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Feline Obesity

An overview of feline nutrition and its pathophysiology

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Budapest, Hungary
2023

Table of Contents

List of abbreviations

- **BARF** - Biologically Appropriate Raw Food / Bones and Raw Food
- **DM** - Diabetes Mellitus
- **FA -** Fatty Acids
- **FIC -** Feline Idiopathic Cystitis
- **FIP -** Feline Infectious Peritonitis
- **FLUTD -** Feline Lower Urinary Tract Disease
- **F-1,6-BP -** Fructose 1,6-bisphosphate
- **GLP-1** - Glucagon-Like Peptide-1
- **HL** - Hepatic Lipidosis
- **HIF** - Hypoxia Inducible factor
- **IF -** Interferon
- **IL -** Interleukin
- **NEFA** - Non-Esterified Fatty Acids
- **NPY-AGRP** - Neuropeptide Y/agouti related protein neurons
- **POM-CART** - Preproopiomelanocortin/cocaine amphetamine related transcript
- **RER -** Resting Energy Requirements
- **TNF –** Tumour Necrosis Factor
- **VLDL** - Very-Low-Density Lipoproteins
- **WSAVA** - World Small Animal Veterinary Association

Abstract

Feline obesity is one of the most common and concerning disorders affecting cats today. It has been found to be associated with multiple disease conditions including Hepatic Lipidosis, Diabetes Mellitus as well as shortened lifespan. The aim of this Thesis is to acknowledge feline obesity as a serious and potentially detrimental health condition in the presence of comorbidities. This Thesis briefly provides an overview of the gut-brain-axis and its role in shaping the eating behaviour of a healthy cat. Furthermore, it explores feline nutrition and outlines various strategies to manage or prevent obesity from both veterinary and pet owner perspectives, while also highlighting potential pitfalls to these approaches. Ultimately the goal is to provide brief overview of feline obesity, its treatment options, associated consequences, and potentially initiate a dialogue about feeding habits of cats, best suited to their individual needs.

1. Introduction

Feline Obesity has noticeably become a global pandemic, affecting between 11.5-63% of the feline population in developed countries worldwide (Tarkosova et al., 2016; Phillips et al., 2017; Arena et al., 2021; Caro-Vadillo et al. 2022). There are many factors that may contribute, such as whether it be for cultural (social) reasons, genetics, beliefs, underlying disease, idiopathic, competition between individuals (Sadek et al., 2018), feeding technology and habits or predisposing factors leading to this condition (Tarkosova et al., 2016; Arena et al., 2021). Obesity is known to affect humans as well as multiple animal species, including production animals, horses, etc (Holst & Gustavsson, 2016).

According to Tarkosova et al. (2016) and the department of Veterinary Medicine of Cornell University, feline obesity can be best described as an additional 20% or more above the ideal body weight expected of any given individual and is the most commonly diagnosed nutritional disorder in domestic cats.

In the wild, species of Felidae are not commonly found to be overweight. Their survival depends on qualities such as patience, stamina, intense energy expenditure, and sometimes even intelligence, as they must catch their prey to sustain themselves. Additionally, they have adapted to endure longer fasting periods between meals. Encountering obese or overweight feral and stray cats prompts questions about the factors contributing to their condition. This includes considerations like access to consistent feeding or large quantities of discarded human food waste (Serisier et al., 2013).

In this Thesis, we will delve into the topic of feline obesity, covering essential aspects such as feline nutrition, the causes of obesity, the pathophysiology of obese cats, preventive measures, weight loss options, and treatment considerations in cases of comorbidities.

1.1. Body Condition Scoring

The following system, namely the Body Condition Score (BCS), has been accepted in order to assess an animal's general condition in a simple and easy to understand manner. Each species has their own scale, and in feline companions as seen in Figure 1 on the following page (*Pet Body Condition Scoring*, 2022), the scale ranges from 1 - 9 where; 1 refers to cachexic, 4 is the ideal weight and 9 is obese. Either extremes of the scale require urgent intervention. There are numerous scales available for download on the internet, and posters hung up in veterinary consult and waiting rooms with simple explanations and easy guidelines for laymen, as well as everyday veterinary staff use.

These signs are commonly used in conjunction with the BCS to assess a cat's weight. The BCS of 8-9 corresponds to an obese cat. However, it's essential to note that the presence of a primordial pouch, a loose flap of skin on a cat's belly, can occasionally make it challenging to rely solely on physical appearance to determine obesity. While an obese cat may have a hanging bulge under the abdomen due to excess fat, the presence of the primordial pouch can sometimes lead to confusion. Therefore, using the BCS in combination with clinical examination, including feeling for ribs and assessing the layer of fat over bony prominences, is a more comprehensive approach to determine a cat's weight status accurately.

In the past two decades, there has been a notable shift in the understanding of pet care, with pet owners and veterinary professionals alike becoming more cognizant of the health implications of feline obesity (Courcier et al., 2010). Efforts to educate pet owners about the severity of this condition have employed creative and engaging methods, such as the “chonk chart”, as shown in the example provided as Figure 2. Although these approaches may appear 'cute' or entertaining on the surface (Phillips et al., 2017), it is important to recognize that these efforts are rooted in a genuine desire to promote superior care for pets and demonstrate compassion from veterinary staff towards both the pets and their owners during times of stress (Janke et al., 2022).

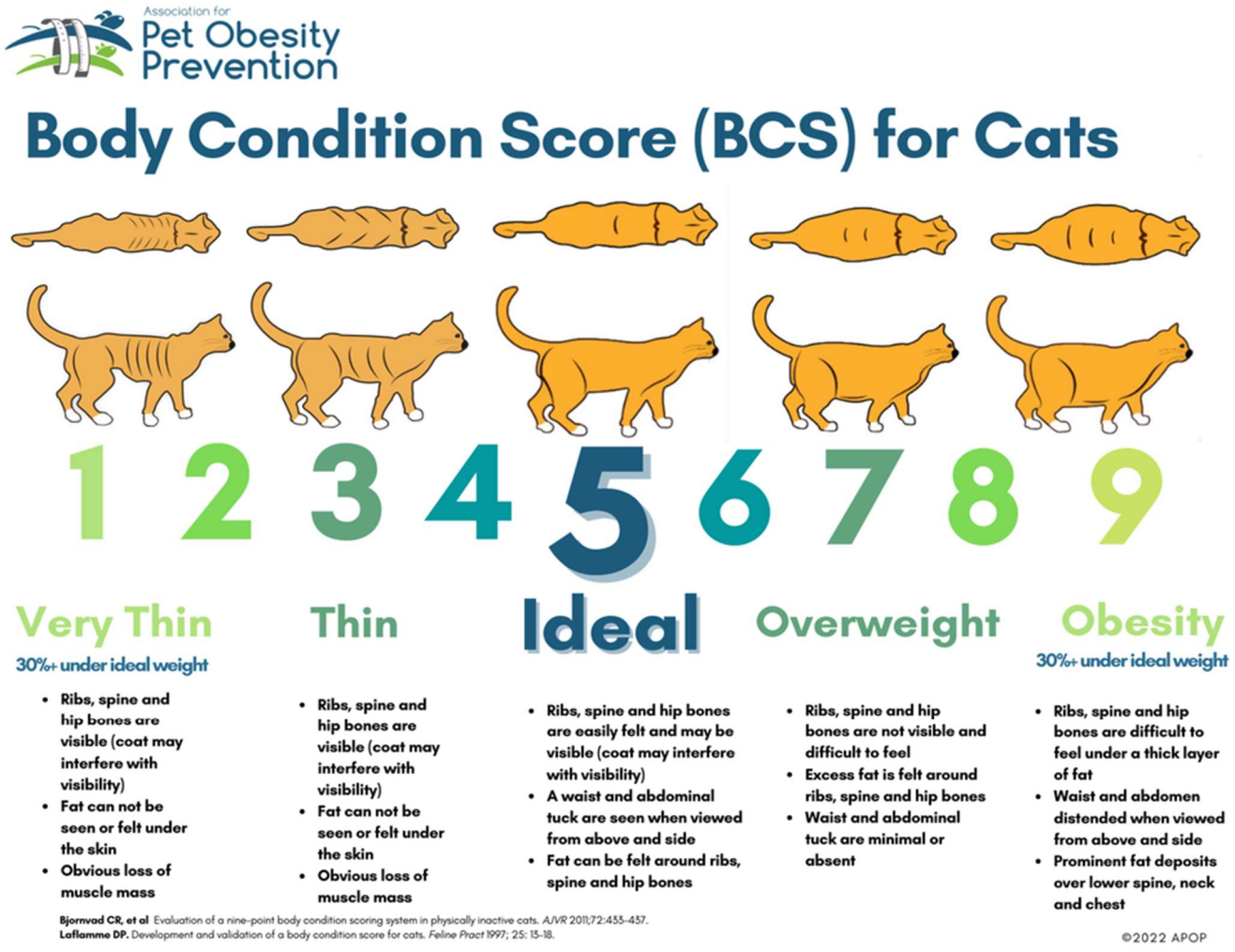

Figure 1:
A Body Condition Scoring poster, used to assess more accurately the body condition of a feline patient

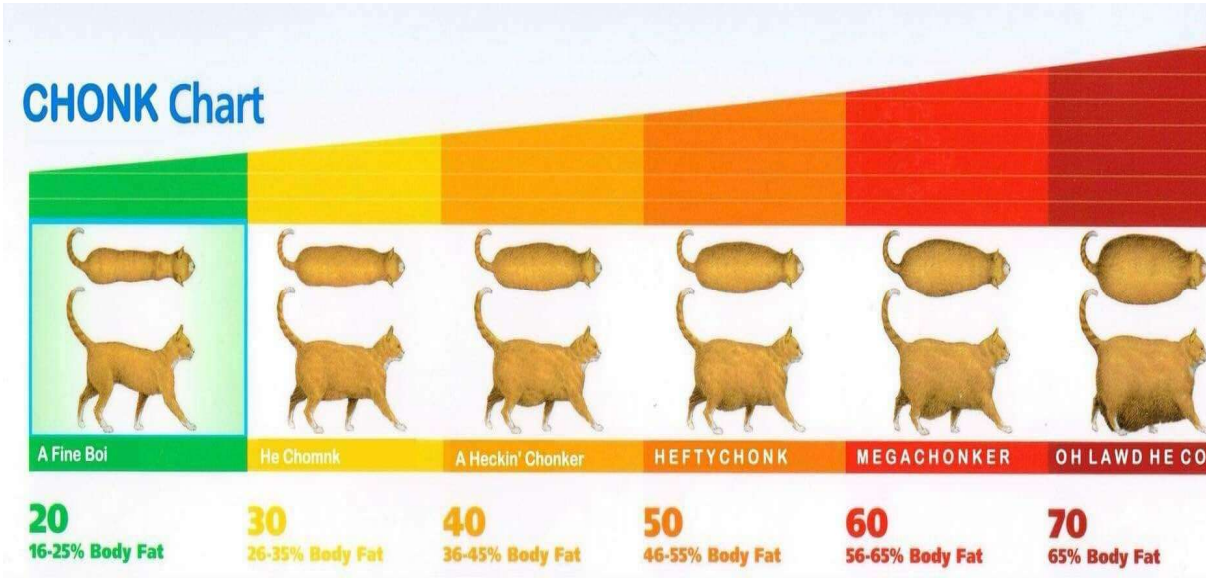

Figure 2:

An example of a "chonk" chart available in a simple to interpret and visually pleasing manner

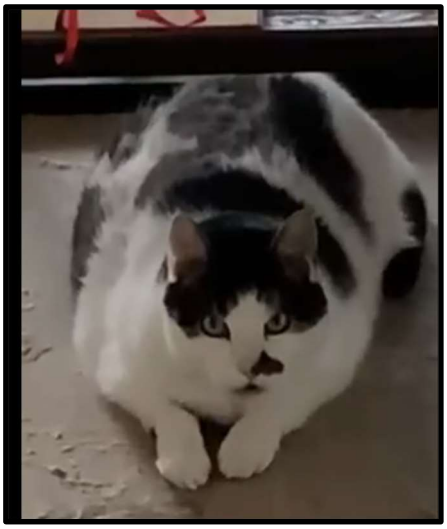

Figure 3:
Obese neutered male from Germany, Europe

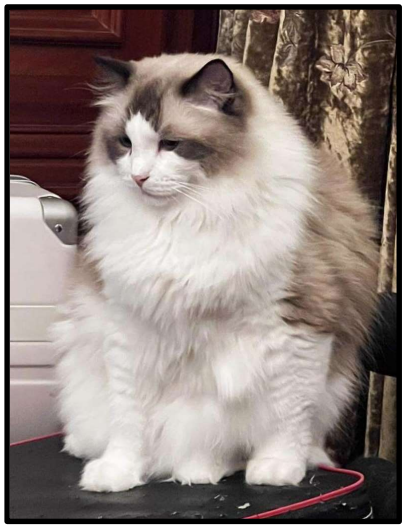

Figure 4:
Obese neutered male from China, Asia

Figure 5:
Obese female from Korea, Asia

Figure 6:
Obese neutered female - South Africa, Africa

In the Figures 3 - 6 above, photos are provided by students attending the University of Veterinary Medicine and Semmelweis University in Budapest of their family pets. From these photographs we can conclude that obesity is not limited to a single continent, country or culture, but rather a condition that can be found worldwide. These cats have a BCS ranging between 6-9 and weigh between 7 and 10kg, although obese cats weighing more than 12 kg have been recorded, excluding large breed cats such as Maine Coons.

1.2. Diagnostic criteria of Feline Obesity

In the study, carried out by Okada et al. (2019), Computed Tomography (CT) scans were performed on feline subjects with a BCS between 5-9. Those showing accumulated visceral and subcutaneous fat masses, with at least two of the following: low adiponectin concentration, high serum amyloid A concentration, and hyperlipidemia with a BCS of at least 7/9 were diagnosed with obesity disease according to Okada et al. (2019). Without these additional markers, and a BCS above 6, they were considered metabolically healthy obese cats.

1.3. Statistics

Recent research findings indicate a concerning prevalence of feline obesity ranging from 11.5% to as high as 63% (Tarkosova et al., 2016; Phillips et al., 2017; Arena et al., 2021). In particular, one study showed a significant increase in the incidence of obesity and overweight status in cats in the USA, with a staggering 90% rise observed between 2007 and 2011. These findings emphasise the growing issue of obesity among feline subjects and the urgent need for effective interventions (Courcier et al., 2010, 2012; Lund et al., 2005; Arena et al., 2021).

According to the 2022 Pet Obesity Prevalence Survey, 58% of cat owners reported they had attempted a weight loss diet for their overweight animals. Of these weight loss strategies, 19% reported successful weight loss, while another 34% had partial success. Furthermore, cat owners reported 5% had regained the weight and 29% had no success (*2022 Pet Obesity Prevalence Survey*, 2023).

Campigotto et al. (2020) developed a method for efficiently managing and analysing large amounts of feline health data on a personal computer with access to large servers. By applying this approach to electronic medical records of over 19 million feline patients, researchers were able to create predictive models for body weight in cats of different ages, breeds, genders, and reproductive statuses. This method can be valuable in feline obesity studies by enabling the exploration and prediction of health parameters, helping to identify trends and factors contributing to obesity in cats.

2. Feline Nutrition

Feline nutrition is a complex and specialised field, distinct from the dietary requirements of humans and other animals. Understanding feline dietary needs is essential for ensuring the health and well-being of our feline companions.

2.1. Carbohydrate Digestion

Cats possess enzymatic capabilities for carbohydrate digestion, with enzymes like Maltase, Sucrase, and Lactase. They can physiologically digest glucose, sucrose, dextrin, and starch. However, it's important to note that compared to some other species, cats exhibit lower enzymatic activity for carbohydrate digestion (Buff et al., 2014). Carbohydrates in the form of fibre may be beneficial in providing feelings of satiety (Loftus & Wakshlag., 2014).

2.2. The Role of High Protein Diets

High-protein diets have been shown to promote normal insulin sensitivity, particularly during calorie-restrictive diets. This is particularly relevant in cases of feline obesity, where reducing fat content can also be beneficial (Loftus & Wakshlag., 2014). In the past, and still today, protein is often considered an especially important consideration in kidney disease patients, however more importantly, the phosphate content should be controlled and monitored in these patients, as hyperphosphatemia has shown more association with the pathological progression of chronic kidney disease (Sparkes et al., 2016).

2.3. High Carbohydrate vs. High Protein diet

Hoenig et al. (2007) carried out a study aimed to investigate the impact of high-carbohydrate/low-protein (HC) and high-protein/low-carbohydrate (HP) diets on glucose and fat metabolism, adipokines, and fat distribution in both lean and obese cats before and after weight loss. The findings revealed that diet HP increased heat production in lean cats but not in obese cats. Regardless of the diet, obese cats exhibited reduced glucose effectiveness and insulin resistance, however demonstrated better suppression of NEFA during “euglycemic hyperinsulinemic clamp” examinations, when fed HC diet compared to lean cats on either diet (Hoenig et al., 2007). Weight loss normalised insulin sensitivity, however obese cats on diet HC retained increased NEFA suppression and experienced less fat loss (Hoenig et al., 2007).

2.4. Dietary Water Requirements

Felines are obligate carnivores, and their natural prey-based diet contains approximately 70% moisture (Hoenig et al., 2011). This high moisture content is essential for their hydration and overall health. Commercial dry diets often require cats to drink additional water to compensate for the lack of moisture in the food. Ensuring an adequate water intake is vital when feeding dry diets to cats.

2.5. Role of Fat in Feline Diet

Fat has a high caloric density, therefore energy density required can be met in smaller meals (Loftus & Wakshlag, 2014; Clark & Hoenig, 2021). Loftus & Wakshlag. (2014) note that high dietary fat results in reduced satiety due to lowered gastric filling. Contrary to some misconceptions, altering the composition (Omega 3:6 ratios, etc) and reducing the dietary fat, rather than solely reducing the overall fat percentage, may be beneficial when modifying a feline diet, as it influences inflammatory mediators produced by adipose tissue (Loftus & Wakshlag, 2014).

2.6. Metabolism and Gluconeogenesis

Feline metabolism is better adapted for glycogenolysis and gluconeogenesis (Hoenig et al., 2011), the production of glucose from non-carbohydrate sources, rather than glucose clearance. Unlike canine livers, feline livers lack detectable hepatic glucokinase activity. Instead, they exhibit higher activity levels of enzymes such as Pyruvate carboxylase, F-1,6-BP, and G-6-P, which play essential roles in gluconeogenesis.

2.7. Microbiome in Feline Nutrition

The relationship between a cat's gut microbiota and its health is significant. A balanced gut microbial population benefits the cat by providing nutrition, regulating the immune system, protecting against pathogens, and promoting intestinal health. Next-generation sequencing has revolutionised microbiota research, revealing that cats, like other mammals, predominantly have *Firmicutes, Bacteroidetes, Actinobacteria*, and *Proteobacteria* in their gut microbiota (Rochus et al., 2014; Lyu et al., 2020). Lyu et al. (2020) found that factors including body condition, age, diet, and diseases can influence a cat's microbiota. However, the extent of these effects varies, and more research is needed to understand their significance. Future studies are required to explore how the microbiome changes in disease

states and in response to diet and environment, as well as its interaction with a cat's genetics and immunity.

2.8. Inter-Individual Variation

It's important to note that although the anatomical structure of feline intestinal compartments is similar across individuals, there is significant variation in the composition of the microbiota. This "inter-individual variation" highlights the importance of personalised dietary considerations for individual cats (Rochus et al., 2014). In Figure 7 below, Rochus et al. (2014) illustrates the general distribution of microbial populations along the gastrointestinal tract of a healthy cat.

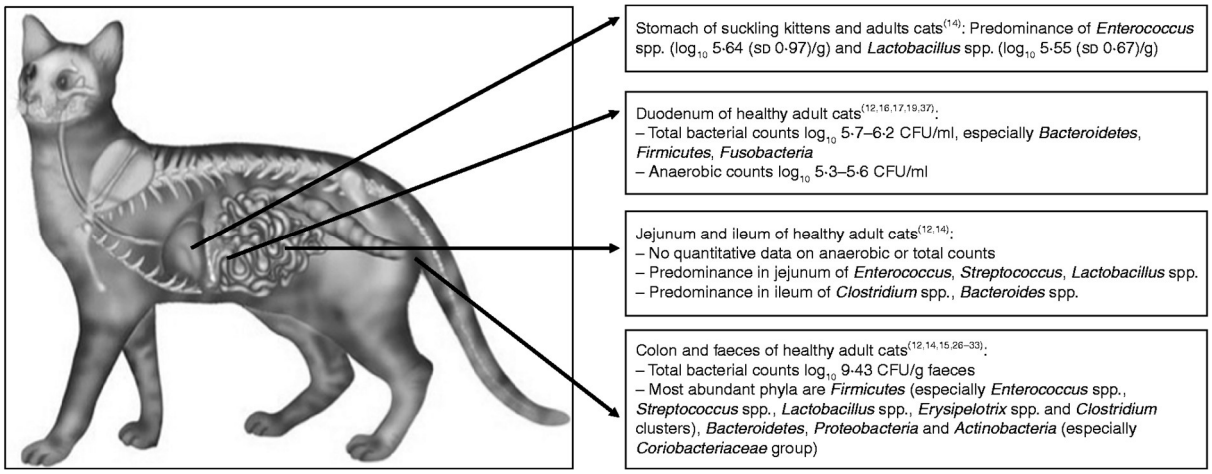

Figure 7:
An illustration of the general distribution of microbial populations along the GIT of a healthy cat (Rochus et al., 2014)

2.9. Self-Regulation of Eating Habits

Cats are unique in their natural ability to self-regulate eating, preferring small, frequent meals alone due to their history as solitary hunters. A healthy cat usually has well-developed regulation of hunger and satiety, which prevents overeating and weight gain. Cats are drawn to fresh food and appreciate dietary variety. Recognizing and respecting these self-regulation mechanisms is key in maintaining feline health, as disruptions can lead to obesity and related issues (Sadek et al., 2018). To support their well-being, controlled portions and a consistent feeding routine should be provided.

A 10-year study by Alegría-Morán et al. (2019) explored factors impacting cat dietary intake and preferences, including body weight, sex, and climate season, which may lead to adaptive changes in eating habits. Findings revealed that body weight and sex influenced food intake, with lower intake in females and higher intake in heavier cats. Preferences were primarily linked to body weight. Hot seasons led to reduced food intake, particularly in females, while males showed more interest during hot seasons. Female preferences remained consistent year-round.

3. Factors Contributing to Feline Obesity

Feline obesity is a complex issue influenced by various environmental, lifestyle, and dietary factors. Indoor confinement with limited environmental enrichment, sedentary behaviour, and reduced energy expenditure are primary contributors to weight gain in cats when coupled with an inappropriate diet (Hoelmkjaer & Bjornvad, 2014). According to Öhlund et al. (2018), certain breeds, such as the Birman and Persian are less likely to exhibit predispositions to obesity compared mixed breed cats, with neutered males displaying a higher susceptibility. Geriatric cats, on the other hand, tend to have a reduced risk of obesity, likely due to age-related factors, underlying health conditions such as Feline Hyperthyroidism and Chronic Kidney Disease, and diminishing organ function (Teng et al., 2020; Arena et al., 2021).

In studies by Teng et al. (2020) and Arena et al. (2021), susceptibility to feline obesity was linked to factors such as age (cats older than 7 years), neutering, indoor-only living, solitary confinement, and stress. Additionally, there was a lack of owner awareness regarding weight

monitoring, ideal body weight for specific lifestyles and breeds, and caloric management, including treats and table food (Teng et al., 2020). These findings emphasise the critical role of veterinary services as veterinarians should actively monitor feline patients during check-ups and provide guidance in order to prevent weight gain becoming excessive (Phillips et al., 2017; Teng et al., 2020).

Studies have indicated that younger cats and those living with other animal companions are at lower risk due to increased physical activity and possible mealtime intimidation in multi pet households (Sadek et al., 2018). Additionally, in utero and postnatal exposure to dietary factors can affect adipose tissue mRNA expression and blood metabolites in kittens, potentially influencing obesity risk (Vester et al., 2009).

Kittens allowed a longer suckling period of at least six weeks show a lower likelihood of becoming overweight, emphasising the importance of adhering to guidelines that recommend keeping kittens with their queens for a minimum of 8 weeks (van Lent et al., 2021).

A study carried out by Opsomer et al. (2022) investigated factors contributing to kittens being overweight at 8 months of age in a homogeneous cat population. It was found that female kittens reached their peak weight earlier than males, and overweight kittens gained weight more rapidly. Overweight kittens, particularly males and those born to overweight mothers, exhibited a higher BCS and weight from an early age. Litter size negatively correlated with being overweight, while birth weight positively correlated with monthly weight gain (Opsomer et al., 2022). These findings suggest the significance of monitoring birth weight, growth rate, and the maternal phenotype to identify kittens at risk of becoming overweight and may be most valuable to breeders who have access to this information.

The indoor lifestyle of cats may elevate the risk of obesity, as outdoor access provides opportunities for increased energy expenditure (Chandler et al., 2016; Teng et al., 2020). However, the principle of "Calories in vs. Calories Out" remains key, however not the sole consideration when aiming for weight loss, as lifestyle changes must also be managed where possible (Linder & Freeman, 2010). Feeding cats commercial pet foods with incomplete or unclear nutritional labels that include carbohydrates and predominantly plant proteins instead of meat proteins can exacerbate obesity risk. Linder & Freeman (2010) suggest that

pet food labelling, caloric information, and weight loss guidance may prove deceptive, as calculations based on Resting Energy Requirements (RER) often result in the overestimation of caloric needs for achieving weight loss. In certain cases, strict adherence to these calculations could lead to weight gain instead.

Hypothyroidism, hyperadrenocorticism, Feline Infectious Peritonitis (FIP) (wet form) and idiopathic factors are medical conditions that can mimic obesity in cats. Hypothyroidism is relatively rare in cats, necessitating thorough blood work and a comprehensive examination to rule out underlying causes. Notably, obesity in dogs exhibits parallels with human obesity, whereas feline obesity appears prevalent in both domestic and feral populations, suggesting additional unidentified factors influencing its occurrence.

3.1. Drug influencing obesity

Within feline pharmacology, certain medications have been observed to influence body weight in cats (Rand & Martin, 2004). Notably, glucocorticoids, commonly employed for their anti-inflammatory properties, have been associated with increased appetite and could consequently lead to weight gain in cats, however Tarkosova et al. (2016) found that glucocorticoids are more likely to lead to Diabetes Mellitus (DM) or Hyperadrenocorticism than weight gain. Additionally, certain antihistamines, anticonvulsants, medications affecting hormone levels, and antidepressant agents may modulate feline metabolism, or increase appetite. The administration of these medications should be undertaken with veterinary oversight, and vigilant monitoring of a cat's weight and overall health is essential when implementing long-term drug regimens.

Recently, the use of unlicensed GS-441524, a nucleoside analogue antiviral drug used in cats afflicted with FIP, a previously fatal disease, may carry risk of obesity following treatment. The drug, a prodrug of Remdesivir, that currently carries a patent for its use in the treatment of COVID-19, prevents the GS-441524 from being approved for veterinary use at this time. The weight gain is attributed to an improvement in appetite during the treatment phase, and subsequently the need for weight loss. This phenomenon has been described by Dr. Niels Pederson of UC Davis in a study published by Pedersen et al. in 2019, In Figures 9 & 10, photos of a domestic shorthair in Budapest, Hungary were taken in 2023 before and after treatment of wet FIP respectively.

Figure 9:
Wet FIP at 4.6kg. May 2023

Figure 10:
Post FIP - Overweight at 5.2kg. October 2023

4. Pathophysiology of Obesity

4.1. The Gut-Brain-Axis

The gut-brain-axis plays a critical role in regulating appetite and feeding behaviour, and understanding its physiology is crucial for comprehending the pathophysiology of various conditions related to metabolism and appetite control, which is clearly described by Loftus & Wakshlag (2014) and Wang et al. (2019). It can be summarised as follows:

Within the brain, appetite centres hold significant influence over eating behaviour. These centres are primarily located in the arcuate nucleus, a region with two adjacent nuclei: pre proopiomelanocortin/cocaine amphetamine related transcript (POMC-CART) and Neuropeptide Y/agouti-related protein neurons (NPY-AGRP).

POMC-CART stimulation leads to a reduction in appetite by activating the hypothalamic feeding centres, specifically the dorsomedial, paraventricular, and lateral hypothalamic nuclei. This activation results in the release of orexins and melanocortin, which together minimise the urge to eat.

Conversely, the NPY-AGRP pathway promotes appetite. When activated, it encourages the feeling of hunger by stimulating the feeding centres in the hypothalamus.

The medulla, located in the brainstem, also plays a crucial role in appetite regulation. It can suppress appetite through the nucleus of the solitary tract, which responds to signals from the gastrointestinal tract, including hormones such as cholecystokinin and insulin released after consuming a meal. Insulin stimulates POMC-CART while inhibiting NPY-AGRP, effectively reducing appetite.

4.2. Pharmacological Interventions

Pharmacological interventions targeting these pathways can be challenging due to the influence of pancreatic secretion and glucose regulation. However, Loftus & Wakshlag (2014) describe two anorexigenic hormones, Glucagon-Like Peptide-1 (GLP-1) and Peptide YY, which show promise for pharmacological intervention to regulate appetite and insulin sensitivity.

GLP-1 reaches the arcuate nucleus, stimulating the POMC-CART and inhibiting NPY-AGRP, effectively curbing hunger. However, it can face resistance at peripheral tissues and in the hypothalamus, often requiring dose adjustments, and may lead to side effects like lethargy and malaise.

Peptide YY, produced in the small intestine, also stimulates POMC-CART and inhibits NPY-AGRP, effectively suppressing hunger. It offers a similar duration of action as GLP-1 but with fewer severe side effects.

Ghrelin, an orexigenic hormone, promotes hunger by stimulating the NPY-AGRP pathway, and countering the effects of Peptide YY and GLP-1.

4.3. GLUT4 expression reduced in case of obesity

In obese cats, there are early changes in glucose metabolism that occur before the development of clinical glucose intolerance (Brennan et al., 2004). Brennan et al. (2004) examined lean and obese cats and found that obese cats had higher glucose and insulin levels during a glucose tolerance test, indicating insulin resistance. The expression of insulin-

regulated glucose transporter protein, GLUT4 was significantly decreased in both muscle and fat tissues of obese cats, and this decrease influenced insulin levels. These findings suggest that alterations in GLUT4 expression in muscle and fat tissues are early events in feline obesity, contributing to insulin resistance even before glucose intolerance becomes apparent in a clinical evaluation.

4.4. Adipose tissue as an endocrine organ

Leptin, a hormone produced by adipose tissue, plays an essential role in the regulation of food intake and body weight control (Loftus & Wakshlag, 2014). It is synthesised and secreted by adipocytes of white adipose tissue and serves as a crucial signalling molecule within the physiological pathways governing appetite and energy balance.

Leptin conveys satiety signals to the arcuate nucleus in the hypothalamus, as a part of the gut-brain-axis (Izquierdo et al., 2019). When leptin levels are within the normal range, it effectively transmits signals of fullness and satisfaction, thereby contributing to the conclusion of a meal and reduced food intake. (Loftus & Wakshlag, 2014)

In cases where adipose tissue mass increases to excess, such as in obesity, there is a parallel increase in leptin secretion. This increase in leptin levels is traditionally expected to intensify the signalling of satiety, theoretically resulting in reduced food consumption and body weight control. However, it is essential to recognize that chronic exposure to elevated leptin levels can lead to a phenomenon known as leptin resistance (Izquierdo et al., 2019).

Leptin resistance describes a condition in which the body becomes less responsive to the satiety signals conveyed by leptin. Consequently, individuals experiencing leptin resistance may exhibit:

- Reduced Satiety: An impaired perception of fullness.
- Overeating: Individuals with leptin resistance may engage in excess food intake.
- Increased Body Weight: A consequence seen with Leptin resistance as mechanisms for appetite control become less effective.

It's important to note that while leptin replacement therapy could be explored as a potential treatment for obesity, its effectiveness may be limited due to the risk of developing an immune response and resistance in some individuals (Izquierdo et al., 2019). Consequently, Izquierdo et al. (2019) suggests alternative approaches to activating leptin and drug interventions are being investigated to address obesity in mouse models and its associated metabolic dysregulations.

5. Consequences of Feline Obesity

Feline obesity presents a substantial health concern, as it predisposes individuals to a spectrum of comorbidities, some of which can be life-threatening without prompt veterinary intervention. These potential conditions include hepatic lipidosis (HL), DM, lameness, urinary tract disease, non-allergic skin disease, neoplasia, and a shortened lifespan (Hoelmkjaer & Bjornvad, 2014; Loftus & Wakshlag, 2014; Clark & Hoenig, 2021). It's important to note that while these conditions are associated with obesity, they are not exclusive to obese patients. Surgical interventions in obese cats carry a heightened risk, leading to increased perioperative mortality rates (Clark & Hoenig, 2021).

The physical effects of obesity can vary in severity. Overweight cats were four times more likely to develop Feline Lower Urinary Tract Disease (FLUTD) than those of a healthy weight, which Piyarungsri et al. (2020) suggested was associated with decreased physical activity, which in turn leads to decreased urination and water intake. Additionally, obesity can lead to fat accumulation around the penis and urethra, potentially causing urethral compression and increased urinary troubles. Furthermore, studies have suggested that cats diagnosed with Feline Idiopathic Cystitis (FIC) have a tendency to ‘stress eat’ and coupled with limited physical activity due to stress, they are at risk of obesity (Piyarungsri et al., 2020).

Overweight and Obese cats frequently experience joint stress and muscle strain, resulting in an increased prevalence of lameness compared to cats of ideal weight (Bjornvad & Hoelmkjaer, 2014). In more severe cases, neutered male cats, castrated at a young age, may suffer from spontaneous fractures and metaphyseal osteopathies (Schwartz, 2013).

Metabolically, obesity leads to alterations in adipokine levels, including leptin and adiponectin, affecting glucose homeostasis, metabolism, immune response, cardiovascular

function, and inflammation, including proinflammatory cytokines such as Interleukins (IL)-1 and IL-6, Tumour Necrosis Factor (TNF)-α and Interferon (IFN)-γ, as well as decrease in antioxidants in the body (Clark & Hoenig, 2016). Chronic inflammation associated with obesity has been suggested as a potential factor contributing to neoplastic conditions, i.e., promoting cell proliferation while inhibiting apoptosis.

Regarding the whisker-to-body size ratio, it may play a vital role in cats' spatial awareness as with rats, assisting them in determining if they can fit into particular spaces (Slovak & Foster, 2021). However, there are no studies done to prove that whiskers lengthen to compensate for increased body surface area posing potential risks of cats becoming trapped in confined spaces. Therefore, there is an opportunity for future investigations to explore this aspect of feline behaviour.

Feline obesity is increasingly recognized as an animal welfare issue, significantly impacting an individual's quality of life (Phillips et al., 2017; Arena et al., 2021). In the following sections, we will delve into the most significant comorbidities associated with obesity in cats.

5.1. Hepatic lipidosis

HL, also known as fatty liver syndrome, occurs due to the rapid breakdown of fats during starvation to fatty acids (FA). These FAs are used as an energy source instead of glucose, and form fatty deposits in and around hepatic cells, overwhelming the liver and consequently decreasing the liver function (Webb, 2018; Brister, 2021). Jaundice follows and can be seen on the mucous membranes.

This syndrome occurs suddenly, following at least 2 - 7 day starvation or period of inappetence and apparent weight loss (Brister, 2021). The prognosis is more detrimental, the later a diagnosis is made. A veterinarian needs to provide rapid and aggressive treatment of nasoesophageal, nasogastric or gastrostomy tube placement, pain control with medications such as butorphanol during hospitalisation. Pancreatitis is commonly seen accompanying HL hence the pain control (Webb, 2018; Brister, 2021).
A diet high in protein, low in fat and supplemented with L-carnitine is recommended. An appetite stimulant, such as mirtazapine or cyproheptadine, liver protectants, such as SAMe,

and potentially treatment against diarrhoea may be attempted, however with severe pancreatitis these treatments may prove futile (Brister, 2021).

HL is one of the most common liver diseases presenting in feline patients most commonly in overweight individuals (Brister, 2021), however it is not limited to cats suffering from obesity, as the onset has also been known to be associated with stress, nutritional deficiency, anorexia, and occasionally idiopathic in nature (Hoelmkjaer & Bjornvad, 2014). Cats are unique in that they are one of few species that suffer significantly from HL, including alpacas, llamas as well as donkeys, horses, cattle, goats and sheep experiencing periods of metabolic stress (Foreman, 2023). Dogs may also experience HL to a lesser degree (Bexfield, N. & Braund, K., 2023), more often in Toy breed puppies developing anorexia followed by hypoglycemia (Egan et al., 2021).

5.2. Diabetes Mellitus

Hoenig & Ferguson, (2002) investigated the factors contributing to the increased likelihood of neutered cats developing obesity and DM. The research examined glucose tolerance, hormone concentrations, and Non-Esterified Fatty Acids (NEFA) levels before and after neutering. The results showed that neutered female cats experienced a significant decrease in caloric requirements for weight maintenance, while insulin levels increased. However, leptin concentrations increased, and NEFA suppression decreased in neutered male cats, indicating reduced insulin sensitivity. These findings suggest that alterations in NEFA suppression, caloric intake, and leptin levels may serve as indicators and potential risk factors for obesity development in neutered cats.

DM Type II in cats is associated more with factors such as inactivity and indoor confinement than with the proportion of dry food intake (Slingerland et al., 2009). Feline obesity is a recognized risk factor for the development of DMII. Common clinical signs leading to the diagnosis of DMII in cats include weight loss, polydipsia, polyuria, and an increased appetite. Fortunately, this condition can often be effectively managed through controlled diet and exercise, and in some cases, it can even be resolved (Kley et al., 2009).

5.3. Shortened Lifespan Due to Obesity

Obesity in cats can lead to a reduced lifespan, with overweight or obese cats typically living to a maximum age of 8 to 11 years (Arena et al., 2021), compared to cats of ideal weight, which can reach ages of 14 to 20 years. This difference in longevity may be attributed to adipose tissue releasing inflammatory hormones, leading to oxidative stress on body tissues and the development of a chronic inflammatory state.

5.4. Cardiopulmonary Disease

Chandler (2016) summarised that although the adverse effects of obesity on feline and canine cardiac and pulmonary health are acknowledged, there is a lack of epidemiological data on its specific risk factors. Abdominal fat, similar to humans, may pose a risk. Increased intrathoracic fat can also have negative consequences. Additionally, obesity can lead to elevated inflammatory markers and neurohormonal changes, potentially contributing to cardiopulmonary issues. The 'obesity paradox,' where overweight cats may have less malnutrition risk due to increased lean tissue, may not necessarily confer true benefits of extra fat.

The study by Caro-Vadillo et al. (2022) explored the relationship between obesity and lung function in cats with bronchoconstriction. Overweight male cats (BCS $\geq$ 6) with bronchoconstriction showed compromised lung function values compared to reference ranges, reduced tidal volume, minute volume, and peak flow rates of inspiration and expiration. While cats being overweight was associated with impaired lung function, it did not result in a more pronounced bronchoconstriction, compared to to normal-weight cats (BCS < 6) in this study consisting of 53 cats of varying BCS.

6. Treatment plans for Feline Obesity

6.1. Prescription or Weight Loss Diet

Prescription weight loss diets for cats are formulated to induce satiety with their high fibre content, reduce energy intake, and provide Omega-3 polyunsaturated fatty acids to counteract oxidative stress (Kley et al., 2009; Wang et al., 2019). These diets often require the inclusion of supplemental vitamins and minerals due to impaired nutrient absorption caused by excess adipose tissue (Kley et al., 2009). Weight loss of 0.5 - 2 % of their body weight is expected per week (Hoelmkjaer & Bjornvad, 2014; Williams & Ward, 2018). While these diets may prove effective, they can be costly and inconvenient to purchase, especially with recent inflation in the veterinary field (Thixton, 2022).

Veterinarians faced with cost-sensitive pet owners may consider referring patients to board-certified veterinary nutritionists whereby alternative diets like wet foods, gently cooked, or home-cooked meals, which may prove to be more affordable and less prone to overfeeding (Villaverde & Chandler, 2022). However, regular follow-ups, food diaries, and monitoring of a cat's condition are recommended to ensure proper nutrition should be encouraged.

While veterinarians may advocate for balanced prescription diets, clients may opt for commercial diets due to cost or convenience. The influence of social media trends and improper feeding practices in the human population may also pose risks to feline nutrition and health, potentially leading to increased veterinary expenses in the future (Buff et al., 2014; Villaverde & Chandler, 2022).

6.2. Dietary Considerations for Obesity Management

Wet cat food is often considered to be most similar to a cat's natural prey, containing higher moisture (approximately 70% or more), protein, and fat content, with minimal carbohydrates (Grunert, 2016). While wet cat food can be used either as a primary source of complete and balanced nutrition, meeting the standards set by the Association of American Feed Control Officials (AAFCO), or in combination with various brands and textures in a rotational feeding approach to ensure daily requirements are met (Coates, 2021). It is important to note that wet food requires careful storage due to spoilage risk, and some cats may be selective

when served cold meals or fed the same meals daily. Rotating proteins, textures, and brands could mitigate the latter.

Dry cat food, on the other hand, is convenient but has drawbacks such as low moisture content, higher carbohydrate content, and risk of potential health complications, including bacterial contamination leading to large amounts of product being recalled (*Recalls & Withdrawals*, 2023). Each cat has individual preferences and needs (Laflamme, 2020), however water availability is always essential when feeding a dry diet. Mixed diets are an option, with exception of prescription diets, where portion control is crucial in order to avoid overfeeding or nutritional imbalances.

Not all weight loss strategies are universally effective for cats. Various diets are available to address feline obesity. Some are high in protein and low in carbohydrate content, while others focus on high fibre content to induce a feeling of fullness. Emerging diets use specific nutrients to boost metabolism (Williams & Ward, 2018).

Biologically Appropriate Raw Food (BARF) diets offer potential benefits but also carry risks, including contamination, infection risks especially to compromised pets and individuals in the family, and nutritional imbalances if not properly calculated (Davies et al., 2019). Frozen diets may be suitable for obese cats due to portion control but require thawing before feeding (Villaverde & Chandler, 2022).

In summary, dietary choices play a critical role in feline obesity management, and owners should consider individual cat preferences, health status, and proper storage and feeding practices.

6.2.1. Pet Food Pricing Trends and Quality Insights

Recent investigations by Thixton (2022) reveals significant price fluctuations in the pet food industry. Over a two-year period, a 5.44kg bag of a popular dry cat food in the USA, saw a striking 103.8% price increase, climbing from $21.67 in 2020 to $41.98 in 2022. In contrast, a popular pet food using human grade ingredients, recorded no price change during the same timeframe.

When analysing major pet food producers, of two popular WSAVA approved science diets, one exhibited the most notable increase, surpassing competitors with a 19% higher price rise than the next. These products fall under the feed grade category, allowing for lower-quality ingredients, non-refrigerated transport and warehousing, and more lenient manufacturing standards. This may raise questions of the significance of the price hikes in feed grade pet foods.

Comparatively, human-grade pet food products experienced more moderate increases, ranging from 16% to 21.8% (Thixton, 2022). These findings offer valuable insights into pricing dynamics and quality disparities in the pet food market.

6.3. Dietary Supplementation

6.3.1. L-Carnitine

L-Carnitine is primarily synthesised in the liver, derived from the amino acids, lysine and methionine, and is required for FA to enter the mitochondria (Center et al., 2012). In cats without supplementation, protein breakdown likely supplies carnitine precursors for liver synthesis during negative energy balance and intensive lipolysis. Research by Center et al. (2012) showed that the energy expenditure was higher in cats that received L-carnitine supplementation, possibly due to acyl-carnitine transporter activity and fatty acid oxidation. However, once supplementation was withheld and feeding unrestricted, weight gain resumed.

6.3.2. Choline

Choline has demonstrated effects on reducing food intake, body weight, and fat mass, ultimately decreasing the risk of obesity in young male sterilised feline populations, as revealed by Godfrey et al. in their 2022 study. The mechanism underlying these effects can be attributed to choline's essential role as phosphatidylcholine in the assembly of very-low-density lipoproteins (VLDL) responsible for transporting triglycerides and cholesterol from the liver (Rankovic et al., 2022). Additionally, choline's role extends to influencing satiety hormones, such as ghrelin. Acetylcholine, a derivative of choline, is believed to exert an inhibitory effect on ghrelin, contributing to reduced appetite and food intake, ultimately leading to the observed reductions in body weight and fat mass in patients (Rankovic et al.,

2022). These findings highlight the potential of choline supplementation as a valuable strategy for weight management in feline populations.

6.3.3. Chromium

Chromium tripicolinate was shown to improve glucose tolerance as well as encourage fat loss in cats, while preserving lean body mass during weight loss (Rand & Martin, 2004).

6.3.4. Vitamin A

Cats supplemented with Vitamin A resisted weight gain when fed a high-fat diet. In obese cats, vitamin A has been shown to normalise the increased leptin levels. Due to the fact that cats with leptin resistance tend to be more insulin resistant, vitamin A supplementation could subsequently improve insulin sensitivity and prevent DM (Rand & Martin, 2004).

6.3.5. Quercetin

During a four-week study by Kobayashi et al. (2020), it was found that Quercetin had an anti-inflammatory rather than an antioxidant effect. This showed improved metabolism of fats in the liver and reduced plasma lipids, effectively controlling hyperlipidemia in obese felines. Cats did not show a loss in body weight and therefore should not be expected. Rather, a quercetin supplemented weight loss diet, high in proteins and low in fat, may prove effective in the management of feline obesity cases. This study acknowledged further studies should include a more diverse and larger population of cats, with varying quercetin concentrations and duration of use to improve this study's findings (Kobayashi et al., 2020).

6.4. Owner Compliance

Feline companions are often perceived as independent, yet many face obstacles when it comes to staying active and entertained. Pet owners' long working hours and inconsistent routines can predispose cats to inactivity and obesity due to calorie imbalances (Arena et al., 2021). Owner compliance is influenced by various factors, including cat behaviour, treat-giving habits, and resistance to dietary changes.

Owner compliance can also be compromised when pet owners refill their pet's food bowl without adhering to a structured routine or controlled/maintenance diet, depending on whether the pet is following a weight loss program (Murphy, 2016). When discussing these

challenges with pet owners, they often express their difficulties in managing cats that exhibit excessive vocalisation and demanding behaviour. Some pet owners find it challenging to resist their cat's demands, while others believe that offering additional treats is a way to express affection (Arena et al., 2021). (partial and complete weight production protocols today - better compliance (German et al., 2023).

In certain cases, particularly with more persistent clients or long-term cat owners, arguments may arise when their cat refuses to consume the recommended diet. However, upon further investigation, it becomes evident that insufficient time was given for the cat to adapt to the new diet, or an appropriate transition period was not followed, despite the availability of numerous helpful tips and techniques. It is important to emphasise the significance of maintaining a healthy and trusting client-veterinarian relationship, built on transparency and open communication, rather than promoting exclusively expensive diet options.

Feeding from the table is a debated topic in relation to feline obesity. Any additional treats, regardless of their source, should be followed by adjustments to the cat's diet to maintain a calorie balance and prevent weight gain (Laflamme, 2020). Another debated aspect is the type of diet, especially dry diets with excess carbohydrates or fat content, which are considered potential contributors to obesity and other health conditions (Laflamme, 2020).

In summary, addressing feline obesity requires attention to various factors, including owner compliance, diet selection, and feeding practices. Tailored weight loss strategies should align with individual cat needs and behaviours (Laflamme, 2020).

6.5. Exercise

Exercising cats can pose challenges, particularly when dealing with disinterested individuals, and obese cats, in particular those that may face discomfort and exhibit reluctance to engage in physical activity. Many cat owners may encounter difficulties in this regard, leading to potential discouragement. However, there are strategies to encourage exercise in cats, such as leash training, interactive toys such as puzzle toys that require manipulation to drop treats, and wand toys as well as other enrichment methods to encourage play. Active play should last at least 10 minutes a day (Rand & Martin, 2004). Laser pointers as a method to encourage physical activity is currently under scrutiny as there is no guarantee

of reward, and may eventually lead to undesirable and obsessive behaviours, contributing to hindered welfare and increased stress of the cat (Kogan & Grigg, 2021). Should a pet owner choose to employ this method of play, a reward, whether a toy or treats (with dietary consideration when on a weight loss diet) should be provided to minimise these concerns.

In South Africa, facilities such as Tygerberg Animal Hospital (TAH) Weight Clinic and Pets in Balance have incorporated innovative approaches to address feline obesity. TAH employs dedicated nurses who specialise in assessing and managing weight loss progress in cats and dogs. Pets in Balance offers a state-of-the-art hydrotherapy treadmill designed to facilitate safe and effective exercise for both cats and dogs. This treadmill is introduced gradually to animals, providing a low-impact workout that minimises stress on joints and tissues by trained animal physiotherapists who oversee the process, offering encouragement and enrichment.

These clinics prioritise regular weight measurements, ensuring that pet owners remain motivated by tracking their pets' progress, which is supported in the article by Loftus & Wakshlag (2014). They also provide a valuable resource for feedback and support, making them essential in the fight against feline obesity. However, it is worth noting that the treadmill was initially developed to aid in the post operative recovery and injury of patients.

6.6. Acupuncture - Traditional Medicine

Acupuncture, a form of traditional Chinese medicine whereby very small needles are placed into trigger points on the body to relieve endocrine, physical and mental ailments in both human and animal patients over millennia. Wang et al. (2019) studies through clinical observations and animal studies suggested that acupuncture exerted a therapeutic effect encompassing a wide range of cellular and molecular events involved in the pathophysiological process of obesity. These findings indicate that acupuncture operates through multitarget mechanisms, and the cumulative modulation of various pathways ultimately contributes to its efficacy in promoting weight loss (Wang et al., 2019).
However, there is much speculation on whether successful weight loss can be achieved following a series of acupuncture treatments due to methodological shortcomings, high diversity in variables, and the presence of publication bias (Fan et al., 2019). In future, studies require high quality trials to achieve an objective and reliable result.

6.7. Hypoxia-Induced Weight Management Studies: Translating Human Research to Animal Models

Research in human subjects has investigated the use of moderate hypoxia under high-altitude conditions to boost energy expenditure and reduce appetite. Typically, these studies involve daily exposure to hypoxia for at least 12 hours over 14 days, aiming to understand its impact on human physiology (Rausch et al., 2018).

One interesting aspect of this research is its focus on hypoxia's potential to influence gene expression, particularly the leptin gene within adipocytes. Leptin, regulated by Hypoxia-Inducible Factors (HIFs), plays a role in food intake modulation and promoting FA utilisation. Investigating the mechanisms behind hypoxia-induced changes in leptin gene expression could have significant implications for weight management strategies.

While this approach holds promise in humans, the feasibility of adapting it for animal models raises questions. Considerations include the cost of maintaining animals in high-altitude simulation chambers and the duration of exposure required for physiological changes.

This concept offers an opportunity to bridge the gap between human and animal studies, potentially uncovering new avenues for weight management in both human and veterinary medicine. However, ethical and practical factors must be carefully assessed before translating these findings to animals.

Rausch et al. (2018) conducted a study examining the effects of moderate hypoxia and exercise on leptin, adiponectin, and visfatin mRNA-expression with Quantitative real-time PCR in obese subjects over several months. This study involved abdominal subcutaneous fat tissue biopsies taken before and after exposure at three and eight months in both hypoxic and control conditions. Results showed no significant differences in leptin levels after three and eight months between the hypoxia and control groups, however adiponectin and visfatin levels showed an increase after three months in the control group compared to the hypoxia group. This suggests that moderate exercise in normal atmospheric conditions was more effective than using hypoxic conditions to elevate adiponectin and visfatin levels.

7. Conclusion

In conclusion, feline nutrition is a specialised field that demands meticulous attention to the unique dietary requirements and physiological characteristics of cats. A well-balanced diet that considers their limited carbohydrate digestion, high moisture needs, and the vital roles of fat and protein is essential in promoting the health and longevity of our feline companions. Ongoing research in areas such as the Gut-Brain-Axis and the microbiome continues to provide valuable insights, contributing to the development of optimal diets for our feline friends. Macro- and micronutrients, body weight, and sex were identified as key factors affecting food intake and preferences.

It is essential to acknowledge that feline obesity is not limited to indoor cats. Addressing the extrinsic factors, (appropriate diets, multi-pet household, lifestyle, routine, treats, resistance to dietary change, etc) as well as intrinsic factors (potential health conditions, birth weight and litter size, suckling period, neuter status, metabolism, etc) with cat owners on an individualised basis is crucial for healthy weight management, overall health condition, and encouraging client-veterinarian communication.

Prescription weight loss & weight management diets are designed to induce satiety, reduce energy intake, and provide essential nutrients. However, these diets may prove expensive, and alternatives such as wet foods with increased water content (empty calories), and potentially reduced carbohydrate and/or fat content, or home cooked meals may be considered with veterinary monitoring. While prescription diets may already incorporate supplements to promote weight loss, alternative diets may consider the supplementation in formulating their feline diets with the help of a board-certified veterinary nutritionist. To conclude, food choices should be tailored to individual cat preference and needs, while keeping the pet owners financial means and capabilities in mind is an important consideration.

Emphasising the importance of exercise for managing feline obesity, strategies such as leash training for dedicated walks, and interactive toys for stimulating and encouraging body movement and play are valuable tools in encouraging cats' motivation. However, in cases with disinterested obese cats, specialised clinics with weight management services and/or

(hydrotherapy) treadmills may provide invaluable support in the battle against feline obesity and associated painful comorbidities.

Furthermore, it is essential to recognize that drawing direct comparisons between cats and humans oversimplifies the matter. Approaches such as employing hypoxia chambers or blindly following diet trends without consideration for feline nutrition and physiology are ethically questionable and may pose more harm than benefit to cats.

Moreover, the associated costs, including expenses and potential stress to cats, make such interventions considerably more burdensome in feline patients compared to humans. Consequently, the potential risks and consequences to feline patients should be thoroughly evaluated before pursuing such approaches.

Acknowledgements

I would like to express my gratitude and thanks to Dr. Jócsák Gergely Péter for his patience, guidance, and support throughout the writing of this Thesis. Thank you to the students that provided photos, and their cats for being excellent visual examples for the purpose of demonstrating feline obesity. I also extend thanks to Charl Cilliers, an engineer, who checked the readability of this Thesis to someone outside of the field who may be interested in the topic in future. Finally, a huge thank you to the Stipendium Hungaricum Scholarship, that made it possible for me to attend this Veterinary certification.

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Thesis progress report for veterinary students

Name of student: JESSICA CATHERINE EVERT

Neptun code of the student: EFZ6C9

Name and title of the supervisor: DR GERGELY PÉTER JÓCSÁK PHD

Department: OF PHYSIOLOGY AND BIOCHEMISTRY

Thesis title: FELINE OBESITY: AN OVERVIEW OF FELINE NUTRITION, THE PATHOPHYSIOLOGY OF OBESITY, CONSEQUENSES THEREOF AND CONDITIONS EXACERBATED BY OBESITY AS WELL AS TREATMENT OPTIONS FOR WEIGHT LOSS & MANAGEMENT

Consultation – 1st semester

	Timing			Topic / Remarks of the supervisor	Signature of the supervisor
	year	month	day		
1.	2020	10	29	First meeting about thesis in person	
2.	2021	09	08	Help/Advice starting the thesis in person	
3.	2021	10	26	First words from articles read "Evert_First page"	
4.	2021	10	28	Requested help accessing an article Laflamme 2010	
5.	2022	09	30	First draft w/ Thesis structure & "Thesis skeleton_Evert" references	

Grade achieved at the end of the first semester: 5 (jeles)

Consultation – 2nd semester

	Timing			Topic / Remarks of the supervisor	Signature of the supervisor
	year	month	day		
1.	2023	03	11	Scientific writing, spelling, etc almost complete	
2.	2023	04	14	All intext referencing & Reference list corrected.	
3.	2023	06	30	Final draft for any corrections, suggestions, remarks, etc.	
4.	2023	09	01	Final draft for remarks w/ most recent corrections & suggestions followed	

5.	2023	10	15	(Any final touches?)	

Grade achieved at the end of the second semester: ..... 5 (jeles) .....

The thesis meets the requirements of the Study and Examination Rules of the University and the Guide to Thesis Writing.

I accept the thesis and found suitable to defence,

.....
signature of the supervisor

Signature of the student: .....

Signature of the secretary of the department: .....

Date of handing the thesis in..... 2023/11/06 .....