach can be enlarged approximately 5 times when full compared to when empty, it has the ability to hold around 2/3 of the gastrointestinal contents. The length of the intestines is only 5-6 times the length of the body, and the undigested feed constituents have normally passed the intestines in 24-30 hours (Meyer, 1990). Compared to many other species, the dog has a very small capacity to digest most fibre types due to a very limited microbial fermentation in the large intestine. For example, cellulose is considered non-digestible, while beet fibre is partly digestible and is used in many dog feeds to improve gastrointestinal health (Clemens, 1996).

Energy

Along with exercise and health care, proper feeding is one of the most important components in the care of dogs. Dogs must be fed a diet sufficient in energy and all nutrients in order to maintain health in all stages of life. Both dogs and traditional farm animals are fed to support good health, but in contrast to farm animals, most dog diets do not aim to maximise growth or milk yield, but rather to enhance the longevity of the animal. Energy is required for normal growth, maintenance, reproduction and physical activity, and is provided by proteins, fats and carbohydrates.

Measurement of energy in feeds

The gross energy (GE) of a feed is the energy released when the feed is combusted. Due to incomplete digestion, energy losses occur with the excretion of faeces, and the remaining energy is referred to as the apparent digestible energy (DE). To calculate the metabolisable energy (ME), losses of energy in the urine and in combustible gases have to be subtracted from the DE (Blaxter, 1989). For the dog, there is a minimal production of combustible gases, which is why these losses are normally not accounted for. ME is the value most commonly used to express the energy content in commercial dog feeds and in dietary requirements of dogs, but sometimes the DE is used. ME can be further divided into the net energy (NE) and heat increment of feeding (HIF), where NE is the energy available to the tissues for maintenance, growth, reproduction and physical work (Blaxter, 1989).

The ME content of a diet or ingredient depends on the animal consuming it and the nutrient composition of the food. The ME can be derived from feeding trials with total collection of urine and faeces, from calculation based on the contents of protein, fat and nitrogen-free extracts (NFE), or by extrapolating data from other species. The ME values obtained in feeding trials are the most accurate, and are regularly performed by some manufacturers of dog feeds. However, they are expensive and require access to a number of animals. A cheaper and more simple method to estimate the ME content is by calculations from the dietary content of protein, fat and NFE using the modified Atwater factors (14.6 kJ/g for protein and NFE, and 35.6 kJ/g for fat). These factors assume an average digestibility of 80% for protein, 90% for fat and 85% for NFE (NRC, 1985).

Energy and nutrient density

The energy density of a feed refers to the energy provided in a given weight, often given as kilojoule (kJ) or megajoule (MJ) per g dry matter (DM). The nutrient density must be high enough both to satisfy the energy demands, and also to supply the dog with sufficient amounts of the nutrients needed. The nutrient density can be expressed on a DM-basis or as the nutrient concentration per energy unit (% DM, g or mg/kJ or MJ). Also, the proportion of the energy originating from protein, fat and NFE is sometimes calculated and is referred to as the energy percentage or energy distribution (Hand *et al*., 2000).

Energy balance

An animal is in energy balance when energy expenditure (EE) corresponds to the energy intake. Lewis *et al*. (1987) showed that for 120 dogs kept under similar conditions and fed to maintain body weight (BW), the ME intakes ranged from 45 to 150% of the average. If an animal consumes more or less than required, this leads to a positive or negative energy balance, respectively, resulting in a weight gain or loss. Today, it is more common that dogs suffer from obesity than that they are too lean (Crane, 1991). Over-consumption of energy during growth has been shown to increase the risk for skeletal diseases, including osteochondrosis and hip dysplasia, especially in large breeds (Hedhammar *et al*., 1974; Kasström, 1975). Later in life, obesity may lead to diabetes (Mattheeuws *et al*., 1984).

Energy expenditure

The energy expenditure (EE) can be divided into the basal energy metabolism (BMR), the voluntary muscular activity, the heat increment of feeding and the adaptive thermogenesis. For non-lactating inactive adult dogs, the BMR is the largest proportion of the EE, and is defined as the energy needed in a thermoneutral environment after a nights fast. Factors influencing the BMR are gender, age, reproductive and hormonal status, body composition and body surface area. The amount of lean body mass has a strong correlation to the BMR (Ravussin *et al*., 1982). The muscular activity is the most variable component of the EE, and the amount used for muscular activity depends on weight and size of the dog, and duration and intensity of the work performed. The HIF represents a small proportion (approximately 10%) of the EE, and is influenced by the energy and nutrient composition of the meals and the nutritional state of the animal. In humans, the size of the adaptive thermogenesis varies with external temperature, alternations in feed intake and with emotional stress (Horton, 1983).

Energy metabolism and body size

The amount of energy needed for animals ranging in size from a mouse to an elephant was described by Brody (1945) in the equation BMR = $70.5W^{0.73}$ (kcal/day). In 1961, Kleiber argued that the exponent 0.75 would not be significantly different from 0.73, so for many years the exponent 0.75 has been used. Later, Heusner (1982a, b) showed that the use of the interspecific mass exponent 0.75 is a statistical artefact. He suggested that within species, the factor 0.67 could be used.

Energy requirements

The maintenance energy requirements (MER) of dogs reveal a huge variation in estimated energy needs, probably due to variation in methods, dog breed and number of animals. The MER is based on factors such as weight, breed, activity, temperament, fur, age, body condition, environmental temperature, and stage of life. A number of equations have been suggested, and the estimates differ largely (Table 1).

Table 1. Estimates of energy requirements based on equations suggested for MER in dogs (kJ/day)

Weight	NRC, 1985[1]	NRC, 1974[2]	Germ. Soc. Nutr. Phys., 1989[3]	Rainbird & Kienzle, 1990[4]	Case *et al.*, 2000[5]
1	417	553	401	640	552
5	1719	1,849	1,341	1,912	1,622
10	3163	3,110	2,255	3,063	2,581
20	5821	5,230	3,792	4,908	4,106
30	8318	7,089	5,140	6,466	5,388
40	10,714	8,796	6,378	7,862	6,533
50	13,039	10,398	7,540	9,151	7,587
60	15,308	11,922	8,645	9,764	8,573
70	17,532	13,383	9,704	11,504	9,505

[1]NRC, 1985: ME=417W$^{0.88}$ kJ/day
[2]NRC, 1974: ME=553W$^{0.75}$ kJ/day
[3]German Society of Nutritional Physiology, 1989, inactive dogs: ME=401W$^{0.75}$ kJ/day
[4]Rainbird & Kienzle, 1990: ME=640W$^{0.68}$ kJ/day
[5]Case *et al.*, 2000, active dogs: ME=552W$^{0.67}$ kJ/day

The MER given above (Table 1) are for adult maintenance. For growing, working, pregnant or lactating dogs and those in a cold environment, an addition for these factors is needed. Growing puppies younger than 2 months of age generally require more than 2 times as much energy per unit of body weight as adult dogs of the same breed. The extra energy needed per kg BW for puppies compared to an adult of the same weight declines with age. Small breeds need extra energy until the age of 6-8 months, while large breeds require extra until 18-24 months of age. Bitches demand slightly more energy during gestation than during maintenance, and in the last third of the gestation, the energy requirement might increase by 10-50%. The lactating bitch and hard-working dogs might have 3- to 4-fold higher energy requirements compared to maintenance (Lewis *et al.*, 1987).

Protein

Protein is necessary to meet the need for amino acids and nitrogen in the body. Amino acids are used for protein synthesis in growth, pregnancy, lactation and tissue repair. In addition, amino acids supply the body with nitrogen, which is used when synthesising non-essential amino acids and other compounds containing nitrogen, for example nucleic acids. Amino acids might also be used as energy, yielding 14.6 kJ ME/g (AAFCO, 2000).

Proteins are the major structural components to build claws, fur, ligaments, muscles, sinews and skeleton. Also, proteins form enzymes (e. g. proteases, lipases and carbohydrases), hormones (e. g. insulin), act as carriers (e. g. transferrin) and transport oxygen (e. g. hemoglobin) in the blood. Contractile proteins such as myosin and actin act as regulators in muscle work. Importantly, antibodies are large protein molecules.

Amino acids

There are 22 alpha-amino acids found in protein chains, and ten of these are essential to the dog; arginine, histidine, isoleucine, leucine, lysine, methionine, phenylalanine, threonine, tryptophan and valine (Hee Haa, 1978; Milner, 1979, 1981; Burns *et al*., 1981). The need for amino acids declines as the puppy becomes adult.

Protein digestibility

The protein digestibility varies with for example type of product, processing technique, and the presence of fibre. The protein digestibilities of lung, tripe, minced meat and soybean meal have been compared by Neirinck *et al*. (1991). High digestibility coefficients were reported for the animal products (90, 94 and 93%, respectively), while the vegetable protein had a lower value (76%). Hegstedt *et al.* (1947) reported that the digestibility for protein ranged from 72 to 88% in an all-vegetable dog diet, and from 83 to 97% when one third of each dietary ingredient was changed to protein from meat. The NRC (1985) stated that the average digestibility of proteins in dog feeds could be estimated as 80%. More recently, commercial dog feeds have been shown to have digestibilities between 75 and 90% (Carey, 1993).

Protein quality

In addition to a high availability of the protein, the profile of the digestible amino acids has to be suitable to the needs. A number of methods to measure the protein quality have been suggested, and the biological value (BV) is the one of the most commonly used. The BV is a measure of the proportion of the digestible nitrogen that is retained ((dietary N-faecal N-urinary N)/(dietary N-faecal N)). Studies to measure the BV are often made with rats as a model animal. One problem with the BV is that it is expressed in percent of the digestible protein and does not account for the total amount of digestible protein in the feed. The net protein utilisation (NPU) is the BV multiplied with the digestibility, and measures the proportion of the total feed nitrogen that is retained by the body. The amino acid profile of different feed ingredients might supplement each other. This means that the BV of a diet might be higher than the weighed mean of the ingredients.

The amino acids that are most commonly limiting in dog feeds are methionine, tryptophan, and lysine (Bovee & Kronfeld, 1981), but arginine, valine and isoleucine have also been reported to be limiting in some dog feeds (Kronfeld, 1982).

Protein requirements

The requirements of protein can be defined as the minimum intake that gives an optimal performance (Schaeffer *et al*., 1989). Commonly, nitrogen balance or growth rate studies have been used to estimate the needs. The nitrogen balance is calculated as the intake of N minus the excretion of N in the faeces and in the urine. The need for protein in the diet depends upon amino acid composition, protein digestibility, energy density of the food, prior nutritional status and physiological state of the individual (Payne, 1965; Burns *et al*., 1982; Schaeffer *et al*., 1989).

Protein deficiency and excess

Dogs that suffer from a protein or amino acid deficiency show retarded growth and/or weight loss, decreased reproductive ability and work capacity. If both energy and protein are deficient, lethargy, reduced digestive efficiency and a lower resistance to infections might result (Maynard *et al*., 1979).

If protein is given in surplus, it can be used as energy (14.6 kJ ME/g; AAFCO, 2000) either directly after deamination or stored as fat in the body. Previously, it has been suggested that high levels of protein might increase the risk for chronic kidney disease (Brenner *et al*., 1982; Murphy, 1983). However, there is no strong evidence that healthy dogs have an increased risk of chronic kidney disease due to a high protein intake.

Fat

Fat is a mixture of a number of compounds, for example triglycerides (TG), waxes, lipoproteins and sterols. Dietary fat is mainly made up of the TG's, and is a concentrated source of energy. Fat provides essential fatty acids, carries fat-soluble vitamins (A, D, E, K) and gives taste and texture to the food. Fat is a constituent of all cell walls and has a number of specific functions, for example in the nervous system.

Fatty acids

Triglycerides are decomposed into their constituents fatty acids and glycerol during digestion. Fatty acids vary in chain length and may be saturated or unsaturated. Most fatty acids in feeds are long chain fatty acids with 16-26 carbon atoms. The saturated fatty acids have no double bounds between the carbon atoms as do the unsaturated. Generally, fats of animal origin contain more saturated fat than vegetable fats. Most plant oils contain 80-90% unsaturated fat, except for palm, olive and coconut oil. Animal fats contain 50-60% unsaturated fat (NRC, 1985).

The fatty acids can also be divided into the n-6 and the n-3 families, where the figures 6 and 3 denotes the site of the first double bond in the carbon chain from the methyl end. So far, only linoleic acid (C18:2, n-6) has been proven to be essential for the dog (NRC, 1985; AAFCO, 2000). Recently, there have been suggestions that the feed should also include the n-3 fatty acids, for example alfa-linolenic acid (C18:3, n-3) available in high amounts in fish oil, mainly to promote skin health (Reinhart, 1996). The metabolites of the n-6 fatty acids might yield 2-series prostaglandins and 4-series leukotrienes during an inflammatory response. These metabolites are more immunosuppressive than the 3-series prostaglandins and 5-series leukotrienes formed by the n-3 fatty acids (Samuelsson, 1991). When there is a ratio between the n-6 and n-3 fatty acids corresponding to 5-10:1, significantly lower levels of 4-series leukotrienes and significantly higher levels of 5-series leukotrienes are formed in the skin compared to when feeding a ratio of 28:1 or higher to healthy dogs (Vaughn *et al.*, 1994). However, many studies addressing this topic provide insufficient data, which makes it difficult to interpret the results obtained. For example, only two studies out of eight scrutinised stated the natural fat content of the feed when analysing possible effects of supplemented fatty acids (Hazewinkel *et al.*, 1996; Wander *et al.*, 1997). Also, only one out of eight studies reported the fatty acid pattern in the feed (Scott *et al.*, 1997). Consequently, more studies need to be done to support the proposed need for n-3 fatty acids in the diet, both for healthy dogs and for those suffering from skin problems.

Digestibility

Fat is digested in the small intestine, and the digestibility of fat is generally very high, ranging from 80 to 95%, depending on source of food. Neither the molecular weight nor the degree of saturation have been shown to have any significant effect on the apparent digestibility of the fats or oils by 10 days old pups (Lloyd & Crampton, 1957). Huber *et al*. (1986) reported that the digestibility of fat from different commercial feeds ranged between 70 and 90%. A large proportion of fat in the diet generally makes the passage through the intestines slower, which increases the digestibility. High amounts of calcium and magnesium might lower the digestibility, as these minerals contribute to soap formation.

Fat as an energy source

Triglycerides are the major source of energy store in the body, yielding on average 35.6 kJ ME/g (AAFCO, 2000). For hard-working dogs, fatty acids are the primary source of energy in the skeletal muscle. Consumption of a high-fat (65% of energy) diet has been shown to increase the maximal rate of fat oxidation in the muscle and the maxiumum VO_2 by approximately 50% compared to a high carbohydrate diet (65% of energy). This increased the ability of dogs to perform endurance work by approximately 30% (Reynolds *et al*., 1996).

Fat requirements

The fat requirement varies with the content of essential fatty acids in the diet and how much fat the animal needs for energy consumption. Moderately active dogs are maintained on diets with 5-8% fat, including at least 1% of the diet as linoleic acid on a DM-basis (AAFCO, 2000). If the nutrient requirements are met, dogs can be maintained on diets with a large variation (13-76%) of the energy originating from fat (Romsos *et al*., 1976).

Deficiency and excess of fat

If the diet is deficient in fatty acids, the fur becomes dry and coarse, eventually with skin lesions and hair loss. Also, these dogs might suffer from otitis externa and an itching and greasy skin (Codner & Thatcher, 1990). Feeding a higher level of fat than can be digested might result in diarrhoea. On the other hand, if fat is supplying a surplus of energy to the dog, it leads to obesity (Edney & Smith, 1986; Hand *et al*., 1989).

Carbohydrates

Carbohydrates are an economical and common source of energy for dogs, and are often the major energy-yielding nutrient in practical dog diets. Carbohydrates can be classified as mono-, di-, and polysaccharides. Examples of monosaccharides are glucose, fructose and galactose. Lactose, sucrose and maltose can exemplify the disaccharides. Examples of polysaccharides are glycogen, starch and dextrins. These carbohydrates are all digested in the small intestine. The polysaccharides hemicellulose, pectin and cellulose are the main part of the fibre fraction.

Carbohydrates have several functions in the body. Glucose is used for example by the central nervous system and has many other functions in the body. Glycogen stored in the muscles or liver might be used as fuel when necessary. Carbohydrates are also used as substrates when forming for example the non-essential amino acids, lactose and vitamin C. Fibres assist in the proper functioning of the gastrointestinal tract (Hand *et al*., 2000), increase satiety (Jackson *et al*., 1997), and might decrease transit time and digestibility (Burrows *et al*., 1982).

Digestibility

Mono- and disaccharides are usually totally absorbed and starch is generally well digested by the dog, in some cases just as well when raw as processed. For example, raw wheat starch is digested to 91-97%, while the processed product is digested to 99%. Raw and processed maize starch is digested to 94-99 and 99%, respectively. However, raw starch from potatoes is only digested to 0-20%, while the boiled product is digested to 95% (Meyer *et al*., 1981).

Lactose and sucrose might cause problems when fed in larger amounts to dogs, but most adult individuals tolerate 1-2 g lactose per kg BW and day (Meyer, 1990). Although not shown in dogs, the sucrase activity in young animals have been shown to be low in other species. Therefor, high amounts of sucrase should be avoided in diets fed to pups (NRC, 1985). Adult animals have been shown to digest sucrose well if a slow adaptation is allowed, and 5 g of sucrose per kg BW and day might be tolerated (Meyer, 1990).

Fibres

Fibre is plant material that consists primarily of cellulose, hemicellulose, pectin and gums and mucilages. Also, the plant fibre fraction contains lignin, a non-carbohydrate phenyl propane polymer. Fibres are digested by bacterial enzymes in the large intestine producing short-chain fatty acids (SCFA) such as acetate, propionate and butyrate. The fibre digestion depends on type of fibre, gastrointestinal transit time, and intake of other dietary constituents (van Soest, 1973). In dogs, pectin, cabbage fibre and guar gum have been shown to have a high fermentability, while beet pulp, rice bran, gum arabic and xanthan gum have been shown to be moderately fermentable. In a study by Reinhart & Sunvold (1996), cellulose, carboxymethylcellulose, and methylcellulose were shown to be non-fermentable.

Dogs have a relatively short gastrointestinal tract, and the total energy contribution from fibre is small. Recent research has shown that dogs fed moderately to highly fermentable fibres have increased colon weights, mucosal surface area and mucosal hypertrophy (enlargement of existing cells) compared with dogs consuming a non-fermentable fibre source. However, the dogs fed the highly fermentable fibres had loose stools, resulting in a higher degree of cryptitis (inflammation of the mucous membrane of the anal crypts; Reinhart *et al*., 1994). Therefor a moderately soluble fibre is recommended to be included in dog feeds.

Need for carbohydrates

Although most practical diets contain a considerable amount of carbohydrates, it is possible for dogs to be maintained without any carbohydrates if the content of glucose precursors (amino acids and glycerol) is high enough (Blaza *et al*., 1989). Kienzle & Meyer (1989) carried out an experiment where pregnant Beagle and Setter bitches were divided into three groups. The first group was given a control diet (with 30% of the energy from carbohydrates and 12g digestible protein/MJ). The second group consumed a carbohydrate-free diet with a high level of protein (20 g digestible protein/MJ), and the third group also were fed a carbohydrate-free diet but with a lower protein level (10 g digestible protein/MJ). Puppies born in the second group were not significantly different from the control group. In the third group, 18% of the puppies were stillborn, and 75% died soon after birth. The authors concluded that glucose was the metabolite missing in the third group of puppies, and that higher protein levels have to be included for proper gluconeogenesis.

Sled dogs running for long periods were studied for 28 weeks by Kronfeld *et al*. (1977). The dogs were divided into three groups, consuming protein, fat and NFE in the proportions 39:61:0 (diet A), 32:45:23 (diet B), and 28:34:38 (diet C) on an energy-basis. The group given diet A had a higher oxygen carrying capacity in the blood, and a higher level of free fatty acids than the other groups.

Minerals

Minerals are essential for the metabolism and constitute approximately 4% of the BW of the dog. The minerals are often divided into the macrominerals (Ca, P, Mg, S, Na, K, Cl) and the microminerals (Fe, Cu, Zn, Mn, I, Se, Co, Cr). Minerals are catalysts in enzymatic reactions, provide skeletal support, enhance nerve transmission and muscle contractions, and function in maintaining the electrolyte balance. Minerals interact, and an excess of one mineral might decrease the uptake of another mineral.

Calcium, phosphorus and magnesium

Calcium and phosphorus are the main constituents of bone, and 99% of the body content of calcium and 85% of the phosphorus is found there. Calcium also has important functions in for example the transmission of nerve impulses, muscle contraction, blood coagulation, and cardiac function. The phosphorus found outside the skeleton is a constituent of the DNA, RNA, some B-vitamin coenzymes, and the cell membrane phospholipids. Also, phosphorus is an important component in the energy metabolism (AMP, ADP, ATP; Case *et al*., 2000). The ability to retain calcium and phosphorus varies with age. In a study by Hoff-Jörgensen (1946), the retention was shown to be a little higher during the 3rd and 4th month after birth, than during the rest of the 200 days of the trial. There have been reports of utilisation of calcium varying from 0 to 100% depending of the dietary sources and amount included, age of the animal and the total calcium level in the diet (Jenkins & Phillips, 1960; Hedhammar, 1980). Calcium and phosphorus are generally less available in vegetable products than in animals products, and in grains phytate can reduce phosphorus availability to only 30%. A calcium-phosphorus ratio of 1.2-1.4 is optimal for utilisation of these minerals (AAFCO, 2000). If a deficiency of calcium and phosphorus occurs, rickets or osteomalacia might be the symptoms. If calcium is given in excess, the skeletal development might be impaired especially in large breeds (Hedhammar *et al*., 1974; Hazewinkel *et al*., 1985), while if phosphorus is given in excess, nutritional secondary hyperparatyroidism might result.

Between 60 and 70% of the magnesium in the body exists in the bones, and most of the rest is found in the intracellular fluid. Magnesium provides structure to the bones, helps in muscle and nerve action, and is important for the intracellular metabolism of carbohydrates and protein. A deficiency may lead to soft-tissue calcification. The uptake is regulated by the needs and excess is not likely.

Sodium, potassium, chloride and sulphur

Two thirds of the potassium is in the form of ions in the intracellular fluid, and helps to regulate the osmotic force, while the other third is bound to proteins. Intracellular potassium also assists in enzymatic reactions. In the extracellular fluid, potassium helps in nerve transmission and muscle contraction. In contrast to most minerals, potassium is not readily stored, and must be supplied daily in the diet. If the dog suffers from a deficiency of potassium, anorexia, decreased growth, locomotive problems (Grevel *et al*., 1993) and heart (Abbrecht, 1972) and kidney lesions (Abbrecht, 1969) lesions may. Symptoms from excess intakes are rare, but if they do occur, the dog may suffer from paresis and a slow heart-beat (Hiatt *et al*., 1975).

In the extracellular fluid, sodium is the major cation, and regulates the osmotic pressure. Chloride is normally associated with sodium, and constitutes two thirds of the total anions present in the extracellular fluid. Dogs have been shown to tolerate high-sodium diets without putting on weight due to water in the body or oedema (Spangler *et al*., 1977), and excesses of sodium can be excreted in the urine by a healthy animal if given free access to water. A minimum requirement for sulphur has not been established for dogs.

Microminerals

Most of the iron in the body is found in the hemo- and myoglobin, but it also functions as a cofactor for the cell respiration in the cytochrome enzymes. The storage of iron is in the liver, spleen, and bone marrow. The degree of absorption of iron depends on chemical form (ferrous 2+ is more easily absorbed than ferric 3+), need of the body, mineral balance of the diet and hormone balance. The degree of utilisation has been reported to be 35-75% in trials (NRC, 1974), but even lower figures have also been reported (5-10%; Stewart & Bambino, 1961). Iron is recycled in the body, and losses are normally very low. Iron deficiency results in anaemia, and excesses are toxic. The toxicity is associated with anorexia, weight loss and decreased serum albumin concentration (NRC, 1985).

Copper is necessary to complete the formation of hemoglobin, for osteoblast activity, and to form melanin, collagen, elastin, and for production of ATP in the cytocrome oxidase system. Copper is primarily stored in the liver. A copper deficiency might lead to anaemia, depigmentation of the fur and impaired skeletal development of growing animals.

Zinc is widespread in the body. It is a component of many enzymes, and is important in the synthesis of DNA, RNA, protein and for cellular immunity (Miller *et al*., 1989). Zinc absorption is affected by the body need for the mineral, the type of feed the zinc originates from, the content of other minerals, and fibre and phytate content. Zinc deficiency can result in anorexia, impaired reproduction and retarded growth, immune system dysfunction, and development of skin lesions (Banta, 1989). If given in excess, zinc may cause calcium and copper deficiency.

Manganese functions as a catalyst in metabolic reactions, and regulates the nutrient metabolism in the mitochondrion. Natural manganese deficiency has not been reported in dogs, and a dietary excess is unlikely.

Iodine is used when forming the hormones T3 and T4 in the thyroid gland, which regulates the metabolic rate. Although not common in dogs, iodine deficiency might result in goitre, and in growing animals cretinism (retarded growth, skin lesions, CNS dysfunction, skeletal deformities). In humans, iodine excess might also result in goitre (Jinkou *et al*., 2000).

Being a component of the glutathione peroxidase, selenium prevents oxidative damage to cell walls. Both dietary excess or deficiency are uncommon in dogs. If it does occur, deficiency may cause skeletal and cardiac myopathies (muscle disease), while excesses can result in inflammations of the heart (myocarditis), liver (toxic hepatitis) or kidney (nephritis).

A minimum requirement for cobalt, fluorine, molybdenum, tin, silicon, nickel, vanadium, and chromium has not been established for dogs.

Vitamins

Vitamins are organic molecules that are divided into the fat soluble vitamins, A, D, E and K, and the water-soluble vitamins, B and C. The fat soluble vitamins are digested and absorbed as dietary fat, stored in the liver and excreted in the bile. The water-soluble vitamins from the feed are absorbed passively in the small intestine and excreted in the urine, and excesses are not stored in the body except for cobalamin.

Fat-soluble vitamins

Vitamin A is in the form of retinol, retinal or retinoic acid in vegetables, while animal products contain active vitamin A. Vitamin A is important for the vision, skeletal growth (osteoclast and osteoblast activity), reproduction and for the epithelial cells. A deficiency of vitamin A can cause impaired growth, decreased reproduction and dermatoses (NRC, 1985). Excesses of vitamin A might result in skeletal abnormalities (Maddock *et al*., 1949).

Vitamin D consists of ergocalciferol (D_2) and cholecalciferol (D_3), and the latter is the most important for omnivores. Vitamin D_3 is formed in the skin when exposed to ultraviolet light. The requirement depends on the ratio of calcium and phosphorus in the feed, and the physiological stage of the dog. Active vitamin D is important for normal bone growth and maintenance. If the dog suffers from a vitamin D deficiency, impaired bone mineralization and osteomalacia in adults or rickets in growing animals could result. If given in excess, the dog might suffer from hypercalcemia, bone resorption, and soft-tissue calcification.

Vitamin E consists of the tocopherols and the tocotrienols and serves as a free radical chain-breaker. An increased fat content in the diet increases the need for vitamin E. The selenium-containing enzyme glutathione peroxidase reduces the peroxides formed. The requirements of vitamin E depend on the level of polyunsaturated fatty acids in the diet. If given in excess, vitamin E is non-toxic, but the requirement for vitamins A and D might increase. If the dog suffers from vitamin E deficiency, skeletal muscle degeneration, impaired immunological response, reproductive failure and retinal degeneration may result (Scott & Sheffy, 1987).

Vitamin K consists of a group of compounds called the quinones (K_1 in green plants, K_2 synthesised by bacteria in the colon). Vitamin K_1 stimulates prothrombin synthesis by the liver in dogs that have consumed coumarin compounds, for example warfarin. Normally, the body produces vitamin K in the large intestine, which is why a dietary deficiency is rare. However, if the bacteria are reduced in number, a vitamin K deficiency might result in increased blood clotting time and hemorrhages.

Water-soluble vitamins

Thiamine (B_1) is important for the carbohydrate metabolism, and the vitamin is heat labile. Thiamine deficiency can occur if certain raw fish are fed, as these contain a high content of thiaminase (Houston & Hulland, 1988). Examples of fish containing levels of thiaminase sufficient to cause thiamine deficiency if fed raw are carp and salt-water herring (Smitt & Proutt, 1944). However, cooking the fish destroys the detrimental effects of thiaminase. A deficiency can affect the CNS, and results in anorexia and weight loss.

Riboflavin (B_2) functions as a coenzyme in energy metabolism, and is easily destroyed by light and irradiation. A deficiency might cause disturbances in the CNS function, and dermatitis.

Niacin (nicotinic acid or nicotinamide) has an important function in enzymes used in the metabolism of protein, fat and carbohydrates. Niacin is alkali-labile. If the dog suffers from too low levels of niacin, it might get black-tongue disease.

Vitamin B_6 can be administered as pyridoxine, pyridoxal, or as pyridoxamine. This vitamin is active in the metabolism of amino acids, in the formation of hemoglobin, and in the conversion of tryptophan to niacin. As the protein level of the diet increases, so does the vitamin B_6 requirement (Bai *et al*., 1991). Dietary deficiency has not been reported in dogs.

Pantothenic acid is converted to form CoA, and deficiencies are rare but may result in anorexia and weight loss.

Biotin is used in many reactions in fatty acid, amino acid and purine synthesis. The feeding of large amounts of raw whites of egg might cause a deficiency of biotin (Lopez *et al*., 1977), due to the fact that avidin, a protein, forms stable complexes with biotin. A deficiency is uncommon, but may cause dermatitis.

Folic acid (folacin) has an important function in the formation of thymidine in the DNA, and a deficiency may result in impaired cellular growth and anaemia. It appears that most of the daily requirement of folic acid is produced in the colon.

Vitamin B_{12} (cobalamin) contains the mineral cobalt, and it is involved in lipid and carbohydrate metabolism. Vitamin B_{12} binds to the intrinsic factor in the intestine, a glycoprotein essential for absorption of the vitamin. Deficiency of vitamin B_{12} might can result in anaemia and impaired neurological functioning. This vitamin is only found in animal products, and excesses can be stored in the liver, muscle, bone and skin.

Choline is important for the function of the neurotransmitter acetyl-choline and for the intracellular fatty acid transport. Choline is also a constituent of cell membranes. Choline deficiency may lead to neurological dysfunction, but this has not been reported in dogs.

Vitamin C (ascorbic acid) is needed in the formation of collagen, dentine and connective tissue. It has been shown that dogs are independent of exogenous sources of vitamin C as they can synthesise vitamin C from glucose (Naismith, 1958).

Water

Water is the single most important nutrient. As stated by Lewis *et al*. (1987): “An animal can survive after losing almost all of its glycogen and storage fat and half of its protein, but a 10% loss of total body water causes serious illness; a 15% loss results in death”. The body of the dog consists of between 43 and 80% water, the lowest value being in obese dogs, and the highest in puppies (Meyer, 1990). The animal gets water by drinking, eating and by metabolic processes in the body. The metabolic water corresponds to a small proportion (5-10%) of the daily water turnover. Voluntary intake of water is around 2- to 3-times the dry matter intake. This is highly dependent on habit, type of food and electrolyte intake, environmental temperature, exercise, physiological state and temperament (Anderson, 1981). The water losses are through the urine, faeces, lungs, and paws. The water requirement is normally satisfied by giving free access to water. For working or lactating dogs, special attention should be paid to the water balance.

Nutrient requirements

The National Research Council (NRC, 1985) has presented minimum nutrient requirements, while the American Association of Feed Control Officials (AAFCO, 2000) has presented recommended nutrient profiles for dog feeds based on commonly used ingredients (Tables 2 and 3). It is important to note that the NRC minimum requirements do not include the safety margins needed when formulating practical diets. Also, the data presented by the NRC (1985) are to a large extent based on studies performed using purified or semi-purified diets, implying that these diets had a higher availability of nutrients than commercial feeds. Consequently, using the NRC minimum requirements in the formulation of practical diets might result in nutrient deficiencies. The AAFCO nutrient profiles were first published in 1992, and provide practical minimum and maximum levels of nutrients in commercial pet foods. Maximum levels were established for nutrients where the potential for toxicosis was a concern. If a maximum value is not stated, this reflects the lack of information on nutrient toxicity in dogs, and it does not imply that the nutrient is safe at any level. Today, pet food manufacturers world-wide are using these standards to formulate nutritionally balanced pet foods. A few years ago, European pet food manufacturers compiled nutrient guidelines for dogs, mainly with data based on the AAFCO standards (Fediaf, 1999). There are also various national guidelines, for example the German energy and nutrient requirements for dogs (Deutsche Gesellschaft für Ernährungsphysiologie, 1989) and company based information, for example the Waltham Company of Pet Nutrition (WCPN, 1993), but these are not used as widely as the AAFCO profiles.

Different types of dog feed

The dog feed market contains a vast supply of feeds, snacks and nutritional supplements. These products are sold in speciality or grocery stores, farmers' co-operatives and in veterinary clinics. In a recent Swedish marketing poll of products intended for normal and healthy dogs, it was found that approximately 40% of the feeds were bought in grocery stores, 35% in speciality stores, and 10% at farmers' co-operative stores. The remaining owners bought the feeds in other places, for example from the breeder. The study also showed that 96% of the dog owners did buy some type of commercial dog feed (ScandInfo Marketing Research, 1996). The feeds vary considerably in nutrient and energy composition, digestibility, palatability and physical form. Many feeds are formulated to provide adequate nutrition, while others are meant to be mixed and supplemented. Complete and balanced diets are either possible to use throughout all life stages or meant for a specific stage of life, for example for adult dogs. Some products are formulated to be beneficial for dogs with specific diseases, for example kidney and heart disease, and these are most commonly complete and balanced.

In 2001, there is a total of 124 companies marketing dog feeds in Sweden. Of these, 25% manufacture only domestic products, 68% sell imported feeds only, and 7% sell both imported and Swedish products. There is a total of more than 1000 dog feed products on the Swedish market, and approximately half of these are labelled as complete and balanced.

Table 2. Nutrient requirements for dogs on a DM-basis (AAFCO, 2000; NRC, 1985)

		AAFCO, 2000[1]			NRC, 1985[2]
Nutrient	Unit	Growth, reproduction min	Adult min	Max	Growth min
Protein	%	22.0	18.0		-
Arginine	%	0.62	0.51		0.50
Histidine	%	0.22	0.18		0.18
Isoleucine	%	0.45	0.37		0.36
Leucine	%	0.72	0.59		0.58
Lysine	%	0.77	0.63		0.51
Methionine-cystine	%	0.53	0.43		0.39
Phenylalanine-tyrosine	%	0.89	0.73		0.72
Threonine	%	0.58	0.48		0.47
Tryptophan	%	0.20	0.16		0.15
Valine	%	0.48	0.39		0.39
Fat	%	8.0	5.0		5.0
Linoleic acid	%	1.0	1.0		1.0
Minerals					
Calcium	%	1.0	0.6	2.5	0.59
Phosphorus	%	0.8	0.5	1.6	0.44
Ca : P ratio		1:1	1:1	2:1	-
Potassium	%	0.6	0.6		0.44
Sodium	%	0.3	0.06		0.06
Chloride	%	0.45	0.09		0.09
Magnesium	%	0.04	0.04	0.3	0.04
Iron	mg/kg	80	80	3000	31.9
Copper	mg/kg	7.3	7.3	250	2.9
Manganese	mg/kg	5.0	5.0		5.1
Zinc	mg/kg	120	120	1000	35.6
Iodine	mg/kg	1.5	1.5	50	0.59
Selenium	mg/kg	0.11	0.11	2.0	0.11
Vitamins & other					
Vitamin A	IU/kg	5000	5000	250,000	3,710
Vitamin D	IU/kg	500	500	5000	404
Vitamin E	IU/kg	50	50	1000	22
Thiamine	mg/kg	1.0	1.0		1.0
Riboflavin	mg/kg	2.2	2.2		2.5
Pantothenic acid	mg/kg	10.0	10.0		9.9
Niacin	mg/kg	11.4	11.4		11.0
Pyridoxine	mg/kg	1.0	1.0		1.1
Folic acid	mg/kg	0.18	0.18		0.2
Vitamin B_{12}	mg/kg	0.022	0.022		0.026
Choline	mg/kg	1200	1200		1250

[1]Presumes an energy density of 1465 kJ/100 g DM.
[2]Presumes an energy density of 1534 kJ/100 g DM.

Table 3. Nutrient requirements for dogs on an energy-basis (AAFCO, 2000; NRC, 1985)

		AAFCO, 2000			NRC, 1985
Nutrient	Units per MJ	Growth, reproduction min	Adult min	Max	Growth min
Protein	g	15.0	12.3		-
Arginine	g	0.42	0.35		0.33
Histidine	g	0.15	0.12		0.12
Isoleucine	g	0.27	0.25		0.23
Leucine	g	0.49	0.40		0.38
Lysine	g	0.52	0.43		0.33
Methionine-cystine	g	0.36	0.29		0.25
Phenylalanine-tyrosine	g	0.61	0.50		0.47
Threonine	g	0.40	0.33		0.30
Tryptophan	g	0.14	0.11		0.10
Valine	g	0.33	0.26		0.25
Fat	g	5.5	3.4		3.2
Linoleic acid	g	0.69	0.69		0.64
Minerals					
Calcium	g	0.69	0.41	1.7	0.38
Phosphorus	g	0.55	0.33	1.1	0.29
Ca : P ratio		1:1	1:1	2:1	-
Potassium	g	0.41	0.41		0.29
Sodium	g	0.21	0.04		0.04
Chloride	g	0.31	0.06		0.06
Magnesium	g	0.03	0.03	0.21	0.03
Iron	mg	5.5	5.5	205	2.1
Copper	mg	0.5	0.5	17	0.19
Manganese	mg	0.33	0.33		0.33
Zinc	mg	8.1	8.1	68.4	2.3
Iodine	mg	0.10	0.10	3.4	0.04
Selenium	mg	0.0072	0.0072	0.136	0.0072
Vitamins & other					
Vitamin A	IU	342	342	17,072	242
Vitamin D	IU	34.2	34.2	342	26
Vitamin E	IU	3.4	3.4	68.4	1.5
Thiamine	mg	0.07	0.07		0.06
Riboflavin	mg	0.15	0.15		0.16
Pantothenic acid	mg	0.69	0.69		0.64
Niacin	mg	0.79	0.79		0.72
Pyridoxine	mg	0.07	0.07		0.07
Folic acid	mg	0.012	0.012		0.013
Vitamin B_{12}	mg	0.0014	0.0014		0.0017
Choline	mg	82	82		81

In 1999, dogs in Sweden consumed 47,368 tons of dry feeds, 7,160 tons canned, 1,220 tons frozen, and 1,810 tons of other (i.e. semi-moist or snacks) products. Approximately 62% of the amount of dry feeds are domestic, while 25 and 13% are from other European countries and North America, respectively. A lower proportion of moist feeds is domestic (38%), while 61% originates from Europe, and 1% from North America. As much as 88% of the complete and balanced feeds are registered as intended for all life-stages. The processes most commonly used in dog feeds in the Swedish market are extrusion (71%), boiling, such as canning (13%), and baking (10%), calculated on the basis of the number of kilos either produced or imported to Sweden (SJV, 2001).

Commercial feeds manufactured in Sweden labelled as complete and balanced are obliged to declare the content of crude protein, crude fat, crude fibre and ash. If the water content is above 14%, the content must be declared (SJV, 1993). Other nutrients that are often labelled on a voluntary basis are NFE, calcium, phosphorus, vitamins A, D and E. Sometimes information on other nutrients, the energy concentration and digestibility is added.

Dry feeds

Dry feeds often contain 6-10% water (Burger & Blaza, 1988), and are often produced by extrusion. To a lesser extent, dry feeds are baked or pelleted. The processing is aimed at improving the digestibility of some complex carbohydrates and the palatability. Baked dog feed is produced by milling the ingredients and making a dough with all ingredients included, then cutting or forming biscuits which are baked in an oven on large plates. When extruding feed ingredients are first milled and mixed to a dough, then cooked under pressure and heat in the extruder. The high temperature (125-150^{o}C), the movement and mixing of the dough, together with the rising pressure makes the cooking very fast (20-60 seconds; Edlund, 1987). At the end of the extruder, the dough gets its final form by being pressed through a die, with possibilities of making different shapes of the final product. After cooling, extra fat is commonly sprayed on the outside of the product (Case *et al*., 2000). The digestibility has been shown to depend more on factors such as temperature and ingredients than on the choice of processing (Edlund, 1987).

The ingredients used in dry feeds are commonly cereal grains (wheat, rice, maize, oats, barley), cereal by-products (wheat germ, corn gluten meal, oat bran), soybean meal, animal products (meat meal, meat and bone meal, fish meal), fats and oils, and vitamin and minerals (NRC, 1985; Case *et al*., 2000).

The energy content in most commercial pet foods ranges between 1200 and 2200 kJ/100 g DM (Case *et al*., 2000). Dry feeds for maintenance contain between 5 and 12% crude fat (NRC, 1985), while those intended for reproduction and work commonly have levels of over 20% fat on a DM-basis (Kallfelz & Dzanis, 1989).

Most dry feeds contain crude fibre levels ranging from 3 to 6%, but there are pet foods with contents of between 5 and 25% on a DM-basis (Kallfelz & Dzanis, 1989; Bartges & Anderson, 1997). The content of amino and fatty acids, type of carbohydrates, digestibility, anti-nutritional factors and availability of minerals is rarely known and declared, for either commercial dog feeds or the table foods given.

Canned, semi-moist and frozen feeds

In Sweden, most canned products are mainly manufactured as complete and balanced diets. The canned feeds are made by mixing the ingredients with water, then heating the mixture to 250°C for 60 minutes in order to pressure sterilise, so called retorting. Canned products are often based on meat (beef, pig, lamb, poultry) and their by-products, textured soy protein or soy flour, and a mix of minerals and vitamins. Canned feeds usually contain 74-78% moisture, 1700-2100 kJ/100g DM, 28-50% crude protein, 20-32% crude fat and 18-57% nitrogen-free extracts on a DM-basis (Case *et al*., 2000). Frozen feeds often have the same dry matter content as canned products.

Semi-moist products often consist of animal by-products, cereals, fats and simple sugars, glycerol, syrup and some preservative, such as sorbate. The content of water in semi-moist products is between 25 and 30% (NRC, 1985). The energy content is between 1200 and 1700 kJ/100 g DM, and the crude protein 20-28%, crude fat 8-14%, and NFE 46-74% of DM (Case *et al*., 2000).

Treats

Treats are available in a large number of types, sizes, colours and flavours. They are often made as biscuits or dried meat products, and are sometimes made of rawhide. Some of the snacks are nutritionally complete, while most are not.

Home-made and table foods

Almost all American dogs are given table foods at least for a period of their life (Pet Food Institute, 1997). A survey of American dog owners showed that 20% of the dogs were served table foods or pet candy every day (AAHA, 1995). European dogs have been shown to consume higher amounts of table foods or home-made diets than the American dogs. For example, 15% of French dogs have been shown to consume only home-made food, and another 15% were served exclusively table scraps (Pibot, 1989).

Chemical analysis of feeds

Proximate analysis

For routine analysis of feeds, the proximate or Weende analysis system is used world-wide. Proximate analysis includes crude protein, crude fat, crude fibre, ash and nitrogen-free extracts (NFE). Analytical figures for nitrogen are multiplied by 6.25 to obtain an estimate of the crude protein. This factor is based on the assumption that the average nitrogen content of the protein in common feedstuffs is 16%. However, this factor may not be correct in all cases as the analysed nitrogen values may include both "true-protein"-nitrogen as well as nitrogen from free amino acids, amines, nucleic acids and dietary fibre (Wenk *et al*., 2000).

The fats are soluble in organic solvents such as ether, which is why fats are also called ether extracts. In foods of animal origin, the ether extract may be composed of almost entirely TGs, while foods of plant origin often contain as much as half of the ether extract in the form of sterols, waxes and other lipids. As non-glyceride lipids give little energy possible to utilise by animals, the estimated energy value of EE of 35.6 kJ/100 g (modified Atwater factor) might be correct for fat sources of animal origin or the refined vegetable oils, but is probably too high for other fat sources of plant origin.

In the proximate analysis, the carbohydrates of the diet are divided into the crude fibre and NFE fractions. Crude fibre is a measurement of the cell wall fibres and represents the fraction of the feed insoluble in sulphuric acid and potassium hydroxide, and contains cellulose, hemicellulose and the non-carbohydrate phenylpropane polymer lignin. NFE is calculated (on a DM-basis) as: 100-crude protein-crude fat-crude fibre-ash, thus being subject to variable errors. Van Soest and McQueen (1973) stated that 80% of the hemicellulose and 20-50% of the cellulose was removed when an extraction with acid and alkali was performed. Also, 10-50% of the lignin remained in the crude fibre fraction after the same treatment. The completely soluble carbohydrates, for example glucose and starch, and also all non-fibrous, ether-insoluble, water-soluble organic material of the foods is accounted for in the NFE estimate. For example, the water-soluble vitamins contribute a minor proportion to the NFE value, just as the fat-soluble vitamins constitute a non-significant part of the crude fat value. The ash fraction contains all inorganic compounds, and is mainly used to calculate the NFE-value of feeds. Normal coefficients of variation for the Weende analysis are 8% for crude protein, 15% for ether extract, 12% for crude fibre and 3% for NFE (Lloyd *et al*. 1978).

Neutral detergent fibre analysis

In the 1980's, van Soest (1982) presented an alternative to the crude fibre (CF) measurement, the use of residues after extraction with neutral (NDF) or acid (ADF) detergent solutions. The crude fibre analysis and detergent methods determine only a fraction of the fibres present, with no close relationship to the analysis of total dietary fibre. For example, the NDF gives values corresponding to between 63 and 91% of the total dietary fibre in soybean meal and maize. The crude fibre values correspond to 21-32% of the total dietary fibre values for the same feed products (Åman & Graham, 1990).

Mineral analysis

Minerals are most commonly analysed using the method called atomic absorption spectrophotometry. Minerals can also be analysed with ICP-AES (Induced Copuled Plasma-Atomic Emission Spectroscopy) where the sample is steamed in a nebulizer. The gaseous sample is then transferred to a plasma with a temperature of approximately 8000^{o}C. In the plasma, the electrons in atoms or ions are excited, and when being de-excited, light is emitted. Different atoms have separate wavelengths, and by measuring the light intensity and wavelength, the concentration of the different minerals can be determined. The coefficients of variation for the analysis of these minerals are: Ca 4%, Mg 4%, Zn 6%, Fe 4%, Mn 3%, Cu 9%, Na 8%, K 7% and P 3% (NMKL, 1991; Bo Olsson, *personal communication*, Analycen, Lidköping).

Methods to register feed intake

In humans, there has been a long tradition of measuring dietary intake. Different methods have been used, all with their limitations and advantages. When measuring dietary intake in populations there is a dilemma – on one hand the researcher is interested in registering energy and nutrient intakes as close to the true intake as possible. On the other hand, the method must often be applicable to a large number of individuals. Although biological markers for intakes of specific nutrients are developed for humans, these provide no absolute standard against which the measurements can be compared for all nutrients in total diets. However, biological markers can be important controls of the performance of a questionnaire for total energy intake or for single nutrients.

As biological markers are not highly developed for dogs, it is often only possible to estimate the relative validity of the total feed intake between two methods in this species. A few researchers have validated studies of dietary intake for dogs living in households (Slater *et al*., 1992 & 1995; Sonnenschein, 1988), while most of the knowledge can be found in human literature as reviewed in the following section.

There are a number of methods to estimate food intake in human populations. The most commonly used methods are weighing, 24-hour and 7-day records, food frequency questionnaires and biological markers. In practice, various methods are often combined and modifications of different methods are used.

Weighed records

The first attempts to weigh and register food intakes of humans were made by Widdowson (1936 & 1947) in the 1920's. The individuals participating in the study weighed, described and noted the amount of cooked food items they consumed. Leftovers were weighed, while the amount of food offals were estimated. The nutrient intake was calculated by using average portions of cooked food together with the feed tables that had recently been composed by McCance and Widdowson (1940).

Food can be weighed on an ordinary scale measuring up till 2 kilos and with an accuracy of $\pm$ 1 grams. There are also more refined methods; Bingham *et al*., (1994) used a PETRA (Portable Electronic Tape Recorded Automatic)-scale, where it is possible to register weight and also record descriptions of the content of the food. An advantage of this type of scale is obvious; it is possible to have very exact measurements of the food intake.

24-hours records or recalls

This method was applied for the first time by Wiehl (1942), who carried out two 24-hours records where all food consumed was registered. The amounts of food were described as standard measurements, such as 1 glass of milk or two slices of bread. Several food items were estimated by eye, and the amount of nutrients was calculated from food composition tables.

When making 24-hour studies, the subjects of the experiment are either to register the food intake continuously during the day (record) or note what has been eaten at the end of the day (recall). Food intake is written down on a blank sheet or in a structured questionnaire with food items mentioned. In a questionnaire, the amount, type and time for consumption is often registered. Sometimes the amounts of food are estimated with picture or drawings of portion sizes or by weighing (Callmer *et al*., 1993). Some studies have estimated the food intake by making two identical portions, where one is weighed and analysed while the other is consumed (Bingham & Cummings, 1985).

An advantage of the 24-hour studies is that a person might relatively well remember what has been eaten the last day compared to a longer time period. However, the food intake for an individual might vary tremendously between single days. If making repeated measurements, the security of this method can be increased (Block, 1982). Heady (1961) registered the food consumption of 116 male bankers during seven days. He found that the mean intakes of the whole group did not differ significantly from day to day, which was the case for single individuals.

7-day record/recall

In the 1940's, Youmans *et al*. (1942) made the first surveys with 7-day estimated diets. The amount of food consumed was registered using household measures by the individuals participating in the study or by another person in the same household. Food items such as bread and cookies were estimated with three-dimensional portion sizes, while fruit and vegetables were registered as small, medium and large sizes.

If using a seven-day diet where the individual in question registers the food intake at the end of the week (7-day recall), a variation due to a single day is avoided (as compared to the 24-hour method). On the other hand, it is possible that another bias appears due to lack of memory of what was eaten a week ago. It is preferable that the dietary intake is registered each day in the week (7-day record) in order to obtain a registration closer to the true consumption

Food frequency questionnaires

The person initially describing food frequency questionnaires (FFQ) was Turner (1940). The first study was performed in three parts. Firstly, the participants were subjected to a 24- or a 48-hour study where the food intakes were recorded. Secondly, the frequency of the consumption of approximately 100 food items was estimated in a food list. Thirdly, the amount of food bought and how the consumption was divided between family members was estimated.

Food frequency questionnaires are the most commonly used method when measuring dietary intake in nutritional studies. The models of the questionnaires are complex; most commonly there is a protocol with a number of food items, and the individual register usual food habits. The questions should be posed so that it is possible to detect possible differences between individuals or populations, depending on the goal of the survey (Bingham, 1987).

The frequency and amount consumed of a specific food can be registered with or without portion sizes. Portion sizes are often standardised, for example one *piece* of bread, or a *glass* of milk. Sometimes the person might fill in a standard size of his own choice (Sempos, 1992). A FFQ with 130 food and portion sizes was developed in Oxford and Cambridge. The frequency of eating each food item was divided in a 9-grades intensity scale from "never/less than once a month" to "6 times a day or more" (Bingham *et al*., 1994).

An advantage of this method is that it is cheap, simple and quick to administer. In addition, it covers a longer time span than the 24-hour method, thus possibly reflecting the dietary intake more correctly than that obtained when only one single day is registered. These advantages imply that it is possible to involve several persons in the survey, giving a higher statistical reliability (Margetts, 1989).

Biological markers

A biological marker is a substance in a biological sample, for example blood or urine, which shows a correlation between the amount of food consumed and occurrence of the marker. Biological markers can be used as independent validity controls for different types of surveys of food intake. An obvious advantage with biological markers is that it is possible to measure a relatively exact nutrient intake for single individuals. A disadvantage is that only specific nutrients can be assayed with biological markers, not the entire nutritional content. To reflect the nutritional status it is possible to analyse for example cholesterol, retinol, carotene and folic acid in whole blood (Bingham & Cummings, 1985; Bingham *et al*., 1991 & 1995).

In humans who are in energy- and protein balance, it is possible to measure the amount of nitrogen in urine by collection for 8 days. The nitrogen excreted is a measure of the utilisation of digested protein intake. The individuals in the study consume p-amino benzoic acid (PABA) as a marker in order to control that all urine has been collected during a 24-hour period. Trials show that among persons consuming 80 mg PABA, 99 ($\pm$6) % could be found in the urine 6 hours later (Bingham & Cummings, 1983). While there is a functioning method for estimating the amount of protein consumed by biological markers, there are no corresponding methods for measuring intakes of fat or carbohydrates (Bingham, 1987).

It is also possible to analyse the content of potassium and sodium in the urine, as they are mainly excreted in the urine. A difference between these two minerals is that sodium has a minimal excretion in the faeces, while a larger and more variable amount of potassium might be found there. The amount of potassium excreted in the faeces may vary between 13 and 35 % of the daily intake (Cummings *et al*., 1976).

The fermentation in the colon is believed to have a protective effect against colon cancer. The concentrations of hydrogen gas and methane, which are produced in this process, are strongly correlated to the production of these gases in the intestines (Le Marchand *et al*., 1992). The expired air might be analysed with respect to CH_4 and H_2. It is possible to find a correlation between early morning samples of expired air and intake of fermentable carbohydrates.

The total energy expenditure can be described by using the doubly labelled water ($^{2}H_2{}^{18}O$) method (Livingstone *et al*., 1990). This method registers the speed of carbon dioxide production by measuring how the stabile isotopes deuterium (^{2}H) and oxygen-18 (^{18}O) disappear after consumption of an oral dose of the labelled water. Deuterium is eliminated from the body as water, and oxygen-18 form water and carbon dioxide (Schoeller, 1990). This method is safe and simple to handle, as the individuals in the trial only have to drink an oral dose and later give a few blood or urine samples. The method has a normal variation of $\pm$2-3 %. It is currently too expensive to be used as a routine method. The doubly labelled water method has been evaluated in a study using 3 cats and 2 dogs (Ballevre *et al*., 1994).

Methods to register physical activity

Although many different methods to assess physical activity have been described (LaPorte *et al*., 1985), survey techniques are the most commonly used methods to register physical activity in humans. In a summary of Swedish studies concerning physical activity and living patterns during the 1990's, 57% used questionnaires only, while the others combined the questionnaire with health measurements such as weight, hight, blood fat or oxygen lung capacity (Swedish Health Institute, 1997). Due to the expense and time needed to measure physical fitness directly, this option is sometimes not a viable alternative in population studies with many participants.

The identification of physical inactivity as a risk factor for specific diseases confirms the need for a valid and reliable questionnaire. In human research, little is known regarding the reliability of the questionnaires used, as questionnaires are often unvalidated (Kohl *et al*., 1988).

Effects of diet on disease

At the time when the nutrient requirements of dogs were not well known and when there was a scarcity of food, many dogs suffered from diseases due to starvation or deficiencies of specific nutrients. Today, the occurrence of diseases due to deficiencies of specific nutrients is rare. Instead dogs more commonly suffer from overnutrition of energy and excess/imbalance of specific nutrients.

Nutrition is important in many diseases, either to prevent, manage or cure disease. For example, nutritionally related skeletal diseases and diabetes are examples of disorders that to a certain extent can be prevented or mitigated with a proper diet. Dogs with diarrhoea, chronic heart disease, urolithiasis and chronic kidney disease are positively influenced by dietary therapy. Individuals in some dog breeds may also suffer from inherited disorders of nutrient metabolism altering their nutritional needs, for example the copper storage disease in the Bedlington terrier and the abnormal purine metabolism in Dalmatians, which demand special dietary considerations. The following examples of diseases with a proven or suspected aetiology including dietary effects may serve as examples of diseases possible to examine in future epidemiological studies including dietary intake and energy balance.

Nutritionally related skeletal diseases

Incorrect feeding during growth is associated with skeletal diseases most commonly seen in breeds with a large adult size. Two important factors for the occurrence of some skeletal disorders are consumption of too generous levels of total energy and calcium (Hedhammar *et al.*, 1974). The effects of excesses and deficiencies of calcium, phosphorus and vitamin D in growing dogs have been thoroughly explored (Hazewinkel *et al.*, 1985, 1991; Hazewinkel, 1989). Detrimental effects of high levels of protein could not be shown to cause skeletal disease in growing dogs provided that they were not oversupplemented with calcium or on a high energy intake (Nap *et al.*, 1991).

Examples of nutritionally related skeletal diseases are hip dysplasia (HD), osteochondrosis dissecans (OCD) and hypertrophic osteodystrophy (HOD). HD is the most common of these three diseases, and is negatively influenced by excessive weight gain between 3 and 8 months of age (Kasström, 1975). Identified risk factors for OCD are age, gender, breed, excessive BW gain, and excesses of calcium (Slater *et al.*, 1991 & 1992). HOD is characterised by excessive bone deposition and bone resorption. The dogs affected are growing rapidly, often at the age of 3-6 months, and possible risk factors are overfeeding and calcium excess.

Diabetes mellitus and obesity

Diabetes mellitus serves as an example of a disease that may partly be caused by a too generous energy intake resulting in obesity, but it is also an example of a disease that may be managed with special dietary treatment. Obesity is the most common nutritionally related health problem in dogs, and between 25 and 44% of pet dogs have been reported to be obese (Hand *et al.*, 1989). Obesity reduces insulin resistance, a direct result of a decrease in insulin receptor numbers. Sometimes, obesity is also associated with decreased insulin response.

Diabetes mellitus is a chronic endocrine disorder caused by the deficiency of insulin. The clinical signs are effects of hyperglycaemia; excessive thirst and urine formation, excessive ingestion of food and in some cases weight loss. Factors increasing the risk of diabetes are obesity, hypothyroidism, Cushing's syndrome, pancreatitis, and a genetic predisposition (Mattheeuws *et al.*, 1984; Stogdale, 1985). The type I diabetes, caused by the autoimmune destruction of the beta cells, represents 70-80% of the diabetes cases in dogs (Hoenig, 1995;

Case *et al*., 2000). Type II diabetes is due to an impaired insulin secretion or insulin resistance.

Nutritionally responsive dermatoses

The nutritionally responsive dermatoses involve protein deficiency, and excess/deficiency of vitamin A, vitamin E, the essential fatty acids or zinc. Also, dogs with a food allergy or hypersensitivity may suffer from skin problems.

A protein deficient diet that causes skin problems is not common as most dogs consume adequate amounts of protein. For dogs with a food-induced allergy, the protein of specific dietary components may cause skin disorders.

Zinc-responsive dermatoses can have a hereditary background, or might be caused by deficiencies or imbalances in the diet. High levels of fibre, calcium or phytate in the diet may decrease the uptake of for example zinc, and therefore cause zinc deficiency, and this has most frequently been seen in growing dogs (Codner & Thatcher, 1993). Zinc deficiency can give clinical symptoms within 2-3 months if calcium is supplied in excess, and the symptoms are impaired growth, anorexia, skin lesions and that the fur becomes dull and coarse.

Some dermatitic dogs show a positive response to the addition of specific fatty acids. The n-3 and n-6 fatty acids function as eicosanoid precursors, as the metabolites of the n-6 fatty acids yield metabolites that are more immunosuppressive than the metabolites formed by the n-3 fatty acids (Samuelsson, 1991), and an optimal ratio between n-6 and n-3 has been suggested to be 5-10:1.

Dogs that are food allergic have an immunological response to at least one dietary ingredient, often resulting in a dermatosis. This type of allergy has been seen before the age of one year, and comprised to 1-2% of all dermatoses seen at veterinary clinics (Scott, 1978).

Dietary induced gastrointestinal diseases

It is very common that dogs suffer from transient dietary induced gastrointestinal diseases. However, the importance of the diet on multifactorial and chronic gastrointestinal diseases is little known. Diseases in the gastrointestinal tract are often responsive to dietary management, for example small intestinal bacterial overgrowth, pathogen overgrowth, exocrine pancreatic insufficiency, and inflammatory bowel disorders. When the dog suffers from a gastrointestinal disease, diarrhoea, vomiting and resulting anorexia are common symptoms. Dietary exposition as an ethiological factor in chronic bowel disease in man has been proposed (Mahmud & Weir, 2001).

Cancer and obesity

Studies indicate that there is an association between neoplasia in the mammary glands and obesity in dogs (Sonnenschein*,* 1988). Obesity is associated with endocrine changes, and has an impact on the prolactin, cortisol, androgen, and oestrogen levels (Hand *et al*., 1989). In studies with rat cells, an increased frequency of different types of neoplasms, both mammary and non-mammary tumours, were produced in response to insulin (Voyles & McGrath, 1979). The data indicate that obesity-induced chronic hyperinsulinemia may increase the risk of cancer. Also, adipose tissue may be a major source of estrogens, and these have been shown to have an impact on the occurrence of cancer in the reproductive system in humans (Simopoulos, 1985).

Aims of the thesis

These studies were performed in order to describe dietary intake and activity in Swedish dogs as a reference for further studies on possible effects on health and disease. The specific aims were:

- To validate a questionnaire on demographics, diet and activity in a defined and insured dog population.

- To compare the demographic data of insured dogs with a sample of all Swedish dogs.

- To describe the dietary patterns and feed intake in a defined and insured population of dogs.

- To estimate the energy intake and variation between sex, weight, breed and individuals in the same population.

- To study the activity and temperament of the dogs examined.

- To analyse and validate the nutrient and energy content in the commercial dog feeds most commonly used against the declared values on the labels and against the recommended canine nutrient profiles.

Materials and methods

This study examined the demographics, dietary patterns, energy and nutrient intake, living patterns, exercise and other types of training in a population of insured, privately owned dogs in Sweden. For this purpose a combined mail and telephone questionnaire was used, and the repeatability and validity of the questionnaire were evaluated. Also the present data for demographic variables were compared with a sample of dogs representing all dogs in Sweden. Moreover, commercial feeds consumed by most dogs in this study were analysed for the nutrient content, and the energy content was estimated (Figure 2).

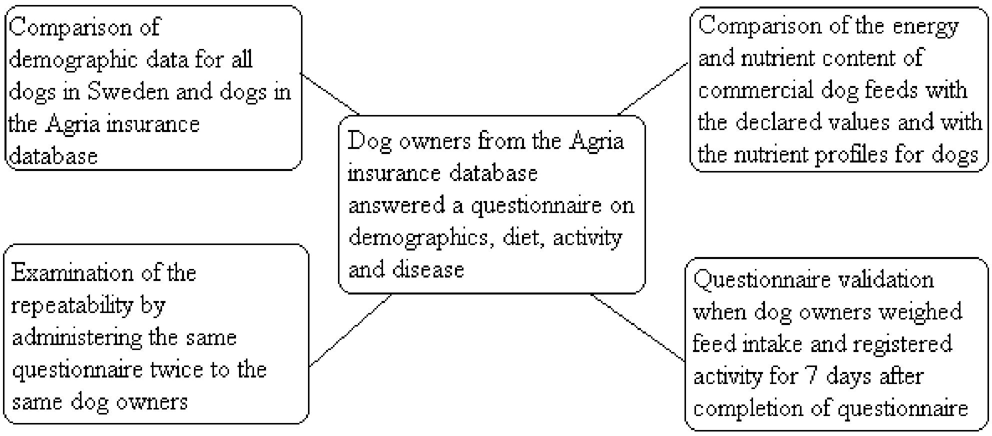

Figure 2. An overview of the studies presented within the scope of this thesis.

Animals and feed samples (Papers I-V)

A simple random sample of 680 pure-bred dogs between 1 and 3 years of age from the Agria insurance database was selected to participate in a mail and telephone survey on demographics, diet and activity (papers I, III and IV). The estimate of the sample size for the questionnaire was based on calculations suggested by Schaeffer *et al.* (1990), assuming a range in consumption of feed equal to 1000 g per day (σ=range/4=1000/4=250 g), bounds of errors $\leq$ 25 g, N=800,000 dogs. These calculations were based on the breeds being post-stratified into four strata according to size (small, medium, large and giant breeds). However, when analysing the data, such a large variation in weight between individuals of the same breed was found, that it was decided to analyse the material in actual weight intervals instead. After completion of the questionnaire, approximately every tenth (n=76) dog owner was asked to also participate in the validation study (paper II).

To study the repeatability, an independent sample of 100 dogs was selected by simple random sampling from the Agria Insurance database, and the questionnaire was administered twice to the same dog owners (paper II). However, as three selected dogs had incorrect owner information, the total sample was reduced to 97 dogs.

Samples of 50 commercial feeds (paper V) representing the most commonly fed products in the survey (paper III) were collected. The majority (79%) of the dogs in the survey was given at least one of the analysed feeds.

Organisation of the studies

The mail and telephone questionnaire (Papers I, III and IV)

The owners of the 680 dogs initially were contacted by mail from Agria with an inquiry about their willingness to participate in the study. This introductory letter explained the purpose of the study, and how the interviews would be performed. The dog owners were asked to respond directly to the research group whether they wanted to participate or not using a pre-stamped envelope. The non-respondents were sent 2 follow-up letters and the third reminder was made by telephone from Agria. The questionnaire and an introductory letter were mailed to those willing to participate in the study, and the following week a telephone interview was performed. The dog owners were asked to fill in the mailed questionnaire prior to the telephone interview to make it as effective as possible.

The questionnaire included questions about demographic data, feeding patterns, appetite, amount, frequency and proportion of commercial feeds, table foods and home-made diets, intake of treats and vitamin and mineral supplements (Appendix A). A list of 26 table foods was presented together with pictures of portion sizes of some foods (Appendix B). Included in the questionnaire were also questions about previous diet, and additional animals in the household. One part of the questionnaire considered exercise and the way the dogs performed and lead their lives, for example how the dog was kept when inside/outside, frequency and amount of time spent on walks, cycle exercise and jogging. A few questions were asked about play, and other training activities performed by the dogs, such as obedience, tracking and hunting. Most questions were of multiple choice type or formulated to register continuous data, but some questions were open, to give the possibility of adding specific information. All questions referred to the current situation, except the ones concerning previous diets.

Validity of the questionnaire (paper II)

After completion of the mail and telephone questionnaire, every tenth dog owner was asked also to participate in the validity study, which was performed on average 62 (SD 19) days after completion of the questionnaire. The respondents were asked to weigh all feed items on an electronic scale with 1g accuracy (Philips HR 2385 Precision) sent by the research group. In addition, the same dog owners registered the living patterns, amount and type of exercise and other training activities performed during 7 days to give data on validity.

The protocol of the 7-day weighed recording was a standardised form, where the dog owner was asked to record all feed consumed by the dog each day (Appendix C). The protocol was divided into commercial feeds (product, type and amount consumed), table foods or home-made diets (food item and amount consumed), supplements (type and amount), and treats (type and amount). For exercise, type, amount and time spent on different types were recorded daily. Eleven of the questions asked in the first questionnaire also were repeated in the 7-day weighed records. After 7 days of recording, the protocol and the electronic scale were returned to the researcher in a pre-stamped box.

Repeatability of the questionnaire (paper II)

The repeatability was based on whether there was agreement between the first and second questionnaires, and the second interviews were performed on average 39 (SD 17) days after the first interview. Questions were posed about current diet on the first occasion and about diet at the time of the first interview on the second occasion. All questions in the combined mail and telephone questionnaire were evaluated for repeatability.

Chemical analysis of commercial feeds (paper V)

Forty-five of the products most commonly used were dry feeds and five were moist (3 canned, 1 frozen and 1 semi-moist) representing 22 and 5 brands, respectively. To estimate the variation in mineral content between batches, an additional 3 samples from different batches of 10 of the dry feeds were examined for mineral content, in total 30 samples.

In the declared values, 69% of all feeds had protein levels equal to or higher than 22%, and 67% had a fat content of more than 10% on a DM-basis. The declared values of dry feeds were 18-36% for protein, 5-26% for fat, and 31-64% for the NFE on a DM-basis. The declared values of crude fibre varied between 1.6 and 3.8%, and the ash content ranged between 3.3 and 10.2% (DM-basis). For calcium and phosphorus, the declared values were 0.59-1.82% and 0.53-1.29%, respectively.

For moist products, the nutrient levels varied between 34 and 40% for protein, 19-35% for fat, 11-34% for NFE, 1.5-3.8% for crude fibre, and 7.7-12.5% for ash (DM-basis). For calcium and phosphorus, the declared values were 0.44-2.00% and 0.44-2.50%, respectively.

The selected feeds were analysed by using conventional methods for crude protein (Nordic Committee on Food Analysis, 1976), crude fat (Official Journal of European Communities, 1984), and crude fibre (Jennishe & Larsson, 1990). The NDF was determined by the method described by Robertson & van Soest (1977). The minerals were analysed at a commercial laboratory (Analycen, Lidköping) by optical ICP/AES (Nordic Committee on Food Analysis, 1991).

Estimation of nutrient and metabolisable energy content

The daily feed and nutrient intake of each dog was calculated from the commercial feeds and other ingredients reported to be given, using a commercial computer-based program (Animal Nutritionist, 1987). The database was modified to suit Swedish conditions for table foods (National Food Administration, 1996), and the declared values of commercial feeds (paper II, III, IV).

The content of metabolisable energy (ME) in each diet ingredient and in commercial products was calculated by using the modified Atwater factors (14.6 kJ/g protein, 35.6 kJ/g fat, 14.6 kJ/g NFE), as adapted in Sweden (Agricultural Board, 1993). The daily intake of ME for each individual dog was calculated by using data on dietary intake and the ME content in the dietary components (papers II, III and IV).

The content of ME in each commercial product was calculated by using the modified Atwater factors given above, called the $ME_{Atwater}$ in paper V. Also, the metabolisable energy (ME_{NDF}) derived from the NDF (Neutral Detergent Fibre) content was estimated. The digestibility of energy (dE) was predicted from the equation suggested by Lindberg & Wandrag (2001). The dietary content of gross energy (GE) was estimated after Schieman *et al*. (1971). The ME_{NDF} was derived by correcting the DE_{NDF} with a urinary energy loss from digestible crude protein of 5.23 kJ/g, as suggested by the AAFCO (2000), and by using an average protein digestibility of 80%, as suggested by the NRC (1985).

Statistical analysis (papers I-V)

The mail and telephone questionnaire (Paper I-IV)

In the mail and telephone questionnaire, the answers were coded "yes" if a specific type of feed, table food, supplement or treat was given at least once a month. The data was analysed using Microsoft Excel (Microsoft Software, 1999), SAS statistical package (SAS Institute Inc., 1999), and Minitab (2000).

The relationship between intake of metabolisable energy and BW was presented as log ME (intake) = log a + b log W with the SAS GLM (General Linear

Models) procedure. The ME (intake) is the metabolisable energy intake, W is the body weight, a is the mass coefficient, and b is the mass exponent. The data in paper IV was analysed by SAS proc univariate normal plot, procedure GLM, one-way Anova, 2-sample t-test, 2-proportion t-test and chi-square test.

Having access to original data from a recently published national survey (Egenvall *et al*., 1999), dogs between 1 and 3 years of age in that study were compared to the dogs in the present study (paper I). For continuous data, the standard deviations from the 2 data sets were pooled, and t-values were calculated. For categorical data, the 2-proportions test and the chi-square test were used (Minitab, 2000). For proportions 95% CI's were calculated using the formula +/-1.96[(proportion (1-proportion))/(n-1)]0.5.

Validity of the questionnaire (paper II)

The validity was evaluated using Spearman's rank correlations for continuous data, such as amount and frequency of energy and nutrient intake, specific intake of commercial and non-commercial feeds and food items, and for exercise and training activities (Minitab, 2000). Sensitivity was defined as the proportions of owners who reported feeding a food item in the questionnaire among all owners who recorded feeding the same food item on the 7-day weighed record. Specificity was defined as the proportion of owners who reported not feeding a food item in the questionnaire among all owners who recorded not feeding the same food item on the 7-day weighed record.

Repeatability of the questionnaire (paper II)

The repeatability of the questions was calculated using Spearman's rank correlations if the question had a continuous response or 4 or more categories. Correlations of 0.5-0.7 were considered very good (Willet, 1990). The kappa statistic was used if there were two or three categories, and measured agreement between the two interviews made. Kappas were considered poor if kappa was <0.4, fair to good if kappa was 0.4-0.75, and excellent if kappa was >0.75 (Fleiss, 1981).

Results

Response percentage and reasons for non-response

The questionnaire (papers I, III, IV)

In total, 461 owners completed the questionnaire, which gave a response percentage of 76% (461/608) for the owners possible to contact, and an overall response percentage of 68% (461/680). The main reason for non-completion of the questionnaire was that dog owners did not wish to participate, and other causes of a negative response were that the persons were not reachable during the period of study, incorrect addresses, and that the dog had died. The dogs belonging to the non-respondents were similar to those owned by respondents with respect to age distribution.

Repeatability and validity study (paper II)

In the repeatability study, the overall response percentage was 66 (n=64/97). However, among dog owners possible to contact, the response percentage was 71%. The reasons for non-response in the repeatability study were that people did not agree to participate (n=25), that the dog was dead (n=1), and that the dog owners were not possible to reach (n=7).

The response percentage in the validity study was 76% (58/76). The reason that the non-respondents declined to participate in the validity study, was that it would be too much work to do a weighed recording for 7 days.

Reliability of demographics, diet, activity and health data estimated by a questionnaire (paper II)

Demographic data

The repeatability for demographic data between the first and second interviews was excellent (0.82-1.00). Questions concerning disease, body weight, subjective body condition score, and the relative size of the dog compared to others in the breed was also excellent (r_{sp} 0.78-0.99, kappas 0.81-1.00).

When comparing demographic data for the selected dogs in the Agria insurance database and a sample of all dogs between 1 and 3 years in Sweden, there was no significant difference between the two groups for sex of the dogs and the 4 most common breeds (Dachshund, German shepherd, Golden and Labrador retriever). However, for neuter status and number of dogs in the household, there was a significant difference between the groups.

Dietary intake

Generally, the repeatabilities for dietary patterns and feed intake were very good to excellent (r_{sp} 0.66-1.00, kappas 0.57-0.95). Commercial feeds generally had higher repeatabilities (r_{sp} 0.68-1.00, kappas 0.82-0.94) than table foods and home-made diets (r_{sp} 0.75-0.80, kappas 0.57-0.78). Single food items were also repeatable (r_{sp} 0.54-0.97) as for the frequency and amount of feed intake, except for milk, meat, chicken and cakes. The repeatabilities for energy intake and specific nutrients were excellent (0.65-0.98).

When comparing the answers (whether a feed or food item was fed or not) between the questionnaires and the 7-day weighed recordings (validation study), most parameters of dietary patterns showed good to excellent sensitivities and specificities (sensitivities 0.50-0.98, specificities 0.48-0.98). Sensitivities were above 0.70 for all table foods, except for black pudding and butter, margarine and oils, while specificities were generally lower (0.25-0.80). The correlations for the frequency and amount of table foods (r_{sp} 0.03-0.81) fed were generally lower than for dry and canned (r_{sp} 0.81-0.92) dog feed in the validation study. The correlations for energy and nutrient intake were excellent in the total diet (0.80-0.96) and in the commercial part of the diet (0.79-0.98). The energy percentage for fat and NFE from the total diet showed high correlations (r_{sp} 0.66 and 0.77, respectively), but was lower for protein (r_{sp} 0.41). However, for the commercial part of the diet, the corresponding values for energy percentages were excellent (r_{sp} 0.80-0.88).

Activity

When comparing data from two subsequent questionnaires, the questions about living patterns and exercise showed very good to excellent repeatabilities (r_{sp} 0.64-0.94, kappas 0.59-0.88), except for the number of walks per day (r_{sp} 0.50). When comparing the data given in the questionnaire and in the weekly recordings (validation study), twelve out of sixteen values for sensitivity and specificity were above 0.70. The correlations for amount and frequency of exercise and other training activities were good to excellent (r_{sp} 0.50-0.77).

Reliability of the energy and nutrient content of commercial dog feeds (paper V)

Declared versus analysed levels of nutrients

The correlation between the declared values and the analysed content of the selected commercial feeds was high for protein, fat and NFE (r_{sp} 0.92-0.94 for dry feeds, and 0.67-0.98 for moist feeds). Although having a high correlation, the fat and protein content for single products differed considerably between declared and actual content. For example, two moist feeds contained 70 and 80% of that declared for protein, and another two canned products had fat contents corresponding to 67 and 81% of that declared. Consequently, four out of five canned feeds deviated significantly from declared values.

The declared calcium and phosphorus content differed to a large extent in many products, and 53% of the dry products showed analysed calcium levels at least 20% above or below declared values (range 43-237%). In moist feeds, 3 out of 5 products showed analysed calcium levels at least 20% above or below declared levels (range 70-210%). For phosphorus, 31% of the dry feeds had analysed levels at least 20% above or below what was declared (range 62-174%). Two out of five moist feeds had analysed phosphorus levels deviating at least 20% from what was declared (range 81-202% of the declared values).

When reanalysing 3 batches of 10 feeds, the coefficients of variation (CV) between feed batches ranged from 0.0 to 26.6% for calcium and between 1.2 and 29.5% for phosphorus. Other minerals that showed the largest CV between batches were sodium (57.8%) and manganese (57.2%) in 2 different feeds.

The 20 more expensive (≥1.50 SEK/MJ) and the 20 cheaper dog feeds (< 1.50 SEK/MJ) showed similar deviations and correlations between analysed and declared values.

Analysed nutrient content versus recommended nutrient profiles

All 45 dry feeds met the requirements for adult dogs for fat, and only one product had a too low protein level (energy-basis) if allowing a 10% deviation from the AAFCO (2000) nutrient profiles. Although allowing a 10% deviation, the levels of some minerals was too low compared to the recommended profiles; calcium (n=1), potassium (n=20), copper (n=2) and zinc (n=4). Also, 6 dry feeds showed calcium levels with 2% calcium or more on a DM-basis.

All moist feeds met the AAFCO (2000) nutrient profiles for protein, fat, calcium and phosphorus for adult dogs (140-200% of the nutrient profiles for protein, 216-270% for fat, 99-232% for calcium, and 143-332% for phosphorus, respectively). Two moist products contained too low levels of zinc, one had too low levels of copper, and another one showed too low levels of iron compared to the AAFCO (2000) profiles with an allowance of a 10% deviation.

Out of 45 dry feeds, 32 feeds were declared complete and balanced for all stages of life. If given to growing or reproductive dogs, and if allowing a 10% deviation from the requirements, 29 of the 32 dry feeds had adequate levels of protein. Also, 31 out of 32 dry feeds showed analysed levels of fat sufficient for this stage of life (energy-basis). If allowing a 10% deviation, 91 and 87% of the dry feeds analysed had a calcium and phosphorus content sufficient for growing and reproducing dogs. If allowing the same deviation from the analysed values, the magnesium, iron and manganese levels were sufficient growing/reproducing dogs in all 32 dry feeds. Some dry feeds did not meet the requirements for growing/reproducing dogs in calcium (n=3), phosphorous (n=4), sodium (n=10), potassium (n=12), copper (n=1), and zinc (n=2).

Only 2 out of 5 moist feeds were declared to be sufficient for growing or reproductive dogs. The first one of these two feeds was sufficient in protein, fat, calcium, potassium, sodium, magnesium, copper, manganese and zinc, but deficient in phosphorous and iron. The other moist feed labelled to be suitable for dogs of all stages of life was sufficient in protein, fat, magnesium, iron and manganese, but deficient in calcium, phosphorus, potassium, sodium, copper and zinc.

Energy content of the feeds

On average, the $ME_{Atwater}$ calculated from the analysed values of protein, fat and NFE of the dry feeds were in agreement with the $ME_{Atwater}$ based on the declared values. The relationship between the $ME_{Atwater}$ and the ME_{NDF} for 45 dry feeds was $ME_{NDF} = 446 + 0{,}663\ ME_{Atwater}$ (r 42.6%, $P<0.0001$). Dog feeds with energy values of 1500-1550 kJ/100 g DM $ME_{Atwater}$ were estimated to 1380-1580 kJ/100 g DM when using the ME_{NDF}. When the NDF-values were 14% or higher on a DM-basis, the Atwater factors seemed to overestimate the energy content by 10-21% in dry feeds, and by 16-37% in moist feeds.

Demographic data

The dog owners (paper I)

Most dog owning families were couples without children (35.1%, CI 30.7-39.5) and couples with at least one child (35.3%, CI 30.9-39.7). It was not as common to own a dog when being a single adult (10.2%, CI 7.4-13.0) and single parents with at least one child were rare (3.5%, CI 1.8-5.2). The majority (79.4%, CI 75.7-83.1) of dog owners was between 30 and 65 years of age, and the average

age for the adults was 43.2 years (SD 12.3). The number of children in the dog owning families was on average 1.85 (SD 0.84), and the average age for children was 10.4 (SD 4.9) years.

The dogs (paper I)

The dogs in the questionnaire study were by design 1-3 years. They were of 124 different breeds, 53.8% (CI 49.2-58.3) males and 46.2% (CI 41.6-50.8) females. The most common breeds were Dachshund, Golden retriever, German shepherd, Labrador retriever, English cocker spaniel and Swedish elkhound. Almost all (98.9%, CI 97.9-99.8) of the dogs were not neutered. The dogs were bought at an early age (mean 3.8 months, SD 4.9), and 90.7% (CI 88.0-93.3) of the dogs were with their current owners before 6 months of age. The average weight of the dogs was 22.1 kg (SD 13.5, range 1.2-75.0). The majority of dogs (92.4%, CI 90.0-94.8) were considered healthy at the time of the interview. For the dogs that were not reported to be healthy, 10 dogs were reported to have skeletal disorders, and 6 individuals had skin problems.

Dietary intake

Dietary patterns and nutrient intake (papers III and IV)

The typical Swedish dog was fed restricted amounts (83.3%, CI 79.9-86.7) most commonly (65.5%, CI 59.5-71.5) twice a day. On average, 74% (SD 22) of the energy intake of the dogs in this study originated from commercial feeds, but large dogs consumed a significantly higher proportion of energy from commercial feeds than did smaller dogs. For example, dogs between 1 and 10 kg consumed on average 62% (SD 25) of the total energy intake from commercial feeds, while dogs between 30 and 40 kg showed a corresponding figure of 80% (SD 20).

Dry dog feed was given to 95.0% (CI 93.0-97.0) of all dogs, and represented a high proportion of the total diets. A high proportion (93.0%, CI 91.0-95.0) of all dogs was given table foods and/or home-made diets, most commonly in small amounts and in addition to a dry dog feed. The table foods fed with the highest frequency and in the largest amounts (DM-basis) were vegetable oil, bread, meat/slaughter residues and sour milk. A low proportion of the dogs consumed canned dog feeds (14%, CI 10.8-17.2). Total feed intakes per kilo BW were lower for larger than for smaller individuals (range 10.6-29.2 g DM/kg BW), although there was a large individual variation.

Almost all (98.0%, CI 96.7-99.3) of the dogs were served some type of commercial feed, and 164 commercial products from 72 commercial brands were represented. On average, commercial feed sources accounted for 77.2 (SD 22.0), 66.9 (SD 24.4) and 77.1% (SD 23.2) of the daily intake of protein, fat and NFE on a DM-basis, respectively. Dogs of low BW ($\leq$ 10 kg) consumed a diet with a significantly smaller proportion of protein, fat, and NFE originating from commercial feeds than larger sizes of dog. Of the calcium and phosphorus consumed, 92.2 (SD 44.2) and 85.9% (SD 23.4) originated from commercial feed sources, respectively. For vitamin A, the average dog consumed 80.2% (SD 25.7) of the intake from commercial feeds, while the corresponding figures for vitamins D and E were 79.2 (SD 23.3) and 91.1% (SD 47.9), respectively.

Total diets contained on average 25.0% (SD 5.3) crude protein, 15.8% (SD 5.2) crude fat, and 46.9% (SD 9.0) NFE on a DM-basis, based on the declared values of commercial feeds and table foods. The ranges in nutrient content of the individual diets were 11-53% for protein, 3-37% for fat, and 9-75% for NFE on a DM basis. On average, the non-commercial part of the diet had a significantly higher fat and a lower protein content than the commercial part. The average levels of calcium and phosphorus were 1.0 and 0.9%, respectively. The corresponding figures for vitamins A, D and E were 15,300, 1,100 and 140 IU/kg DM, respectively.

Seventy percent of the dogs had protein intakes that ranged from 20 to 30% of DM. There was a large variation in dietary fat content between breed, size and individual, but 70% of the dogs had fat intakes ranging from 10 to 20% of DM. For calcium and phosphorus, 70% of the dogs had intakes of 0.71-1.44% and 0.63-1.05% of DM, respectively. The vitamins A, D and E were given to 70% of the dogs in the ranges 5,391-18,260 IU, 551-1,297 IU, and 67-186 IU, respectively.

Over half (62%) of the dogs were given commercial treats, and for these dogs the average intake was 10 g (SD 12) per day as fed. Vitamin and mineral supplements were given to 24% of the dogs, and most supplements were given as combined multimineral- and vitamin products.

Energy Intake (paper IV)

For all dogs in the study, the energy intakes could be described by the equation ME (intake) = $554W^{0.66}$ (r 0.58, P 0.0001), where ME (intake) is the daily intake of metabolisable energy (kJ/day), and W is the body weight (kg). For the dogs with BW's ranging from 1 to 75 kg, the ME intakes ranged from 401 to 26,729 kJ/day, with a median intake of 4,095 kJ/day. The energy intakes (kJ/kg $BW^{0.66}$) showed large variations within the same weight. For example, the coefficient of variation (CV) was 51% for dogs weighing 30 kg (mean 534, SD 271), and 35% (mean 609, SD 213) for dogs with a BW of 20 kg. The average energy intakes per kg metabolic BW was 9% lower (P<0.05) for females than males (579 and 630 kJ/kg $BW^{0.66}$, respectively).

The average dog consumed a diet with 1,627 kJ/100 g DM (range 1,177-2,080). On average, the total diets contained 15 g (range 7 to 29) crude protein, 10 g (range 2-21) crude fat and 30 (range 5-64) g NFE (Nitrogen Free Extracts) per MJ. The dogs consumed diets where on average protein, fat and NFE contributed 23, 34 and 43% of the energy, respectively. The energy percentage from fat was higher ($P<0.05$) in the part of the diet originating from table foods and home-made diets than from commercial dog feeds.

Activity (paper IV)

Dogs considered to be calm (20%) and moderately active (33%) in their temperament had average energy intakes that were similar; 594 (SD 264) and 591 (SD 237) kJ/kg $BW^{0.66}$, respectively. Although not significantly different from the dogs considered moderately active, dogs considered to be very active had a tendency ($P=0.07$) to a higher energy intake (634 kJ/kg $BW^{0.66}$, SD 247).

Most dogs spent more time outdoors in the summer compared to the winter, and when their owners were free from work compared to when they were working. The majority (82%, CI 78.4-85.5) of the dogs played with other dogs, and 44% (CI 39.5-48.5) performed this type of activity every day. Over half (53%, CI 48.4-57.6) of the dogs chased stick or balls thrown by their owner, and above one fourth did this every day.

Almost all (97%, CI 95.4-98.6) dogs were taken for walks, and the majority was walked at least once daily (84%, CI 80.6-87.3). The dogs that were exercised by walking did this on average 79 (range 1-300) minutes per day. Other types of exercise performed by fewer dogs were running beside a bicycle (29%; 16 min/d, range 2-120) and jogging (16%; 24 min/d, range 1-347).

Over half (60%, CI 55.5-64.5) of the dogs were trained in different activities, such as obedience, searching, tracking or hunting, on average 35 (SD 31, range 1-227) minutes per day for those that performed any of these activities. Hunting was the activity performed most commonly and by the largest proportion (27%, CI 22.9-31.10) of the individuals, 32 min/d, range 1-146), but was strongly influenced by seasonal variations. A third (31%, CI 26.8-35.2) of the dogs was trained in obedience (21 min/week, range 2-129), and 18% (CI 14.5-21.5) of the dogs were tracking, either human or game tracks (13 min/week, range 1-69).

The dogs that were reported to be exercised for a short period every day (less than 1 hour), generally did not consume less energy per kg BW than dogs exercising up to 5 hours a day. On average, dogs weighing between 30 and 50 kg had the highest total activity level, but the range in activity level within each size group was large.

Discussion

This study indicates that it is possible to estimate dietary intake and activity by using validated survey techniques for dogs living in households. Demographics, diet, activity and some health parameters were shown to be both repeatable and valid in a defined Swedish population of dogs. However, when representative commercial dog feeds were analysed for the energy and nutrient content, it became apparent that declared values for some minerals need special attention, as the reliability of the declared values is sometimes low. As the response percentages of the studies performed were reasonable, the present data should be representative for Swedish dogs at an age between 1 and 3 years.

Reliability of a questionnaire and reasons for bias

Choice of participants

The individuals chosen for a study might be different from a true population mean either by chance or because a non-representative group has been selected. In the present study, a statistical comparison for demographic data with the general dog population in Sweden was made (paper I), and there was no significant difference between these two samples for sex and breed distribution. Although a statistically significant difference was noted for the proportion of dogs that was not neutered (99% in the present study versus 97% for dogs 1-3 years old in the national Gallup), the difference was considered negligable.

Earlier studies in canine nutritional epidemiology (Slater *et al*., 1992 & 1995; Sonnenschein, 1988) selected dogs from veterinary clinics, and conclusions for dietary intake and exercise patterns were drawn based on these sub-populations. However, there is a risk that dogs seen at veterinary clinics might be different from the general dog population.

In this study, the response percentage is as high as in other published studies of dietary intake in populations of dogs (Slater *et al*., 1992 & 1995; Sonnenschein, 1988). As the database of Agria was confidential, the dog owners were asked to participate by Agria before the research group could make any contact with the respondents. If the study were to be repeated, it would be preferable to be able to telephone owners directly after a mailed informatory letter, as it is very time-consuming to send out reminders and make follow-ups of the non-respondents. Also, the response percentage would possibly have been higher if telephoning directly after an informatory letter, as most owners that were telephoned after having received 3 mailed requests, did indeed respond positively about participating.

Choice of period

In the present study, the interviews were performed from February to June in 1997, and as the interviews were not repeated during different times of the year, we know nothing about possible seasonal variations in the dietary intakes of the dogs. However, as the average dog diet is mainly based on commercial feeds with a relatively constant composition and as an average three quarters of the energy intake originates from commercial feed sources, the seasonal variations in dietary intake should generally be smaller than in humans (paper IV). Bingham *et al*. (1994) performed a trial with humans during four periods of a year, and reported a trend towards a lower total food consumption from April to September. There were also significant differences in the intakes of carbohydrates, calcium, iron and retinol between the periods October-January and July-September.

Estimation of amount consumed

Ideally, everything consumed by each individual of a population of dogs should be accurately measured during a longer period of time to obtain reliable data. However, due to the cost and amount of work needed, questionnaires often are regarded as a compromise between speed and accuracy. The repeatability of a questionnaire measured at two points might give a useful approximation of questionnaire performance. To discover if the measurements made using a questionnaire are accurate, it is necessary to compare them with another, more intensive or invasive method of measurement that has known validity. In nutritional epidemiology, there is no absolute standard against which all measurements can be compared; therefore, it is only possible to estimate the relative validity of total nutrient intake between two methods. The methods compared in this investigation were the 7-day weighed record and the food frequency and amount questionnaire. None of these methods can measure feed intake without error, the questionnaire is reproducible within individuals and the measurements agrees with the weighed recordings. More accurate methods (such as biological markers) are expensive and time-consuming, and it is only possible to validate one nutrient at a time. Although more accurate methods might be better for validating single food items or energy expenditure, for estimation of total diets in dog populations the validated questionnaires are the best option at the moment.

Many studies in man have shown that there is an overestimation of food intake in food frequency questionnaires compared to weighed diets (Bingham, 1987). Callmer *et al*. (1993) reported that two food frequency questionnaires made on 206 men and women both overestimated the total energy intakes compared to a weighed diet. Also, men over-reported their intake more than women did (29-32 % and 13-25 %, respectively). In the present study, the energy and nutrient intakes were very similar in the questionnaire and in the weighed records, possibly due to the fact that many dogs eat a relatively similar diet from day to day compared to humans. Also, many humans are very weight conscious, and might underreport when weighing their own diet. Instead of actually weighing sweets they report, perhaps they refrained to eat it. When weighing the food intended for their dogs, it is possible that dog owners do not under-report the dietary intake to the same extent, as the feed is not intended for themselves.

The way the questions are formulated and posed are of importance in this type of study. It is essential to know the degree of precision in the response that is necessary to be able to analyse the collected data. An important issue is whether it is always of highest priority to calculate the exact feed intake. Absolute levels of dietary intake are most important when giving recommendations for feed intake, to draw up nutrient guidelines, or when estimating the prevalence and incidence of a health problem.

Other factors do bias the true food intake. Persons in a study might misinterpret a question and therefore make a false reporting of food intake. Individuals might also misjudge the true food intake. Scales used in a study might have a too low precision or actually show a false weight.

In humans, Bingham *et al*. (1994) showed that correlations between 16-day weighed diets and a questionnaire ranged between 0.13 and 0.57 for different nutrients, except for alcohol that had a higher correlation. As dog diets generally vary less in composition from day to day than human diets, one can expect higher correlations between questionnaires and weighed registrations. This has also been shown in the present study (paper II); the correlations for nutrient and energy intake ranged from 0.72 to 0.79 for repeatability of the questionnaire, and between 0.80 and 0.85 in the validity study.

Other reasons for bias

If making a survey with many participants, it is common not to analyse all or any food that they consume. Instead, it is customary to use food tables to calculate the theoretical nutrient intake. In this study, the nutrient and energy values declared for the commercial dog feeds were used in the calculations. For table foods, the values given in the Swedish food composition table were used (National Food Administration, 1996). When using table data the values are of course subject to normal individual variation in dietary composition, but variations in nutrient value may also be due to processing, storing, digestibility and availability. The variation in table foods is not taken into account in the present study. However, as a validation of commercial feed intake, the most commonly served dog feeds were analysed for energy and nutrient content (paper V). The present studies have shown that commercial dog feeds were generally reliable for the energy-giving nutrients, but were often less reliable for minerals. The vitamins in the commercial dog feeds were not analysed in this study.

Demographic data

It was shown that the insurance database used for these studies, are representative for all dogs between 1 and 3 years old in Sweden. Dogs in Sweden are found to be different from other populations in the respect that Swedish dogs are to a very high extent not neutered. For example, in an Australian survey, only 8 and 43% of the females and males were intact, respectively (Blackshaw & Day, 1994). Also, the Swedish dogs are collected by their owners at an early age and commonly stay with the same owner (Hedhammar *et al*., 1999), something that has been shown to be different in other populations (Moulton *et al*., 1991; Rowan, 1991).

Although measured and validated, the occurrence of different diseases were only used as indications and were not used as parameters for further analysis. This was because the disease measurements were subjective. Also, too few individuals suffered from diseases of interest and could therefore not be used with any reliability. In future epidemiological studies, disease data from veterinary records, or preferably screening programs verifying also non-affected individuals, should be used instead of owner information. The data of the body condition score was used cautiously, and should also be considered indicative as it was subjectively judged by the dogs owners. In future studies, the questionnaire should include questions about whether the dog was increasing or decreasing in weight at the time of the study.

Dietary intake

The dietary intakes of the dogs were shown to have high repeatability and validity. The feeding patterns in dogs were shown to remain similar over time, which is why the long-term effects of specific feeding patterns or intakes of high or low levels of specific nutrients should be possible to evaluate.

Dietary patterns and nutrient intake

The typical dog was given a large proportion of its diet as dry feed with a topping of table foods, most commonly twice a day. In this study, 98% of the dogs were shown to consume some type of commercial dog feed. This was in accordance with a Swedish poll performed in 1996, where 96% of the dogs consumed some type of commercial dog feed. The poll also showed that 76% of the dogs were mainly given a dry feed, which is also in accordance with the present study (ScandInfo Marketing Research, 1996). In another Swedish poll made in 1987, 90% of the dogs had consumed dry feeds during the preceding month, and 80% consumed this type of feed every day (Svenska Testhuset AB, 1988). These are slightly lower figures than are presented in this study. As this poll was performed

10 years before the present survey, it is possible that an increasing proportion of Swedish dogs indeed consume commercial feeds.

In other countries, there are very different estimates of the proportion of dogs that receive commercial feeds. For example, 62% of the French dogs were shown to be given commercial feeds regularly, corresponding to on average 27% of the total energy intake (Bonnavaud, 1989). Remillard *et al*. (2000) stated that on average, European dogs consume 70% of their energy from home-made diets, ranging from 50% in the United Kingdom to 90% in Italy. Consequently, the type of questionnaire used in the present study would have to be re-evaluated if used in other populations. Possibly, it would be more difficult to estimate the dietary intakes with a high reliability if higher amounts of table foods are fed than that to Swedish dogs.

A Swedish study in 1996 showed that 17% of the dogs were mainly served a home-made diet (ScandInfo Marketing Research, 1996). In the present study, only 3% of the dogs consumed home-made diets as a major part (>65% on an as fed-basis) of their diet. However, if those that consumed home-made diets and/or table foods were summed, 16% of the dogs in the present study consumed these types of foods as a major part of their diet, a finding which agrees with the Swedish study from 1996. If giving an international perspective, for example 15% of the French dogs have been shown to consume only home-made food, and another 15% were served exclusively table foods (Pibot, 1989). It was concluded that in a European perspective, Swedish dogs consume a small part of their dietary intake as non-commercial feeds. However, a higher proportion of Swedish dogs consume table foods (93%) than was reported by Slater *et al*. (1992) in a study on American dogs, where 39% were given table foods. In a later study, Slater *et al*. (1995) found that 56% of the dogs in another American population consumed table foods. The difference in the proportion of dogs that consume table foods might of course be due to different traditions and habits concerning feeding dogs. However, in this study it was noted that when asking the question whether or not table foods were given, fewer dog owners responded yes than when asked about specific table foods. For example, many dog owners did not report that they served their dog vegetable oil, egg yolk, or sour milk a few times a week in an overall question. It is also possible that some dog owners believe that the table foods they serve are more or less considered as supplements (e. g. egg yolk, vegetable oil) rather than table foods, and therefor they do not report feeding table foods in an overall question. Consequently, it is possible that those giving answer for an overall question might underestimate the proportion of dogs that actually consume table foods.

In this study it has been shown that in most cases it is possible to give a smaller part of the total diet as table foods and still have a nutritious diet. However, the table foods given to most dogs in this study were indeed higher in fat content than most commercial feeds. Dogs prone to being overweight might have a better control of energy and fat intake if consuming only commercial feeds or a balanced home-made diet, thus avoiding table scraps.

The majority of dogs were fed a diet where protein and fat were adequate according to the AAFCO (2000) nutrient profiles. However, the variation in fat and protein intake ranged considerably, which is why possible health effects of a low or high consumption should be possible to evaluate. If allowing a 10% deviation for possible analytical variations, the analysed commercial dry dog feeds met the nutrient profiles for adult dogs (AAFCO, 2000) in all cases for fat, and in all except one for protein. For the dry feeds declared as complete and balanced for all stages of life, 91% were adequate in protein and 97% for fat if allowing the same 10% deviation. All moist feeds met the requirements for protein and fat for adults, while one out of two products intended for all stages of life were deficient in protein. On average, the reliability for protein and fat in commercial feeds was shown to be high.

Most dogs consumed calcium and phosphorus according to recommended levels when the calculations were based on the declared values (AAFCO, 2000). The repeatability and validity of the amounts of calcium consumed in the questionnaire was high compared to the 7-day weighed recordings. However, as the analysed calcium levels in over half (53%) of the feeds deviated at least 20% from declared values for dry feeds, the overall reliability of calcium intake was low. Dogs not consuming adequate amounts of calcium when using the declared values, possibly consumed even lower "true" levels, and dogs consuming high levels of calcium might in fact consume "true" levels higher than the maximum recommended level. The finding that dog feeds often deviate from declared values primarily for minerals are of importance for future studies in canine nutritional epidemiology.

The mineral content of the analysed feeds were in some feeds shown to deviate from the recommended AAFCO (2000) nutrient profiles. If allowing a deviation of 10% from the minimum levels of minerals for adult dogs, still 24 out of 50 feeds showed lower levels of one mineral each. Out of the feeds intended for dogs in all stages of life, 22 out of 34 feeds was more than 10% lower in one or more minerals. The nutrient content of minerals not examined, for example iodine, remains unknown. It is concluded, that for future studies in canine nutritional epidemiology access to the analysed content of specific nutrients might be necessary as the deviation from the declared values does occur in many dogs feeds regardless if purchased at a high or a low cost.

Vitamins A, D and E were also shown to be consumed in recommended amounts for the majority of individuals if calculated on declared values. Out of 460 individuals, 51, 37 and 28 dogs consumed too low levels of vitamins A, D and E, respectively. No dogs consumed too high levels of vitamin A, while 14 and 5 dogs had intakes above recommended maximum levels for vitamin D and E, respectively. In the present work, the vitamin contents of commercial feeds were not analysed, so the validity of vitamin contents in dog feeds on the Swedish market remains unknown.

Total diets that did cause deviations from recommended levels were those consisting of only table foods (too low levels of vitamins and minerals) or complete and balanced commercial feeds supplied with extra vitamin and mineral supplements (too high levels of vitamins and minerals).

Energy intake

The population of dogs in the present study had energy intakes that were in the middle range of various suggested equations for ME. Many earlier studies have suggested MER much higher than the energy intakes registered for the dogs in this survey (paper IV). In most animal species the variation of adult body weight is limited, but in dogs the range is more than 100-fold. Therefore, a careful consideration should be given to the equations used to predict the ME requirements in different dog populations.

Large variations were shown for energy intakes depending on weight, breed and individual. Factors associated with variations of energy intake between individuals are age, weight, breed, gender, neuter status, activity level and body condition.

The energy levels of analysed feeds estimated by the modified Atwater factors, failed to separate dog feeds by energy level as compared to when the energy was estimated from the NDF-value (paper V). For example, dog feeds with energy values of 1500-1550 kJ/100 g DM $ME_{Atwater}$ were estimated to between 1380-1580 kJ/100 g DM when using the ME_{NDF}. This estimated difference in energy most probably decreases the precision in the energy intakes.

Labelling commercial dog feeds as “light”, “normal” and “high” energy is often confusing, as each manufacturer has its own perception of what is considered light, normal or high energy. The products show a large variation and overlap between products, and instead of the terminology of for example “light products” as a concept, it would be more valuable to compare the actual energy and nutrient contents of the feeds in question.

A belief that manufacturers of expensive dog feeds have a better control of the production and less variation from the nutrient profiles than those of cheap feeds was not verified in the present study. This study has shown that the price is not a strong determining factor for the deviation from declared values. Expensive feed showed the same size of deviation from declared energy and nutrient values as did the lower cost feeds.

Activity

For the first time, dog activity has been shown to be both repeatable and valid in a population of dogs. The activity level is important to measure as this might be a factor responsible for a large part of the variation in energy intake. There are many studies of the importance of exercise and nutrition in hard-working dogs, but only limited data examining the activity of normal family dogs. It is also important to register different types of activity, as these factors alone might be of significance for health and specific diseases.

In the present study (paper IV), dogs considered as having a calm or moderately active in the general temperament had average energy intakes very similar; 594 (SD 264) and 591 (SD 237) kJ/kg $BW^{0.66}$, respectively. Although not significantly different from the dogs considered moderately active, dogs considered to be very active had a tendency (P=0.07) to a higher energy intake (634 kJ/kg $BW^{0.66}$, SD 247). There was no significant difference in the energy intake of dogs depending of the amount of exercise registered in this survey. Although the judgement of the temperament of the dog is very subjective, it seems as if the overall temperament could be of greater importance for the energy intake than variation in the amount of exercise performed by the dogs. Some dogs walk very slowly beside their owners while others run around and have a very high activity when taken for walks. This difference in general temperament and activity is probably not accounted for when only registering the amount of time spent on walks per day, as the intensity of the exercise was not registered.

Future studies

In Sweden, there are excellent opportunities to perform both cross-sectional as well as longitudinal studies in the dog population as a high proportion of the dogs are registered, genetically defined, housed by the same owners from an early age to death, and are often also possible to follow already from birth at the breeder.

Dietary Intake

In this study good estimates of the current diet for adult dogs have been presented. Also, dog owners were shown to recall the previous type of consumption well. Using dog populations in comparative epidemiological studies could prove to be useful because the diet of most dogs is relatively consistent in composition compared with human diets, and dogs consume a relatively constant diet from an early age. Population studies on dog nutrition therefor could add to our understanding of nutrition as related to health in ways that laboratory experiments cannot. Although dogs live long enough to acquire degenerative and chronic diseases, they have a shorter life span than people. This fact makes it possible to evaluate the health effects that are influenced by environmental factors in a shorter time compared to studies with humans.

As examples of possible parameters to examine in further studies, the *ad libitum* and the meal fed dogs as well as commercial and home-made diets could be compared with respect to specific diseases. As dietary intake showed large variations between breeds, future epidemiological studies should be performed in one or a few selected breeds at a time.

If table foods are given in large amounts, it would be vital also to analyse specific table foods. For example, if the calcium intake is of interest, at least the table foods rich in this nutrient should be paid attention to. If a low proportion of the dietary intake consists of table foods, it is probably sufficient only to analyse the commercial dog feeds consumed.

Beside the chemical analysis made of commercial dog feeds in the present study, it would be of value to analyse the vitamins, and the fatty and amino acids. Some minerals not analysed, for example iodine, would also be of great value to analyse as iodine is important for the thyroid function, and some dog feeds have been indicated to contain excessive amounts of this nutrient (Castillo *et al*., 2001).

Activity

As there was a large variation in energy intake between individuals, it would be interesting to compare and scrutinise dogs of the same weight, gender and activity level but with energy intakes that differ. What was the reason for the differences in recorded energy intakes? What would be the effects of seasonal variations in exercise patterns?

Conclusions

The conclusions from the present thesis are as follows:

- A mail and telephone questionnaire was shown to be both repeatable and valid for demographics, diet and activity in dogs.

- The insured dogs were shown to be representative for all Swedish dogs of the same age.

- A typical Swedish dog consumed 75% of the energy intake from commercial feeds, and a smaller part as table foods, but there were large variations between individuals.

  The absolute majority of the dogs were fed total diets supplying adequate amounts of the nutrients. Total diets that did cause deviations from recommended levels were those consisting of only table foods (too low levels of vitamins and minerals) or commercial feeds supplied with extra vitamin and mineral supplements (too high levels of vitamins and minerals).

- The energy intakes were at the same range as in previously published studies on maintenance energy requirements of adult dogs, but varied due to sex, breed and weight.

- Three quarters of the dogs performed some type of activity for one hour or more per day, but although substantial variations were recorded, there was no significant difference in energy intake that could be related to the amount of activity recorded. However, there was a tendency (P=0.07) that the general temperament of the dog had a greater influence of the energy intake.

- The analysed protein and fat content in commercial feeds on average was highly correlated with the declared values and with the recommended nutrient profiles. However, especially the calcium but also the phosphorus contents of commercial dog feeds often deviated from declared values, and did not always meet the AAFCO (2000) nutrient profiles. More expensive feeds had the same magnitude of deviation from declared energy and nutrient values as did feeds of a lower cost.

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