doi: 10.17221/145/2015-VETMED

Feline obesity – prevalence, risk factors, pathogenesis, associated conditions and assessment: a review

D. Tarkosova[1], M.M. Story[2], J.S. Rand[2], M. Svoboda[1]

[1]Faculty of Veterinary Medicine, University of Veterinary and Pharmaceutical Sciences, Brno, Czech Republic
[2]School of Veterinary Science, University of Queensland, Gatton, Australia

ABSTRACT: Obesity is recognised as the most common multifactorial nutritional disorder of pet cats. Studies from several countries have indicated that between 11.5% and 63% of cats are overweight or obese. Breed, age, sex, reproductive status, the pet-owner relationship, owners' perceptions of their cats' body condition, type of diet, frequency of feeding, and environment have all been identified as potential risk factors for the development of obesity in cats. Obesity has significant implications for feline health and welfare as it has mechanical and metabolic effects and can predispose cats to conditions such as diabetes mellitus type 2, hepatic lipidosis, lameness, oral cavity disease, urinary tract disease, dermatological disease, and neoplasia. An important aspect of preventing and managing obesity is the evaluation of body condition to determine ideal body weight and to formulate an appropriate weight loss plan. Several methods have been developed for this purpose. This review uses recent scientific literature to discuss various aspects of feline obesity, including its prevalence, proposed risk factors, pathogenesis, associated conditions, and methods of assessment.

Keywords: overweight; obese; body condition; cat

List of abbreviations

BCS = body condition score, **CT** = computed tomography, **DEXA** = dual-energy X-ray absorptiometry, **MMS** = muscle mass scoring, **QMR** = quantitative magnetic resonance

Contents

doi: 10.17221/145/2015-VETMED

1. Introduction

Obesity is the deposition of excessive adipose tissue secondary to greater calorie intake than energy expenditure (Burkholder and Toll 2000; German 2006; Laflamme 2006; Zoran 2009; Zoran 2010; Michel and Scherk 2012), and is the most common multifactorial nutritional disorder of pet cats (Michel and Scherk 2012; Linder and Mueller 2014). Obesity in cats has mechanical and metabolic effects, thereby influencing quality of life and increasing the risk of developing conditions such as diabetes mellitus (Scarlett and Donoghue 1998), hepatic lipidosis (Burrows et al. 1981), urinary tract disease (Lund 2005), oral cavity disease (Lund 2005), neoplasia (Lund 2005), dermatological disease (Scarlett and Donoghue 1998; Lund 2005), and lameness (Scarlett and Donoghue 1998). The frequency of obesity in pet cats combined with its significant adverse effects means that prevention and management are critically important for maintaining optimal health and welfare of cats. Effective prevention and management of feline obesity require accurate identification of obesity in individual cats, as well as appreciation of its prevalence and knowledge of risk factors, which several recent studies have investigated (Allan et al. 2000; Russell et al. 2000; Lund 2005; McGreevy et al. 2008; Colliard et al. 2009; Courcier et al. 2010; Cave et al. 2012; Courcier et al. 2012; Corbee 2014). Different methods of assessing body composition and categorising the level of obesity have been developed. The terms overweight and obese are commonly used as a simple way of denoting the severity of excessive fat mass. Individuals are typically classified as overweight if 10% to 20% heavier than ideal body weight and obese if more than 20% heavier than ideal body weight (Zoran 2009; Laflamme 2012; Linder and Mueller 2014). There are also more complex systems, such as body condition score (BCS) which combines visual assessment and palpation of adipose tissue mass to divide body composition into several defined categories (Laflamme 1997; German 2006; German et al 2006). This review will use recent scientific literature to highlight key features of obesity in cats, including its prevalence, proposed risk factors, pathogenesis, associated conditions, and methods of assessment.

2. Prevalence of obesity in cats

The results of multiple studies published in the last 15 years suggest that, in western countries, anywhere from 11.5% to 63% of pet cats are overweight or obese (Allan et al. 2000; Russell et al. 2000; Lund 2005; McGreevy et al. 2008; Colliard et al. 2009; Courcier et al. 2010; Cave et al. 2012; Courcier et al. 2012; Corbee 2014). This wide variation in prevalence is likely due to several factors. These studies were conducted in a range of geographical locations, and risk factors for feline obesity may vary by geographic area. For example, feeding practices (Laflamme et al. 2008) and the proportion of neutered (Slater et al. 2008; Chu et al. 2009; Murray et al. 2009; Johnson and Calver 2014) and indoor cats (Slater et al. 2008; Murray et al. 2009) may vary by country. In addition, the population of cats studied varied in terms of size and type. Three studies each assessed between approximately 1000 to 8000 cats (Lund 2005; McGreevy et al. 2008; Courcier et al. 2012), but the others each enrolled only around 100 to 400 cats, making the results more prone to biases (Allan et al. 2000; Russell et al. 2000; Colliard et al. 2009; Courcier et al. 2010; Cave et al. 2012; Corbee 2014). In some studies, the cats were chosen from a random selection of households in a predetermined area (Allan et al. 2000; Russell et al. 2000; Cave et al. 2012). In other studies, cats that presented to certain veterinary clinics were enrolled (Lund 2005; McGreevy et al. 2008; Colliard et al. 2009; Courcier et al. 2010; Courcier et al. 2012). In another study, cats from two cat shows were assessed (Corbee 2014). Furthermore, different methodologies were used in the various studies, including different definitions of overweight and obese and different body condition scoring systems. Most of the studies used a 5-point BCS scale (Allan et al. 2000; Lund 2005; McGreevy et al. 2008; Colliard et al. 2009; Courcier et al. 2010; Courcier et al. 2012), but some used a 9-point scale (Cave et al. 2012; Corbee 2014) and one study used a 17-point scale (Russell et al. 2000). It is possible that this could have resulted in differences in how cats were classified, particularly for cats that were on the border of two categories. One study demonstrates the effect that using different BCS systems can have on the classification of weight, as 63% of the cats examined in this study were classified as overweight or obese on a 9-point BCS scale but only 27.4% were classified into these groups when a 5-point BCS scale was used (Cave et al. 2012). Also, in some studies, there was a single trained assessor (Allan et al. 2000; Russell et al. 2000; Courcier et al. 2010; Corbee 2014), in others, there were two

doi: 10.17221/145/2015-VETMED

trained assessors (Colliard et al. 2009; Cave et al. 2012) and, in the remaining studies, BCS score was assigned by the attending veterinarian when each cat presented to the veterinary clinic (Lund 2005; McGreevy et al. 2008; Courcier et al. 2012). In the studies with one or two assessors, it is likely that the body condition scoring system was applied more consistently than in those studies where the BCS was determined by a variety of veterinarians. However, it is possible that use of only one or two assessors could have caused consistent bias in the way the body condition scoring system was applied, and so certain categories may have been favoured. In most studies, the accuracy and precision of the assessors were not reported, nor was their training adequately described.

2.1. Great Britain

The lowest prevalence of feline obesity was found in a retrospective cross-sectional study based on data from 47 first opinion companion animal veterinary practices spread throughout Great Britain (Courcier et al. 2012). The BCS of 3219 cats that presented from 2008 to 2010 was extracted retrospectively from a national database (Courcier et al. 2012). Attending veterinarians evaluated the BCS of cats at each consultation using a 5-point scale, with a BCS of four considered overweight and a BCS of five considered obese (Courcier et al. 2012). However, there was no indication of whether a BCS diagram or explanation of criteria for each score was used, or whether practice veterinarians were just asked to rank the cat as very underweight, underweight, ideal, overweight or obese (Courcier et al. 2012). 9.7% of cats were classified as overweight and 1.8% as obese (Courcier et al. 2012). In contrast, a much higher prevalence of obesity was found in two other studies from Great Britain (Russell et al. 2000; Courcier et al. 2010). In Glasgow, 118 adult cats that presented to a first opinion charity veterinary practice were assessed by a trained veterinary student (Courcier et al. 2010), using a similar 5-point BCS scale to that used in the study by Courcier et al. (2012). Cats were assessed over a three week period in 2008, of which 28.8% were classified as overweight and 10.2% as obese (Courcier et al. 2010). A study of 136 cats from west London performed in 1998 found that 48% of cats were classified as overweight and 4% as obese (Russell et al. 2000). In this study, cats from households in a selected area were evaluated by a trained assessor using a 17-point BCS scale that was created by adding half-point increments to an existing 9-point system (Laflamme 1997). A BCS of 6 to 7.5 was classified as overweight, and a BCS of 8 or above as obese (Russell et al. 2000). The large difference in prevalence could be due to the studies from Glasgow (Courcier et al. 2010) and London (Russell et al. 2000) using a single, trained assessor to prospectively evaluate a small number of cats from a limited geographic area, compared to the other retrospective study where data from a large number of cats from a wide area were analysed, and where BCS had been assigned during routine consultations by various veterinarians who might not have used a BCS diagram or consulted explanations for each score (Courcier et al. 2012). The level of training of the assessor has been shown to be associated with the accuracy of body condition scoring in cats (Shoveller et al. 2014). Because the study by Courcier et al. (2012) used secondary, retrospective data, the data are more prone to errors and inconsistencies in classification, compared to primary, prospective data used in the studies from Glasgow (Courcier et al. 2010) and London (Russell et al. 2000). In addition, in the study by Courcier et al. (2012), nearly 50% of the cats were up to two years of age. However, in the study from Glasgow, only 17.8% of cats were between one and two years of age (Courcier et al. 2010), and obesity has been shown to be more common in middle aged cats (Kronfeld et al. 1994; Scarlett et al. 1994; Robertson 1999; Lund 2005; Kienzle and Bergler 2006; McGreevy et al. 2008; Colliard et al. 2009; Courcier et al. 2012).

2.2. United States

BCS data from 8159 adult cats presented to 52 first opinion companion animal veterinary practices in the United States in 1995 were collected from practice databases (Lund 2005). Attending veterinarians assigned a BCS to the cats at each consultation, using a 5-point BCS scale (Lund 2005). The average BCS of a cat for the year was used for statistical analysis and the definitions of overweight and obese were slightly different to those used in other studies (Allan et al. 2000; McGreevy et al. 2008; Colliard et al. 2009; Courcier et al. 2010; Courcier et al. 2012), with a BCS of greater

doi: 10.17221/145/2015-VETMED

than 3.5 and up to 4.5 considered overweight and a BCS of greater than 4.5 considered obese (Lund 2005). 28.7% of cats were classified as overweight and 6.4% as obese (Lund 2005).

2.3. New Zealand

A cross-sectional study performed in New Zealand in 1993 assessed the body condition of 182 cats from a random sample of houses in a selected area (Allan et al. 2000). An interviewer experienced in assessing feline body condition assigned the cats to categories of extremely thin, thin, normal weight, overweight or extremely overweight (Allan et al. 2000). 25.8% of cats were categorised as either overweight or extremely overweight (Allan et al. 2000). 23.1% of the cats were assessed as overweight and 2.7% as extremely overweight (Allan et al. 2000). A later study compared the results from 1993 to a sample of 200 adult cats from the same area in 2007 (Cave et al. 2012). Two interviewers used a 9-point scale (Laflamme 1997) to assess BCS (Cave et al. 2012). 63% of the cats examined were assessed as overweight or obese with a BCS of 6 or greater (Cave et al. 2012). To compare the results to those from 1993, the 9-point scale was converted into the 5-point scale used in the earlier study (Cave et al. 2012). 27.4% of the cats assessed in 2007 were then classified as overweight or extremely overweight using the 5-point scale (Cave et al. 2012). Thus, there was no evidence to support any significant increase in feline obesity in this area during the time between the studies (Cave et al. 2012).

2.4. Australia

A survey of 1042 adult cats presented to 48 Australian veterinary practices was performed in 2000 (McGreevy et al. 2008). The BCS of the cats was assessed by the attending veterinarians using a 5-point scale (McGreevy et al. 2008). 26.2% of cats were classified as overweight, with a BCS of 4, and 6.6% as obese, with a BCS of 5 (McGreevy et al. 2008).

2.5. France

In 2006, two veterinarians trained in body condition scoring of cats assessed the BCS of 385 healthy cats presented to the vaccination department of a veterinary school in France (Colliard et al. 2009). They used a 5-point scale, where a BCS of 4 was classified as overweight and 5 as obese (Colliard et al. 2009). 19% of the cats were classified as overweight and 7.8% as obese (Colliard et al. 2009).

2.6. The Netherlands

A study from the Netherlands assessed the BCS of 268 show cats of 22 breeds (Corbee 2014). BCS was evaluated using a 9-point scale (Laflamme 1997) by the same board-certified nutritionist at two different cat shows (Corbee 2014). 45.5% of the cats were assessed as overweight, with a BCS greater than 5 and up to 7, and 4.5% were assessed as obese, with a BCS greater than 7 (Corbee 2014).

3. Risk factors for development of obesity in cats

The causes of obesity are multifactorial and proposed risk factors include breed, age, sex, reproductive status, the pet-owner relationship, owners' perceptions of their cats' body condition, type of diet, frequency of feeding, and environment (Sloth 1992; Kronfeld et al. 1994; Scarlett et al. 1994; Robertson 1999; Allan et al. 2000; Russell et al. 2000; Lund 2005; Kienzle and Bergler 2006; McGreevy et al. 2008; Colliard et al. 2009; Heuberger and Wakshlag 2011; Cave et al. 2012; Courcier et al. 2012; Corbee 2014).

3.1. Breed

There are currently no proven genetic factors which predispose particular cat breeds to obesity. Some studies have found that obese cats are more likely to be domestic shorthair (Lund 2005), domestic longhair (Lund 2005), domestic mediumhair (Lund 2005), Manx (Lund 2005) or mixed breed (Scarlett et al. 1994; Robertson 1999; Lund 2005). However, in other studies, breed was not found to be a risk factor for obesity (Courcier et al. 2010; Courcier et al. 2012). The study of show cats by Corbee (2014) demonstrated significant differences in the average BCS between cat breeds, which the author hypothesised was related to the type

doi: 10.17221/145/2015-VETMED

of body shape considered ideal in the breed standards. The study included 22 different breeds, including Cornish Rex, Sphynx, Abyssinian, Devon Rex, Oriental Shorthair, Maine Coon, Ragdoll, Burmese, Norwegian Forest Cat, British Shorthair, and Persian (Corbee 2014). Breeds more prone to obesity tended to be described as chubby, cobby, sturdy, square, round, powerful, muscular, broad chested and bull necked, and so these breed standards may favour a type of cat that is prone to obesity (Corbee 2014).

3.2. Age

The results of several studies have indicated that obesity is more common in middle-aged (five to 11 year old) cats (Kronfeld et al. 1994; Scarlett et al. 1994; Robertson 1999; Lund 2005; Kienzle and Bergler 2006; McGreevy et al. 2008; Colliard et al. 2009; Courcier et al. 2012), likely due to age-related reductions in metabolic rate and physical activity.

3.3. Sex and reproductive status

Sex and reproductive status appear to influence the risk of developing obesity as several studies have shown a higher prevalence of obesity in neutered cats (Sloth 1992; Scarlett et al. 1994; Robertson 1999; Allan et al. 2000; Russell et al. 2000; Lund 2005; McGreevy et al. 2008; Colliard et al. 2009; Courcier et al. 2012) and male cats (Scarlett et al. 1994; Robertson 1999; Lund 2005; McGreevy et al. 2008; Colliard et al. 2009; Courcier et al. 2012). Sex hormones are important regulators of metabolism, especially oestrogen which has a role in the regulation of food intake, energy expenditure and fat deposition (Cooke and Naaz 2004; Cave et al. 2007). In humans, oestrogen is known to inhibit lipogenesis by reducing the activity of lipoprotein lipase (Cooke and Naaz 2004). However, there is uncertainty over whether this mechanism is involved in post-neutering increases in adipose tissue in cats (Kanchuk et al. 2003). Neutering decreases the metabolic rate and calorie requirement of cats, which may then lead to an accumulation of adipose tissue (Flynn et at. 1996; Root et al. 1996; Fettman et al. 1998; Mitsuhashi et al. 2011). When 22 shorthair adult female cats were fed at maintenance energy requirements for intact cats before and after ovariohysterectomy, all the cats increased body weight by 16% and BCS by one point after ovariohysterectomy (Mitsuhashi et al. 2011). Several studies in cats have also reported a significant increase in food intake after neutering, which leads to weight gain and decreased physical activity (Fettman et al. 1998; Kanchuk et al. 2003; Backus et al. 2007; Belsito et al. 2009).

3.4. Pet-owner relationship and perception of obesity

The pet-owner relationship is an important factor in the development of feline obesity. One study has shown an association between cats and owners being overweight when the owners were 60 years of age or older (Heuberger and Wakshlag 2011). The authors of a study of the pet-owner relationship concluded that their results indicated that the owners of overweight cats were closer to their cats, over-humanised them more and may have been using them as a replacement for human interaction (Kienzle and Bergler 2006). Owners of overweight cats spent more time watching them eat and less time playing with them than owners of lean cats (Kienzle and Bergler 2006). It has been suggested that owners who willingly comply when their pet begs for food may do so because they find it psychologically rewarding (Sloth 1992). Several studies have shown that owners often underestimate their pet's body condition score (Allan et al. 2000; Kienzle and Bergler 2006; Colliard et al. 2009; Courcier et al. 2010; Cave et al. 2012) and some studies have shown that this is a risk factor for feline obesity (Allan et al. 2000; Colliard et al. 2009; Cave et al. 2012).

3.5. Dietary factors

The study from London by Russell et al. (2000) that investigated the prevalence of feline obesity also examined the influence of feeding regimen on body condition. The owners of the 136 cats enrolled in the study were asked questions about feeding practices, including what type of diet was fed (wet or dry) and the frequency of feeding (Russell et al. 2000). However, the amount of food given and the composition of the diet were not assessed (Russell et al. 2000). Cats fed *ad libitum* with canned food had a higher mean BCS than cats meal-fed canned food (Russell et al. 2000). However, mean BCS did

doi: 10.17221/145/2015-VETMED

not differ significantly between cats fed dry food fed *ad libitum* and cats meal-fed dry food, or between cats fed canned food and to cats fed dry food (Russell et al. 2000). A study from the USA of 2000 cats presented to 31 private veterinary practices did not find an association between *ad libitum* feeding and obesity (Scarlett et al. 1994). The study of 118 cats from Glasgow by Courcier et al. (2010) also did not find that *ad libitum* feeding was a risk factor for obesity, as the odds of being overweight or obese were greater in cats fed two or three times daily compared to those fed *ad libitum*. The study by Allan et al. (2000) identified the consumption of fresh meat or fish as possibly leading to feline obesity, perhaps because fresh meat and fish are more palatable for cats, which could then lead to excessive consumption. In the studies by Scarlett et al. (1994) and Lund (2005), overweight and obese cats were more likely to be fed a premium or therapeutic diet. This may be because premium and therapeutic diets have less carbohydrate and more fat (and protein), and therefore higher energy density compared to non-premium and non-therapeutic lines of cat food. There is also a relationship with treat feeding and obesity and it has been observed that overweight cats tend to be fed more treats than normal weight cats (Russell et al. 2000; Kienzle and Bergler 2006). Dietary fat and energy density are positively associated with weight gain in *ad libitum*-fed cats, while carbohydrate content above 40% of metabolisable energy (ME) is negatively associated with weight gain (Backus et al. 2007; Coradini et al. 2011; Hewson-Hughes et al. 2011). There appears to be a "carbohydrate ceiling" in cats whereby, at carbohydrate levels found in many economy feline diets (> 40% ME), energy intake is reduced to limit carbohydrate intake (Backus et al. 2007; Coradini et al. 2011; Hewson-Hughes et al. 2011).

3.6. Environmental factors

Several environmental factors appear to be associated with the development of feline obesity, including indoor housing (Sloth 1992; Robertson 1999), a sedentary or inactive lifestyle (Scarlett et al. 1994), living in a single or two cat household (Robertson 1999), and no dog living in the household (Allan et al. 2000). It is likely that these factors predispose cats to obesity through a reduction in energy expenditure due to reduced physical activity. Indoor cats have less opportunity to expend energy through physical activities such as interaction with animals outside the household, exploration and roaming (Scarlett et al. 1994; Slingerland et al. 2009; Levine et al. 2016). Cats in single or two cat households are also likely to spend less energy engaging in activities such as playing and fighting with other cats, compared to those housed with multiple other cats (Robertson 1999; Slingerland et al. 2009; Levine et al. 2016). A similar effect may also be seen in cats that live in households without dogs. The reduction in opportunities for physical activity would be compounded when cats are housed indoors in a single cat or two cat household without a dog. In addition, there is possibly an interaction between these environmental factors and reproductive status as, compared to intact cats, neutered cats are more sedentary (Hart et al. 1973; Belsito et al. 2009) and therefore may be predisposed to obesity due to decreased energy expenditure combined with reduced maintenance energy requirements (Root et al. 1996; Fettman et al. 1998; Mitsuhashi et al. 2011).

4. Pathogenesis and conditions associated with obesity in cats

There are distinct differences between the two types of adipose tissue present in mammals (Loyd and Obici 2014). White adipose tissue is an important endocrine organ and stores energy (Harwood 2012; Loyd and Obici 2014). In contrast, brown adipose tissue is responsible for energy expenditure via non-shivering thermogenesis in response to cold exposure and diet (Hull and Segall 1965; Rothwell and Stock 1979; Loyd and Obici 2014). In obesity, the amount of white adipose tissue increases due to the imbalance between energy intake and expenditure resulting in the excess energy being stored as triglycerides in the white adipose tissue (Ussar et al. 2014). Excessive adipose tissue deposition then leads to mechanical and metabolic consequences.

4.1. Mechanical effects of obesity

Mechanical effects of fat deposition and increased body weight may lead to increased stress on joints and muscles, restricted grooming, and impaired respiratory function (Scarlett and Donoghue 1998; German 2006; Garcia-Guasch et al. 2015). In

doi: 10.17221/145/2015-VETMED

a study from the USA, cats described as obese were 4.9 times more likely to develop lameness requiring veterinary care compared to those described as being at an optimal weight (Scarlett and Donoghue 1998). In addition, spontaneous capital physeal fractures and metaphyseal osteopathy of the femoral neck appear to be more common in young, obese, neutered male cats (Craig 2001; McNicholas et al. 2002; Lafuente 2011).

4.2. Metabolic effects of obesity

Adipose tissue has an important role in energy homeostasis which is centrally regulated by neural, hormonal and nutrient-related signals (Morton and Schwartz 2011). As well as storing energy, adipose tissue is an important endocrine organ and produces hormones and peptides collectively known as adipokines (Radin et al. 2009; Michel and Scherk 2012). Increased fat deposition leads to abnormal production and secretion of adipokines, which can affect glucose homeostasis, metabolism, inflammation, immunity, and cardiovascular function (Radin et al. 2009). The adipokines most well known in cats and dogs are leptin, adiponectin and some of the proinflammatory cytokines such as interleukins, tumour necrosis factor alpha and interferon gamma (Radin et al. 2009; Zoran 2010). The main functions of leptin are to decrease food intake and increase energy expenditure (Morton and Schwartz 2011; Begg and Woods 2013). Leptin concentrations are higher in obese cats than lean cats (Hoenig et al. 2007) and concentrations increase with weight gain (Coradini et al. 2013). In a study on the effects of weight gain on fasting and postprandial blood concentrations of leptin, postprandial leptin concentrations were increased markedly after a weight gain phase, but not when cats were lean, and greater abdominal fat mass led to greater leptin secretion after a meal (Coradini et al. 2013). Leptin has an effect on tissue insulin sensitivity and, together with insulin, regulates long-term energy stores and glucose homeostasis (Morton and Schwartz 2011). In studies performed in mice, those with genetic leptin deficiency or leptin receptor deficiency developed hyperphagia, obesity, hyperinsulinemia, and diabetes mellitus (Coleman 1978; Morton and Schwartz 2011). Leptin concentration decreases with weight loss and this is thought to contribute to the sensation of hunger (Havel 2004; Hoenig et al. 2007). Adiponectin has anti-inflammatory properties and increases insulin sensitivity by enhancing glycolysis and fatty acid oxidation, and by decreasing hepatic gluconeogenesis (Radin et al. 2009; Kil and Swanson 2010; Bjornvad et al 2014). Adiponectin secretion from adipocytes is stimulated by insulin and circulating levels are influenced by macronutrients such as carbohydrates (Radin et al. 2009; Tan et al. 2011). Adiponectin concentrations are lower in obese cats compared to lean cats and concentrations increase with weight loss (Hoenig et al. 2007; Muranaka et al. 2011; Bjornvad et al. 2014).

4.3. Conditions associated with obesity in cats

Obesity has been associated with a number of diseases in cats, including endocrine disorders (German 2010). It can therefore negatively affect quality of life and longevity (German 2006; Sallander et al. 2012). Weight gain significantly lowers insulin sensitivity, with each kilogram increase in body weight reducing insulin sensitivity by approximately 30% (Hoenig et al. 2007), and a 44% increase in body weight over 10 months decreasing insulin sensitivity by around 50% in adult cats (Appleton et al. 2001). In addition, one study found that the risk of developing diabetes mellitus was two times higher in overweight cats and almost four times higher in obese cats, compared to cats in optimal body condition (Scarlett and Donoghue 1998). Overweight and obesity are risk factors for urinary tract disease (Lund 2005), hepatic lipidosis (Burrows et al. 1981), dermatological disease (Scarlett and Donoghue 1998; Lund 2005), oral cavity disease (Lund 2005), and neoplasia (Lund 2005). Obesity may also affect coagulation. In a study of haemostatic parameters in 72 domestic shorthaired cats, the results indicated that obesity could lead to faster initiation of coagulation, although only the rate of fibrin formation was altered so further investigation is required (Bjornvad et al. 2012). Perioperative mortality rates are higher for overweight and obese patients. Death associated with anaesthesia or sedation was found to be 2.8 times more likely in cats weighing more than 6 kg compared to those weighing between 2 and 6 kg (Brodbelt et al. 2007).

5. Assessment of body composition

Assessment of body composition is important in the nutritional management of obesity because it assists in determining ideal body weight and energy

doi: 10.17221/145/2015-VETMED

requirements (Munday 1994). The most commonly used methods for assessing body composition divide the body into two compartments, (1) the fat mass and (2) the fat-free mass, which includes muscle, bones, and intracellular and extracellular water (Munday 1994). Accurate assessment of body composition is required for the identification of obesity and for the formulation of a weight loss plan that ensures fat-free mass is maintained whilst fat mass is reduced (Jeusette et al. 2010; Brooks et al. 2014).

5.1. Dual-energy X-ray absorptiometry

Dual-energy X-ray absorptiometry (DEXA) instruments use X-rays of two energies to estimate bone mineral content, lean mass and fat mass (Jeusette et al. 2010; Hoelmkjaer and Bjornvad 2014). DEXA results have been shown to correlate well with the chemical analysis of body composition in cats and dogs (Speakman et al. 2001). Consequently, DEXA is often used as the reference method for the assessment of body composition (Hoelmkjaer and Bjornvad 2014). However, DEXA assumes the hydration of the fat-free mass is constant and so accuracy can be affected by the level of muscle hydration (Speakman et al. 2001; Jeusette et al. 2010). This method has several disadvantages such as the exposure to radiation, the need for sedation, the cost, and the technical expertise required, which limits its use to the research setting (German 2010; Bjornvad et al. 2011).

5.2. Body weight

The advantage of measuring body weight is that it is a simple, repeatable and objective measurement that does not require expensive equipment or special expertise to perform. However, ideal body weight varies according to conformation and body weight alone does not provide any information on body composition (Bjornvad et al. 2011). Nevertheless, body weight should be measured for each cat as part of the routine examination procedure to detect changes over time, and to facilitate early implementation of dietary changes to prevent obesity (Baldwin et al. 2010; Brooks et al. 2014). To improve accuracy and repeatability when weighing cats, it is recommended that well maintained paediatric scales or scales designed for small animals are used and that the same scales are used for repeated measurements of the same animal (Zoran 2009).

5.3. Body condition and muscle mass scoring systems

Body condition scoring systems are practical, semi-quantitative methods that allow estimation of body fat percentage through visual assessment of body shape and palpation of adipose tissue (Laflamme 1997; German 2006; German 2010; Hoelmkjaer and Bjornvad 2014). The most commonly used systems are the 5-point and 9-point scales, with the use of one over the other in clinical practice being based on personal preference (Laflamme 1997; Thatcher et al. 2000; Zoran 2009). Body fat percentage estimated using the 9-point BCS scale is repeatable and correlates well with body fat measured by DEXA (Laflamme 1997; German et al. 2006; Bjornvad et al. 2011; Borges et al. 2012). BCS systems do not provide an assessment of muscle mass, and so muscle catabolism may not be recognised if muscle mass is not also assessed (Baldwin et al. 2010; Michel et al. 2011). Muscle catabolism can occur in sick, injured, underweight and overweight individuals, and is particularly easy to overlook in overweight and obese individuals, as the excess fat mass can obscure any muscle loss (Baldwin et al. 2010; Michel et al. 2011). Therefore, it is recommended that both BCS and muscle mass scoring (MMS) are performed whenever the body composition is assessed (Baldwin et al. 2010; Michel et al. 2011). MMS involves visual assessment and palpation of the amount of muscle covering the temporal bones, scapulae, lumbar vertebrae and wings of the ilia (Baldwin et al. 2010; Michel et al. 2011). A study involving 44 cats found that a 4-point feline MMS system had substantial repeatability and fair-to-moderate reproducibility when cats were scored by ten different evaluators on three separate occasions (Michel et al. 2011). The correlation between the MMS and lean body mass as determined by DEXA was only modest, presumably because MMS only assesses muscle mass, whereas DEXA measures total lean body mass which includes both muscle and viscera (Michel et al. 2011). A limitation of the study is that it was performed on healthy cats and so the results may not be applicable to cats affected by disease

doi: 10.17221/145/2015-VETMED

(Michel et al. 2011). It is recommended that evaluation of body condition score and muscle condition score should be a part of the routine health assessment of cats (Baldwin et al. 2010; Brooks et al. 2014).

5.4. Morphometric measurement

Morphometric analysis based on measurement of certain parts of the body using a tape measure is a simple and non-invasive way to provide an estimation of body composition (Hawthorne and Butterwick 2000; Zoran 2009; Witzel et al. 2014). Different methods have been suggested but all involve substituting the measurements into an equation that calculates body mass index, which is an estimate of the percentage of body fat (Butterwick 2000; Hawthorne and Butterwick 2000; Witzel et al. 2014). Preliminary results indicate that morphometric measurements are more accurate than BCS for assessing body composition (Hawthorne and Butterwick 2000; Witzel et al. 2014) and that body fat percentage calculated using morphometric measurements correlates well with that measured by DEXA (Hawthorne and Butterwick 2000; Hoelmkjaer and Bjornvad 2014). However, further validation is required to confirm these results, to determine which method is the most accurate, and to establish if these methods can be accurately applied to cats of different breeds and cats affected by disease (Witzel et al. 2014). Another limitation is that this technique requires more cooperation from the cat, as it is more time-consuming to perform and accuracy of the measurements depends on the cat being compliant (Zoran 2009; Hoelmkjaer and Bjornvad 2014).

5.5. Ultrasonography

Ultrasonography can be used to monitor changes in body composition through measurement of the subcutaneous fat layer thickness (Borges et al. 2012). Measurement of subcutaneous fat using ultrasound appears to correlate well with results of DEXA and is easy and simple to perform, with the equipment often available in clinical practice (Munday 1994; Borges et al. 2012). However, this method is not validated for determining body composition in cats (Zoran 2009; Borges et al. 2012).

5.6. Magnetic resonance imaging and computed tomography

Imaging techniques such as quantitative magnetic resonance (QMR) and computed tomography (CT) can be used to estimate body fat, but there has been little evaluation of their use in assessing body composition in cats (Buelund et al. 2011; Zanghi et al. 2013). In addition, practical use of QMR and CT is limited by the cost and technical expertise required and, for CT, the need for general anaesthesia and the exposure to radiation (Buelund et al. 2011).

5.7. Bioelectrical impedance

Bioelectrical impedance is a simple, non-invasive, fast and portable way to estimate body composition (Elliott et al. 2002a; Elliott et al. 2002b; Stone et al. 2009). A bioelectrical impedance device applies a low-voltage, high-frequency electric current to the patient and then the resistance of the tissues to this current is used to determine body composition (Stone et al. 2009; Jeusette et al. 2010). The greater the water content of the tissues, the higher the conductance (Jeusette et al. 2010). Adipose tissue has lower conductance as it is dehydrated, and therefore increased adipose tissue results in increased resistance to the current (Stone et al. 2009). The position of the electrode and hydration status can affect results (Stone et al. 2009). Preliminary studies have demonstrated that bioelectrical impedance can be used to estimate total body water and extracellular water in healthy cats (Elliott et al. 2002a; Elliott et al. 2002b), but more investigation of its use in clinical practice for assessing body composition in cats is required.

6. Conclusion

With epidemiological studies indicating that up to 63% of pet cats are overweight or obese, feline obesity has become a significant health issue. Several potential risk factors for the development of obesity in cats have been identified, including being male, neutered, middle-aged, housed indoors, and fed treats. Chronic increased fat deposition in cats negatively affects their health and quality of life. Therefore, it is important to be able to easily and accurately identify cats that are overweight and

doi: 10.17221/145/2015-VETMED

obese so that they can receive appropriate treatment promptly in order to minimise negative effects on their health. Several techniques have been proposed to evaluate ideal body weight and body composition in cats. Body weight and BCS are the techniques most commonly used in small animal veterinary practice. Measurement of body weight is easy, simple, repeatable and objective but does not provide information on body composition. BCS is repeatable, validated in cats, provides information on body fat percentage and has good correlation with DEXA, the reference method for body composition assessment. However, BCS does not measure muscle mass. MMS is repeatable and has fair correlation with DEXA, although there is a lack of studies testing this method in cats affected by disease. Several other methods such as morphometric measurements, ultrasonography, QMR, CT and bioelectrical impedance have been proposed for use in cats, but are not yet validated for use in this species. In addition, whilst techniques involving diagnostic imaging of adipose tissue, such as DEXA, QMR and CT, are likely to be more accurate than indirect methods, such as BCS, their practical use is limited by cost, availability of equipment, technical expertise required, exposure to radiation, and the need for anaesthesia/sedation. BCS and MMS do not require any equipment and can be performed in the conscious cat, and so they are the most practical techniques for use in clinical practice, although some level of experience is needed to perform them accurately. The use of body weight, BCS and MMS together provides an objective assessment of body weight combined with an evaluation of adipose tissue mass and muscle mass, and so provides a fairly comprehensive assessment of body composition. Therefore, it is recommended that evaluation of body weight, body condition score, and muscle condition score should be part of routine health assessments for cats so that obesity can be identified and managed appropriately.

7. REFERENCES

Allan F, Pfeiffer D, Jones B, Esslemont D, Wiseman M (2000): A cross-sectional study of risk factors for obesity in cats in New Zealand. Preventive Veterinary Medicine 46, 183–196.

Appleton D, Rand J, Sunvold G (2001): Insulin sensitivity decreases with obesity, and lean cats with low insulin sensitivity are at greatest risk of glucose intolerance with weight gain. Journal of Feline Medicine and Surgery 3, 211–228.

Backus RC, Cave NJ, Keisler DH (2007): Gonadectomy and high dietary fat but not high dietary carbohydrate induce gains in body weight and fat of domestic cats. British Journal of Nutrition 98, 641–650.

Baldwin K, Bartges J, Buffington T, Freeman LM, Grabow M, Legred J, Ostwald Jr D (2010): AAHA nutritional assessment guidelines for dogs and cats. Journal of the American Animal Hospital Association 46, 285–296.

Begg DP, Woods SC (2013): The endocrinology of food intake. Nature Reviews Endocrinology 9, 584–597.

Belsito K, Vester B, Keel T, Graves T, Swanson K (2009): Impact of ovariohysterectomy and food intake on body composition, physical activity, and adipose gene expression in cats. Journal of Animal Science 87, 594–602.

Bjornvad CR, Nielsen DH, Armstrong PJ, McEvoy F, Hoelmkjaer KM, Jensen KS, Pedersen GF, Kristensen AT (2011): Evaluation of a nine-point body condition scoring system in physically inactive pet cats. American Journal of Veterinary Research 72, 433–437.

Bjornvad CR, Wiinberg B, Kristensen AT (2012): Obesity increases initial rate of fibrin formation during blood coagulation in domestic shorthaired cats. Journal of Animal Physiology and Animal Nutrition 96, 834–841.

Bjornvad CR, Rand JS, Tan HY, Jensen KS, Rose FJ, Armstrong PJ, Whitehead JP (2014): Obesity and sex influence insulin resistance and total and multimer adiponectin levels in adult neutered domestic shorthair client-owned cats. Domestic Animal Endocrinology 47, 55–64.

Borges NC, Vasconcellos RS, Carciofi AC, Gonçalves KNV, Paula FJA, Filho DEF, Canola JC (2012): DXA, bioelectrical impedance, ultrasonography and biometry for the estimation of fat and lean mass in cats during weight loss. BMC Veterinary Research 8, 1–9.

Brodbelt DC, Pfeiffer DU, Young LE, Wood JLN (2007): Risk factors for anaesthetic-related death in cats: results from the confidential enquiry into perioperative small animal fatalities (CEPSAF). British Journal of Anaesthesia 99, 617–623.

Brooks D, Churchill J, Fein K, Linder D, Michel KE, Tudor K, Ward E, Witzel A (2014): 2014 AAHA weight management guidelines for dogs and cats. Journal of the American Animal Hospital Association 50, 1–11.

Buelund LE, Nielsen DH, McEvoy FJ, Svalastoga EL, Bjornvad CR (2011): Measurement of body composition in cats using computed tomography and dual energy x-ray absorptiometry. Veterinary Radiology and Ultrasound 52, 179–184.

Burkholder WJ, Toll PW (2000): Obesity. In: Hand MS, Thatcher CD, Reimillard RL, Roudebush P, Morris ML,

doi: 10.17221/145/2015-VETMED

Novotny BJ (eds.): Small Animal Clinical Nutrition. 4th ed. Topeka, KS: Mark Morris Institute. 401.

Burrows C, Chiapella A, Jezyk P (1981): Idiopathic feline hepatic lipidosis: The syndrome and speculations on its pathogenesis. Florida Veterinary Journal 10, 18–20.

Butterwick R. (2000): How fat is that cat? Journal of Feline Medicine and Surgery 2, 91–94.

Cave NJ, Backus RC, Marks SL, Klasing KC (2007): Oestradiol, but not genistein, inhibits the rise in food intake following gonadectomy in cats, but genistein is associated with an increase in lean body mass. Journal of Animal Physiology and Animal Nutrition, 91, 400–410.

Cave NJ, Allan FJ, Schokkenbroek SL, Metekohy CA, Pfeiffer DU (2012): A cross-sectional study to compare changes in the prevalence and risk factors for feline obesity between 1993 and 2007 in New Zealand. Preventive Veterinary Medicine 107, 121–133.

Chu K, Anderson WM, Rieser MY (2009): Population characteristics and neuter status of cats living in households in the United States. Journal of the American Veterinary Medical Association 234, 1023–1030.

Coleman DL (1978): Obese and diabetes: two mutant genes causing diabetes-obesity syndromes in mice. Diabetologia 14, 141–148.

Colliard L, Paragon B, Lemuet B, Bénet J, Blanchard G (2009): Prevalence and risk factors of obesity in an urban population of healthy cats. Journal of Feline Medicine and Surgery 11, 135–140.

Cooke PS, Naaz A (2004): Role of estrogens in adipocyte development and function. Experimental Biology and Medicine 229, 1127–1135.

Coradini M, Rand J, Morton J, Rawlings J (2011): Effects of two commercially available feline diets on glucose and insulin concentrations, insulin sensitivity and energetic efficiency of weight gain. British Journal of Nutrition 106, 64–77.

Coradini M, Rand JS, Morton JM, Arai T, Ishioka K, Rawlings JM (2013): Fat mass, and not diet, has a large effect on postprandial leptin but not on adiponectin concentrations in cats. Domestic Animal Endocrinology 45, 79–88.

Corbee RJ (2014): Obesity in show cats. Journal of Animal Physiology and Animal Nutrition 98, 1075–1080.

Courcier EA, O'Higgins R, Mellor DJ, Yam PS (2010): Prevalence and risk factors for feline obesity in a first opinion practice in Glasgow, Scotland. Journal of Feline Medicine and Surgery 12, 746–753.

Courcier EA, Mellor DJ, Pendlebury E, Evans C, Yam PS (2012): An investigation into the epidemiology of feline obesity in Great Britain: Results of a cross-sectional study of 47 companion animal practises. Veterinary Record 171, 560.

Craig LE (2001): Physeal dysplasia with slipped capital femoral epiphysis in 13 cats. Veterinary Pathology Online, 38, 92–97.

Elliott D, Backus R, Van Loan M, Rogers Q (2002a): Evaluation of multifrequency bioelectrical impedance analysis for the assessment of extracellular and total body water in healthy cats. The Journal of Nutrition 132, 1757S.

Elliott DA, Backus RC, Van Loan MD, Rogers QR (2002b): Extracellular water and total body water estimated by multifrequency bioelectrical impedance analysis in healthy cats: A cross-validation study. The Journal of Nutrition 132, 1760–1762.

Fettman MJ, Stanton CA, Banks LL, Johnson DE, Hamar DW, Hegstad RL, Johnston S (1998): Effects of weight gain and loss on metabolic rate, glucose tolerance, and serum lipids in domestic cats. Research in Veterinary Science 64, 11–16.

Flynn MF, Hardie EM, Armstrong PJ (1996): Effect of ovariohysterectomy on maintenance energy requirement in cats. Journal of the American Veterinary Medical Association 209, 1572–1581.

Garcia-Guasch L, Caro-Vadillo A, Manubens-Grau J, Carreton E, Camacho AA, Montoya-Alonso JA (2015): Pulmonary function in obese vs non-obese cats. Journal of Feline Medicine and Surgery 17, 494–499.

German AJ (2006): The growing problem of obesity in dogs and cats. The Journal of Nutrition 136, 1940–1946.

German AJ (2010): Obesity in companion animals. In Practice 32, 42–50.

German AJ, Holden SL, Moxham GL, Holmes KL, Et Al. (2006): A simple, reliable tool for owners to assess the body condition of their dog or cat. The Journal of Nutrition 136, 2031–2033.

German AJ, Ryan VH, German AC, Wood IS, Trayhurn P (2010): Obesity, its associated disorders and the role of inflammatory adipokines in companion animals. Veterinary Journal 185, 4–9.

Hart BL, Barrett RE (1973): Effects of castration on fighting, roaming, and urine spraying in adult male cats. Journal of the American Veterinary Medical Association 163, 290–292.

Harwood Jr HJ (2012): The adipocyte as an endocrine organ in the regulation of metabolic homeostasis. Neuropharmacology 63, 57–75.

Havel PJ (2004): Update on adipocyte hormones regulation of energy balance and carbohydrate/lipid metabolism. Diabetes 53 (Suppl. 1), S143–S151.

Hawthorne A, Butterwick R (2000): Predicting the body composition of cats: Development of a zoometric measurement for estimation of percentage body fat in cats. Journal of Veterinary Internal Medicine 14, 365.

doi: 10.17221/145/2015-VETMED

Heuberger R, Wakshlag J (2011): Characteristics of ageing pets and their owners: Dogs v. Cats. British Journal of Nutrition 106, 150–153.

Hewson-Hughes AK, Hewson-Hughes VL, Miller AT, Hall SR, Simpson SJ, Raubenheimer D (2011): Geometric analysis of macronutrient selection in the adult domestic cat, Felis catus. The Journal of Experimental Biology 214, 1039–1051.

Hoelmkjaer KM, Bjornvad CR (2014): Management of obesity in cats. Veterinary Medicine: Research and Reports 5, 97–107.

Hoenig M, Thomaseth K, Waldron M, Ferguson DC (2007): Insulin sensitivity, fat distribution, and adipocytokine response to different diets in lean and obese cats before and after weight loss. American Journal of Physiology: Regulatory Integrative and Comparative Physiology 292, R227–R234.

Hull D, Segall MM (1965): The contribution of brown adipose tissue to heat production in the new-born rabbit. The Journal of Physiology 181, 449–457.

Jeusette I, Greco D, Aquino F, Detilleux J, Peterson M, Romano V, Torre C (2010): Effect of breed on body composition and comparison between various methods to estimate body composition in dogs. Research in Veterinary Science 88, 227–232.

Johnson J, Calver M (2014): Prevalence of desexed cats in relation to age in a convenience sample of Western Australian cats. Australian Veterinary Journal 92, 226–227.

Kanchuk ML, Backus RC, Calvert CC, Morris JG, Rogers QR (2003): Weight gain in gonadectomized normal and lipoprotein lipase – deficient male domestic cats results from increased food intake and not decreased energy expenditure. The Journal of Nutrition 133, 1866–1874.

Kienzle E, Bergler R (2006): Human-animal relationship of owners of normal and overweight cats. Journal of Nutrition 136, 1947S–1950S.

Kil DY, Swanson KS (2010): Endocrinology of obesity. Veterinary Clinics of North America: Small Animal Practice 40, 205–219.

Kronfeld DS, Donoghue S, Glickman LT (1994): Body condition of cats. Journal of Nutrition 124, 2683S.

Laflamme D (1997): Development and validation of a body condition score system for cats: A clinical tool. Feline Practice 25, 13–18.

Laflamme DP (2006): Understanding and managing obesity in dogs and cats. Veterinary Clinics of North America: Small Animal Practice 36, 1283–1295.

Laflamme DP (2012): Companion animals symposium: Obesity in dogs and cats: What is wrong with being fat? Journal of Animal Science 90, 1653–1662.

Laflamme DP, Abood SK, Fascetti AJ, Fleeman LM, Freeman LM, Michel KE, Bauer C, Kemp BL, Van Doren JR, Willoughby KN (2008): Pet feeding practices of dog and cat owners in the United States and Australia. Journal of the American Veterinary Medical Association 232, 687–694.

Lafuente P (2011): Young, male neutered, obese, lame? Non-traumatic fractures of the femoral head and neck. Journal of Feline Medicine and Surgery 13, 498–507.

Levine ED, Erb HN, Schoenherr B, Houpt KA (2016): Owner's perception of changes in behaviors associated with dieting in fat cats. Journal of Veterinary Behavior: Clinical Applications and Research 11, 37–41.

Linder D, Mueller M (2014): Pet obesity management: Beyond nutrition. Veterinary Clinics of North America: Small Animal Practice 44, 789–806.

Loyd C, Obici S (2014): Brown fat fuel use and regulation of energy homeostasis. Current Opinion in Clinical Nutrition and Metabolic Care 17, 368–372.

Lund EM (2005): Prevalence and risk factors for obesity in adult cats from private us veterinary practices. International Journal of Applied Research in Veterinary Medicine 3, 88–96.

McGreevy P, Thomson P, Pride C, Fawcett A, Grassi T, Jones B (2008): Overweight or obese cats presented to Australian veterinary practices, risk factors and prevalence. Australian Veterinary Practitioner 38, 98–107.

McNicholas JR, Walter T, Wilkens BE, Blevins WE, Snyder PW, McCabe GP, Applewhite AA, Breur GJ (2002): Spontaneous femoral capital physeal fractures in adult cats: 26 cases (1996–2001). Journal of the American Veterinary Medical Association 221, 1731–1736.

Michel K, Scherk M (2012): From problem to success: Feline weight loss programs that work. Journal of Feline Medicine and Surgery 14, 327–336.

Michel KE, Anderson W, Cupp C, Laflamme DP (2011): Correlation of a feline muscle mass score with body composition determined by dual-energy x-ray absorptiometry. British Journal of Nutrition 106, S57–S59.

Mitsuhashi Y, Chamberlin AJ, Bigley KE, Bauer JE (2011): Maintenance energy requirement determination of cats after spaying. British Journal of Nutrition 106, S135–S138.

Morton GJ, Schwartz MW (2011): Leptin and the central nervous system control of glucose metabolism. Physiological Reviews 91, 389–411.

Munday HS (1994): Assessment of body composition in cats and dogs. International Journal of Obesity and Related Metabolic Disorders 18, S14–S21.

Muranaka S, Mori N, Hatano Y, Saito TR, Lee P, Kojima M, Kigure M, Yagishita M, Arai T (2011): Obesity induced changes to plasma adiponectin concentration and cholesterol lipoprotein composition profile in cats. Research in Veterinary Science 91, 358–361.

doi: 10.17221/145/2015-VETMED

Murray J, Roberts M, Whitmarsh A, Gruffydd-Jones T (2009): Survey of the characteristics of cats owned by households in the UK and factors affecting their neutered status. The Veterinary Record 164, 137–141.

Radin MJ, Sharkey LC, Holycross BJ (2009): Adipokines: A review of biological and analytical principles and an update in dogs, cats, and horses. Veterinary Clinical Pathology 38, 136–156.

Robertson ID (1999): The influence of diet and other factors on owner-perceived obesity in privately owned cats from metropolitan Perth, Western Australia. Preventive Veterinary Medicine 40, 75–85.

Root MV, Johnston SD, Olson PN (1996): Effect of prepuberal and postpuberal gonadectomy on heat production measured by indirect calorimetry in male and female domestic cats. American Journal of Veterinary Research 57, 371–374.

Rothwell NJ, Stock MJ (1979): A role for brown adipose tissue in diet-induced thermogenesis. Nature 281, 31–35.

Russell K, Sabin R, Holt S, Bradley R, Harper EJ (2000): Influence of feeding regimen on body condition in the cat. Journal of Small Animal Practice 41, 12–17.

Sallander M, Eliasson J, Hedhammar A (2012): Prevalence and risk factors for the development of diabetes mellitus in Swedish cats. Acta Veterinaria Scandinavica 54, 61.

Scarlett JM, Donoghue S (1998): Associations between body condition and disease in cats. Journal of the American Veterinary Medical Association 212, 1725–1731.

Scarlett JM, Donoghue S, Saidla J, Wills J (1994): Overweight cats: Prevalence and risk factors. International Journal of Obesity and Related Metabolic Disorders 18, S22–S28.

Shoveller AK, Digennaro J, Lanman C, Spangler D (2014): Trained vs untrained evaluator assessment of body condition score as a predictor of percent body fat in adult cats. Journal of Feline Medicine and Surgery 16, 957–965.

Slater MR, Di Nardo A, Pediconi O, Dalla Villa P, Candeloro L, Alessandrini B, Del Papa S (2008): Cat and dog ownership and management patterns in central Italy. Preventive Veterinary Medicine 85, 267–294.

Slingerland LI, Fazilova VV, Plantinga EA, Kooistra HS, Beynen AC (2009): Indoor confinement and physical inactivity rather than the proportion of dry food are risk factors in the development of feline type 2 diabetes mellitus. The Veterinary Journal 179, 247–253.

Sloth C (1992): Practical management of obesity in dogs and cats. Journal of Small Animal Practice 33, 178–182.

Speakman JR, Booles D, Butterwick R (2001): Validation of dual energy X-ray absorptiometry (DXA) by comparison with chemical analysis of dogs and cats. International Journal of Obesity and Related Metabolic Disorders 25, 439–447.

Stone R, Berghoff N, Steiner J (2009): The use of a bioelectric impedance device in obese and lean healthy dogs to estimate body fat percentage. Veterinary Therapeutics 10, 59–70.

Tan HY, Rand JS, Morton JM, Fleeman LM, Armstrong PJ, Coradini M, Ishioka K, Verkest KR, Richards AA, Rawlings JM (2011): Adiponectin profiles are affected by chronic and acute changes in carbohydrate intake in healthy cats. General and Comparative Endocrinology 172, 468–474.

Thatcher CD, Hand MS, Remillard RL (2000): Small animal clinical nutrition: An iterative process. In: Hand MS, Thatcher CD, Reimillard RL, Roudebush P, Morris ML, Novotny BJ (eds.): Small Animal Clinical Nutrition. 4th ed. Topeka, KS: Mark Morris Institute. 5.

Ussar S, Lee KY, Dankel SN, Boucher J, Haering M-F, Kleinridders A, Thomou T, Xue R, Macotela Y, Cypess AM (2014): Asc-1, pat2, and p2rx5 are cell surface markers for white, beige, and brown adipocytes. Science Translational Medicine 6, 2–10.

Witzel AL, Kirk CA, Henry GA, Toll PW, Brejda JJ, Paetau-Robinson I (2014): Use of a morphometric method and body fat index system for estimation of body composition in overweight and obese cats. Journal of the American Veterinary Medical Association 244, 1285–1290.

Zanghi BM, Cupp CJ, Pan Y, Tissot-Favre DG, Milgram NW, Nagy TR, Dobson H (2013): Noninvasive measurements of body composition and body water via quantitative magnetic resonance, deuterium water, and dual-energy x-ray absorptiometry in cats. American Journal of Veterinary Research 74, 721–732.

Zoran DL (2009): Feline obesity: Clinical recognition and management. Compendium on Continuing Education for the Practising Veterinarian 31, 284–293.

Zoran DL (2010): Obesity in dogs and cats: A metabolic and endocrine disorder. Veterinary Clinics of North America: Small Animal Practice 40, 221–239.

Received: 2015–05–28
Accepted after corrections: 2016–04–23

Corresponding Author:

Dagmar Tarkosova, University of Veterinary and Pharmaceutical Sciences Brno, Faculty of Veterinary Medicine, Small Animal Clinic, Palackeho 1/3, 612 42 Brno, Czech Republic
E-mail: tarkosova.d@gmail.com