

Analyzing the demographic factors affecting overweight and obese dogs

by

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Abstract

Obesity is the most common form of malnutrition among U.S. dogs. The Association for Pet Obesity Prevention reported that 59% of U.S. dogs are overweight or obese (APOPP, 2022). With an estimated 84 to 89 million dogs inhabiting 45% of U.S. households, increasing dog ownership underscores the need for effective obesity mitigation strategies (AVMA Pet Ownership and Demographics Sourcebook, 2022). Obesity, characterized by an increase in adipose tissue beyond the ideal body fat range of 15% to 20% (Hand, Thatcher, Remillard et al., 2010). Obesity predisposes dogs to numerous adverse health consequences, shortening lifespan, inflating veterinary costs for owners, and compromising the quality of life of the dogs (Kealy et al., 2002; Lund et al., 2006).

In Chapter 2 the 1000 Dog Study, findings revealed that overweight and obese dogs comprised 48% of senior participants, with no significant age or sex differences noted in weight categorization. This suggests that sex and intact factors may not be definitive determinants of weight status among senior dogs. Overweight and obese dogs exhibited significantly higher averages of comorbid conditions, including oral, dermatological, neoplastic, musculoskeletal, cardiovascular, urinary/renal, ocular, and neurological disorders. Conversely, healthy, ideal-weight senior dogs consumed 100% of their daily food as commercial dry or wet food, attributed to the ease of accurate portioning and the ability to tailor feeding based on the dog's weight status. Notably, overweight and obese dogs had higher triglyceride levels, indicating excessive caloric consumption and adipose tissue accumulation. Blood parameter assessments showed greater white blood cell and neutrophil counts in overweight and obese dogs, suggestive of an inflammation-related or immune response tied to increased adiposity.

Chapter 3 of the Geo Study found that 60.7% of U.S. and Canadian dogs had been previously diagnosed as overweight and/or obese by veterinarians. Spayed females and neutered males were significantly more likely to be overweight or obese, whereas intact females were less likely to be diagnosed as overweight or obese, implying hormonal influences on weight stability. An analysis of dietary intake found that dry food consumption was significantly associated with a reduced obesity prevalence, while home-cooked food correlated positively with obesity. Supplement usage analyses found that the absence of supplements correlated with reduced obesity risk, although it was not significant post-adjustment. Overweight and obese dogs were more predisposed to mobility issues, skin conditions, digestive problems, stress disorders, and oral health conditions. Moreover, household demographics played a role in the weight status of dogs. Owners over 25 years of age, those with employment, and those earning over \$45,000 annually were more likely to have overweight or obese dogs, reflecting the socio-economic complexities surrounding dog obesity.

Geo Study survey results found a disparity between perceived and actual weight classifications among dog owners, with many owners misjudging the weight status of their dogs. Owner misclassification points to gaps in awareness or denial regarding the body condition of their dogs. The two studies highlight the multifaceted nature of canine obesity, influenced by genetic, dietary, health, and owner-perception factors, underscoring the importance of early diagnosis and intervention. Effective veterinary guidance is crucial in educating dog owners about viewing obesity as a preventable condition and implementing necessary nutritional and lifestyle modifications to mitigate associated health risks.

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Chapter 1 - Review of the Literature

Pet Food Landscape

The global pet food industry is a continually expanding market, valued at \$115.50 billion in 2022 and anticipated to reach \$163.70 billion by 2029 (*Pet Food Market Size, Industry Growth, Global Trends, Analysis, 2030.* , 2022). Dogs represent a significant segment of the pet food market and are the most prevalent pets in the United States (*2022 AVMA Pet Ownership and Demographics Sourcebook* 2022). According to the American Veterinary Medical Association (AVMA), in 2020, 45% of U.S. households owned a dog, averaging 1.46 dogs per household, an increase compared to previous years (*2022 AVMA Pet Ownership and Demographics Sourcebook* 2022).

The human-animal bond between dogs and humans has historical roots. Some researchers suggest dogs were largely self-domesticated with minimal human intervention, while other theories highlight the importance of pet-keeping (Tancredi & Cardinali, 2023). Theories regarding dog domestication often relate to food accessibility. A prominent hypothesis suggests hunter-gatherers in Eurasia had enough leftover game to support both human and wolf populations, facilitating domestication as year-round pets (Lahtinen et al., 2021). Research by Corsato Alvarenga et al. (2021) indicates domestic dogs exhibit higher expressions of starch-digestive enzymes and glucose metabolism than wolves. The upregulation of starch digestion is a distinctive adaptation hypothesized to have resulted from coexistence with humans, whose nutritional intake are rich in starches.

The evolution of the modern pet food industry has transitioned from table scraps to precisely formulated pet foods meeting exact nutritional needs, including specific health

conditions. The first commercially available pet food was introduced in 1860 by James Spratt, creator of Spratt's Dog Cake (Hand, Thatcher, Remillard, et al., 2010).

F.H. Bennett pioneered the first dog food marketed as a complete food, defined as a sole source of nutrition providing all essential nutrients required for sustaining canine life. Bennett's product was initially named Maltoid, later rebranded as Milk-Bone (Phillips, 2014). Maltoid biscuits were produced in various sizes to accommodate the needs of dogs of different sizes. Similar to Maltoid, most contemporary dog foods in market are formulated to be complete nutritional sources.

The F.H. Bennett Biscuit Co., the creator of Maltoid, was acquired by the National Biscuit Co., now known as Nabisco, in 1931 (Phillips, 2014). Nabisco was the first to introduce dog food sales in grocery stores. Before their entry, pet food was primarily available in establishments specializing in livestock and farm equipment. Pet foods sold in specialty stores are often labeled as "premium," in contrast to "popular" pet foods found in grocery outlets (Lund et al., 1999).

Pet foods are available in different forms including dry and wet forms. Dry variants, with a low moisture content of less than 20%, are typically packaged in bags (AAFCO, 2020). In contrast, wet variants, which have a higher moisture content of over 65%, are usually sold in cans or pouches. Prior to 1922, all commercially available dog food in the U.S. was classified as dry food. The Chappel brothers introduced Ken-L Ration in 1922, the first wet dog food in the U.S. (Phillips, 2014). By 1910, canned dog food comprised 91% of the U.S. pet food market. During WWII, pet food was deemed non-essential, and tin used for canned products was redirected to support the war effort. Wet pet food recovered by 1946, comprising 85% of the U.S. pet food market. In 1948, Dr. Mark Morris Sr. and his wife developed the first therapeutic

dog food, specifically designed for a dog with kidney disease, later known as Hill's Prescription Diet (*History of Hill's Pet Nutrition: Our Journey in Pet Care. Hill's Pet Nutrition*). The food, known as Hill's Prescription Diet k/d, became the first therapeutic diet available for dogs. Therapeutic pet food is specifically formulated for dietary management of pets with specific medical conditions, such as kidney disease or obesity, and typically requires a prescription from a veterinarian for use.

The majority of commercial dry pet foods in the U.S. market undergo a process called extrusion. During extrusion, ingredients are forced through a die, shaping and cutting the mixture into kibbles. The Ralston Purina Company pioneered extruded pet food in 1957 and introduced the first semi-moist pet food in 1970 (Phillips, 2014). Semi-moist pet food has a moisture content ranging from 20% to 65% (AAFCO, 2020).

Wellness pet foods are designed to fulfill the nutritional needs of healthy pets and are available without a veterinary prescription. In 1963, Hill's Ralston Purina advanced the wellness pet foods category by developing the first line of life-stage-specific nutrition (About Purina). Various life-stage-specific foods, including products for puppies, adults, and seniors, are now available on the market.

In the mid-1980s, the National Research Council issued a report on nutrient recommendations for pet foods, considering factors such as physical activity and life stage, as well as the nutrient utilization in the body and diseases related to nutritional imbalances. The revised report continues to guide scientists and government officials in the formulation and regulation of pet food. As scientific understanding and consumer demands evolve, pet food companies must adapt to market changes.

The Food and Drug Administration (FDA) gained regulatory authority over human and pet foods with the enactment of the Federal Food, Drug, and Cosmetic Act (FD&C Act) in 1938. The act mandates pet foods adhere to safety standards and be produced following good manufacturing practices (*FDA's regulation of Pet Food. U.S. Food and Drug Administration. , 2024*). Although therapeutic pet foods are not classified as pharmaceuticals by the FDA, those intended for treating or preventing diseases must be distributed under the supervision of a licensed veterinarian (*FDA's regulation of Pet Food. U.S. Food and Drug Administration. , 2024*). Established in 1909, the Association of American Feed Control Officials (AAFCO) collaborates with the FDA to regulate the increasing number of commercial animal feed products, setting standards, definitions, and policies to ensure regulatory compliance. However, with the expiration of the longstanding Memorandum of Understanding (MOU) between the FDA and AAFCO on October 1, 2024. The FDA plans to review its pre-market animal food review programs and will issue two draft guidance documents to guide this process.

Obesity Impact

In the United States, overweight status and obesity are the most common forms of malnutrition in dogs. Overweight status in dogs is defined as a body fat percentage of 26% to 35%, while obesity is defined as a body fat percentage of 36% and above (Witzel et al., 2014). Dogs are considered to be at an ideal weight when they have 15% to 25% body fat relative to their total body weight (Hand, Thatcher, Remillard , et al., 2010). Both overweight status and obesity result from increased adipose tissue beyond ideal body fat ranges. An increase in the body weight of adult dogs is typically attributed to a rise in body fat composition, as adult dogs

are fully grown and their weight gain is not due to growth (Hand, Thatcher, Remillard , et al., 2010).

The Association for Pet Obesity Prevention (APOP) conducts nationwide surveys among veterinary clinics to monitor changes in obesity rates among cats and dogs (APOP, 2022). The most recent APOP 2022 survey found 59% of dogs in the U.S. were overweight or obese, with 37% reported as overweight and 22% as obese. In 2017, APOP found that 56% of dogs were reported to be overweight or obese, representing a 3% increase in overweight and obesity rates from 2017 to 2022. Although obesity is not a new condition in dogs, its prevalence has been increasing since the 20th century (APOP, 2022; Lund et al., 2006). In 1995, a cross-sectional study found 34% of adult dogs in U.S. private veterinary practices were overweight or obese, with 29% being overweight status and 5% obese, respectively (Lund et al., 2006). The 2022 APOP report reflects a 25% increase in dogs reported as overweight or obese compared to 1995, indicating a 42% rise over 27 years. While variability in rates can be influenced by data collection methods, findings consistently indicate an upward trend in the prevalence of overweight and obesity among dogs in the U.S. As overweight status and obesity rates grow, it is important for veterinarians and pet owners to understand how to identify and address overweight or obese dogs.

Clinical Presentation

The increasing prevalence of overweight dogs in the U.S. necessitates veterinarians and pet owners gain the ability to identify overweight or obese dogs. The most precise method for determining the body composition of a dog is chemical analysis, which involves separating muscle, fat, and bone from a deceased animal's carcass. However, chemical analysis as a method

is not feasible for most research studies and clinical practices. Dual-energy X-ray absorptiometry (DEXA) is regarded as the optimal method for assessing body composition in canine research. Dual-energy X-ray absorptiometry has been employed to validate other body fat estimation techniques (Laflamme et al., 1994; Witzel et al., 2014). Initially developed for humans, DEXA is a non-invasive technique for determining body composition by measuring lean tissues, fat mass, bone mineral content, and bone mineral density (Speakman et al., 2001). The measurements have been validated against chemical analyses of both ground cadavers and dissected cadavers and were found to have strong correlations in both studies (Speakman et al., 2001). However, variations in lean body mass hydration can reduce the accuracy of DEXA measurements, as the method assumes uniform tissue hydration (Speakman et al., 2001). Dual-energy X-ray absorptiometry is not commonly used in clinical practice due to its cost, the need for specialized expertise, and the requirement for dogs to be sedated during scanning.

Alternative methods for measuring body composition include computed tomography (CT) and bioimpedance (BI). Computed tomography is used in research to assess body fat in dogs and has been validated against DEXA, showing a strong correlation with total body mass and lean tissue mass (Turner et al., 2019). Unlike DEXA, CT allows researchers to assess fat distribution in specific body regions. Bioimpedance utilizes a low-level electrical current to measure conductance. Bioimpedance uses a low level electrical current to measure conductance. In the body, fat tissue is less conductive than muscle due to its lower hydration, allowing the BI machine to differentiate between muscle and fat. This enables the BI device to measure the amount of fat in the body. A study by German et al. (2010) attempted to validate a handheld BI monitor, which claimed manufacturer validation for dogs, against DEXA; however, the study did not substantiate the accuracy claims. Although BI correlated significantly with DEXA, only 17%

of measurements fell within an acceptable 95% range of difference (German et al., 2010). The BI device tended to overestimate low body fat and underestimate high body fat. Despite needing accuracy improvements before clinical adoption, bioimpedance tools show potential as a cost-effective and portable method for assessing body fat compared to DEXA.

Body Condition Scoring (BCS) is the most commonly used tool in clinical practice for assessing body composition in dogs (Santarossa et al., 2018). To utilize a BCS it involves a subjective evaluation on either a 5-point or 9-point scale, based on visual assessment and hands-on palpation of the dog. The BCS scale is recommended for dogs over one year of age due to its lack of validation in growing dogs, which can lead to inaccurate assessments. When surveyed, veterinarians and clinic staff were asked to identify all methods they use to evaluate the weight status of dogs. Clinic employees more frequently employed the 5-point scale (68.8% of participants) compared to the 9-point scale (38.1% of participants) (Santarossa et al., 2018).

The 9-point BCS scale has been validated against DEXA, while the 5-point scale has not been validated (Laflamme et al., 1994). In the validation study, a BCS of 5 out of 9 was considered ideal, corresponding to a total body fat percentage of $19\% \pm 8\%$, with each BCS interval representing an increase of approximately 5% in total body fat (Laflamme et al., 1994). The study found no difference in total body fat percentages within a BCS unit across different breeds; however, a difference was observed between sexes, with females having higher percentages within each BCS unit (Laflamme et al., 1994). The study evaluated eight breeds, and further research is needed to determine the suitability of the BCS scale for ectomorphic breeds, such as greyhounds, and endomorphic breeds, such as bulldogs. In a follow-up study, researchers identified an ideal BCS of 5 out of 9 associated with an $11\% \pm 2\%$ body fat percentage and an 8.7% increase in body fat for each BCS level (Mawby et al., 2004). Mawby et al. (2004) noted

differences in body fat percentages might be attributed to the use of different breeds, but also to variability in individual grader assessments.

A study was conducted to evaluate the feasibility of assigning BCS to dogs using photographic images (Gant et al., 2016). The researchers used both top and side images of each dog and had a grader assess photos using the 9-point BCS scale. While BCS scores derived from images showed a positive correlation with DEXA results, they were less accurate than in-person assessments. The discrepancy was hypothesized to result from the additional benefit of palpation involved in direct examination (Gant et al., 2016). Graders found it easier to identify dogs with an ideal BCS but faced challenges in distinguishing overweight dogs (BCS 6-7) from obese dogs (BCS 8-9) (Gant et al., 2016). The study highlighted challenges in assessing BCS from photos, such as variations due to hair coat and photo angles. Dog breed can significantly influence BCS scores; for instance, one study found significant differences in DEXA body fat percentages within a grade based on dog breeds (Jeusette et al., 2010). The study had limitations, as the dogs ranged from BCS 3 to 7 on the 9-point scale, not covering the full range of the BCS scale. Nonetheless, it found greyhounds had significantly less body fat within the same grade compared to poodles, rottweilers, dachshunds, and golden retrievers. While huskies had more body fat than other breeds, this was only significantly different from greyhounds (Jeusette et al., 2010). Variations within a BCS grade are undesirable in a standardized scale, as they can lead to inaccurate assessments of body fat in dogs.

Size, Health and Physical Evaluation (S.H.A.P.E.) is an algorithm-based system that uses similar visual and palpable characteristics to the existing 9-point BCS scoring system (German, 2006). It prompts users to perform a hands-on evaluation of the dog's body and input the answers into the system, placing the dog on a 7-point A-G scale based on weight status of the dog. A

validation study reported a similar correlation to DEXA measurements as the 9-point BCS scale, finding it more objective and accurate than the BCS system (German, 2006). Using S.H.A.P.E., owners were equally shown to overestimate or underestimate the condition of their dog (German, 2006). The S.H.A.P.E assessment contrasts with the 5-point BCS scale, where 38% of owners underestimated their dog's BCS, and 11% overestimated the BCS score (Yam et al., 2017).

The Body Fat Index (BFI) scale is another method used in clinical practice for evaluating body fat, though it is less commonly used than other methods (Santarossa et al., 2018). The BFI scale was developed to address the lack of sensitivity in assessing upper body fat ranges on the BCS scale, which groups body fat percentages over 45% into a single category (Laflamme et al., 1994). Grouping dogs over 45% body fat into one score renders the BCS inadequate for evaluating the degree of obesity in dogs. After a dog is identified as overweight or obese through the BCS, the BFI scale is optimal for further assessing the extent of obesity. Both scales are advised to be used only for dogs over one year of age as they lack accuracy for growing dogs. Similar to the BCS, the BFI scale relies on visual assessment and palpation of the dog to determine body fat percentage, with a rating of 20 considered ideal, 30 indicating overweight status and 40, 50, 60, or 70 denoting obesity (Witzel et al., 2014).

The BFI scale has been validated against DEXA, and when used by a skilled evaluator, it is more accurate than the BCS scale (Witzel et al., 2014). In a study, BCS were within 10% of DEXA-measured body fat for 13% of dogs and within 20% for 40% of dogs. When assessed with the BFI scale, 53% of dogs were within 10% of DEXA-measured body fat, and 91% were within 20% (Witzel et al., 2014).

Morphometric measurements represent another method for assessing body composition in dogs. Various equations in the literature utilize body measurements to estimate body fat, each

recommending different specific body measurements. One study found among veterinarians and clinic staff who consistently measured body composition, 41.2% used morphometric measurements, while 45.2% of respondents regarded body measurements as having a neutral level of difficulty (Santarossa et al., 2018). One study found that morphometric measurements are more accurate than the 5-point BCS method for estimating body fat percentage in dogs when evaluated against DEXA (Witzel et al., 2014). However, Jeusette et al. (2010) introduced an equation method incorporating multiple dog breeds and several body measurements, which was initially deemed clinically unacceptable when compared to DEXA measurements but showed improvement when adjusted by breed.

Another study focused on beagles and examined the chest-to-abdominal girth ratio in an attempt to objectively measure body composition. The researchers discovered a significant association between the chest-to-abdominal girth ratio and the BCS score of the dog (Chun et al., 2019). As the method was only evaluated in beagles, further evaluation across a broader range of breeds is necessary for it to become a more universally applicable method for determining body composition in dogs. Morphometric measurements are less commonly used in clinical practice, potentially due to the increased complexity and lower validation compared to other methods.

Causes of Obesity

Obesity is a multifactorial disease with potential environmental and genetic factors. A study by Sypniewski and Szydlowski (2023) investigated polymorphisms in three adipokine genes related to body mass resistin (RETN), interleukin-6 (IL6), and tumor necrosis factor (TNF) and assessed their distribution across lean, overweight and obese canines. The research analyzed 260 dogs, including 136 Labrador Retrievers, and identified two polymorphic sites in the TNF

gene with significant differences between overweight/obese and lean Labradors. The findings parallel reports of similar TNF polymorphisms in humans that contribute to obesity predisposition (Mankowska et al., 2016).

Further, Sypniewski and Szydlowski (2023) examined 50 adult Labrador Retrievers for 41 orthologous genes linked to human obesity. The ADCY3 gene emerged as significantly associated with overweight status in dogs. The gene, known for its role in catalyzing cyclic AMP synthesis from ATP, is implicated in obesity in both human and murine models due to its critical function as a metabolic mediator.

Additionally, research published in Science Advances identified a genetic mutation in the pro-opiomelanocortin (POMC) gene in Flat-Coated Retrievers (FCRs) and Labrador Retrievers, correlating with increased adiposity and deviation from optimal body weight (Dittmann et al., 2024). The study aimed to explore whether the mutation induces heightened hunger in Labradors. Labradors possessing the mutation displayed significantly greater interaction ($P < 0.005$) with a scent-accessible sausage in a sealed box. In a separate experiment offering ad libitum food every 20 minutes, no significant differences in satiety were observed between mutated and non-mutated dogs (Dittmann et al., 2024). Implying the mutation may prompt increased food-seeking behavior towards owners, the satiation rate remains comparable to dogs without the mutated POMC gene.

Researchers also identified the POMC mutation in FCRs as a factor contributing to approximately 25% lower resting energy rates in adult dogs (Dittmann et al., 2024). In the study, researchers selected healthy FCRs aged 2 to 7 years of lean body condition. Dogs were acclimated to an experimental chamber where their energy expenditure was measured in the post-absorptive state using an indirect calorimeter with a flow-through system. Analysis of

covariance revealed significantly lower resting energy expenditure in dogs with the mutation compared to dogs without ($F_{1,16} = 16.85$, $P \leq 0.001$). Reduced resting energy expenditure signifies those dogs with the mutation need less energy to maintain their body weight at rest, potentially predisposing them to obesity.

Genetic findings are promising in identifying dogs genetically predisposed to obesity, aiding owners and breeders in taking preventive measures to reduce the risk of obesity in dogs. A cross-sectional study identified certain breeds, Cocker Spaniel, Labrador Retriever, Dalmatian, Dachshund, Rottweiler, Golden Retriever, and Shetland Sheepdog, as more prone to being overweight status (Lund et al., 2006). Body size also influences obesity predisposition, as a 2023 cohort study found toy and small dogs (< 10 kg) were more likely to be overweight or obese, while giant dogs (≥ 40 kg) were less likely (Benka et al., 2023). However, lifestyle factors such as food, exercise, and housing conditions were not considered in the analysis and may vary across different weight categories of dogs.

In the U.S., spaying or neutering is common for preventing unwanted pregnancies. However, while sterilization is effective for population control, a study reported spayed or neutered dogs are twice as probable to be overweight or obese (Benka et al., 2023). A Danish study investigated obesity risk factors in dogs two years and older, revealing neutered males had a significantly higher risk (pairwise comparison, male dogs: $P < 0.001$) of being overweight or obese than intact males, though the association with weight and obesity was not observed in females (Bjørnvad et al., 2019).

In a retrospective cohort study conducted by Banfield Pet Hospitals, researchers tracked 155,199 dogs to investigate the temporal relationship between gonadectomy and overweight/obesity prevalence (Benka et al., 2023). The study concluded the timing of

sterilization may predispose dogs to weight gain. Specifically, toy and small and medium dogs sterilized at six months of age or younger had significantly diminished odds of becoming overweight or obese, whereas large dogs sterilized before six months were more predisposed to being overweight status. Additionally, age influences obesity risk in dogs, with increased BCS significantly associated with advancing age in female dogs but not in males (Bjørnvad et al., 2019).

Owner behavior and husbandry practices notably affect canine obesity. While many owner-controlled factors influence the weight of the dog, the strength of the bond between owner and dog does not correlate with obesity in dogs (Bjørnvad et al., 2019; Webb et al., 2020). The disconnect may arise from varied perceptions of bonding. Owners may associate bonding with activities such as walking, while others equate it with treat giving. Notably, owners who perceived higher costs in dog care had a higher probability to have overweight dogs (Webb et al., 2020). Moreover, the weight status of the dog owner can increase the risk of the dog being obese. Owners who are overweight or obese are statistically more probable to have obese dogs (Bjørnvad et al., 2019).

Excess caloric intake is a decisive factor in canine weight management. Most calories consumed by dogs are regulated by humans, and owner feeding practices deeply impact weight status. Although commercial dog food labels provide feeding guidelines, compliance varies. An observational study in Glasgow assessed owner proficiency in interpreting food labels and found 49% accurately determined the recommended wet food amount, and 44% for dry food (Yam et al., 2017). Despite a general underestimation of feeding amounts by owners in the study, 38% of the dogs were overweight, highlighting discrepancies in label interpretation. The study did not account for the physical act of portioning food by grams or cups, which may introduce further

errors in feeding behavior. However, even if the owner accurately feeds the dog according to the label, most feeding guidelines use the current body weight of the dog for the recommendation. If an owner feeds an overweight dog based on its current body weight, the dog will remain overweight.

Webb et al. (2020) identified a significant correlation between owner perceptions and dog obesity. Specifically, owners who believed others perceived them as overfeeding their dogs were more likely to have overweight dogs. Bjørnvad et al. (2019) revealed feeding dogs two meals per day was linked with a lower likelihood of being overweight status compared to a single daily meal. Furthermore, dogs fed ad libitum conditions exhibited lower average BCS than dogs on a time restricted schedule. Kealy et al. (2002) demonstrated the necessity of portion-controlled foods to mitigate gradual obesity associated with free feeding practices. Dogs maintained at an overweight status had notably higher BCS and reduced lean body mass relative to dogs on calorically restricted food intake.

The consumption of diverse food sources contributes to obesity in dogs. According to Lund et al. (2006), obese dogs more frequently consumed "other food," homemade, semi-moist, or canned foods as the main daily food intake of the dog. Other foods include meat, food by-products, commercial treats, or table scraps. The impact of treat feeding on weight status varies by study (Bjørnvad et al., 2019; Webb et al., 2020). Webb et al. (2020) reported no significant association between treat feeding and obesity risk. Conversely, Bjørnvad et al. (2019) reported dogs were a significantly increased risk of obesity when owners fed treats during inactive periods such as snacks or concurrent with owner meals.

Solutions for Obesity

Studies have identified efficacious strategies for managing weight loss in dogs, primarily focusing on caloric restriction and specially formulated weight loss foods. A study, known as the Purina Lifespan study, involved monitoring 48 golden retrievers divided into two groups: a control group fed ad libitum until the age of 3.25 and a test group, which was the restricted feeding group and received 25% less food. When all dogs in the study reached 3.25 years of age, the all dogs were switched to an adult formula to maintain weight (Kealy et al., 2002). Study results indicated a marked increase in median lifespan for the restricted feeding group, which lived up to 13 years compared to 11.2 years for the control group. Additionally, BCS was significantly lower in the restricted group ($4.6 \text{ pts} \pm 0.19$) compared to the control group ($6.7 \text{ pts} \pm 0.19$). The restricted group also maintained lean body mass longer, delaying muscle loss associated with age (Kealy et al., 2002). Moreover, the age at which half of the dogs from each group needed treatment for chronic conditions was lower in the control group at 9.9 years, as opposed to 12.0 years in the restricted group. The findings suggest caloric restriction can prolong the life of a dog and delay the onset of conditions necessitating medical intervention.

In a research study, dogs were fed a high-fiber food enriched with coconut oil, L-carnitine, lipoic acid, lysine, and leucine. The high fiber food was shown to facilitate significantly greater weight loss than a standard maintenance foods, alongside improved fat metabolism (Floerchinger et al., 2015). Caloric restriction and dog food formulated for weight loss demonstrate effectiveness under controlled research conditions (Floerchinger et al., 2015).

However, achieving weight loss in home settings presents complexities beyond the limitations encountered in controlled environments. Variables such as multiple individuals feeding the dog, unintended extra meals, and access to non-dog food calorie sources can obscure

accurate caloric intake measurements. In canine weight loss study, researchers observed no significant differences in energy intake between dogs fed either a high-protein, high-fiber food or a high-protein, medium-fiber food during the study. Post-study, however, dogs transitioned to standard maintenance foods experienced increased energy intake, whereas dogs continuing on the weight loss foods gained less weight (German et al., 2012). The authors posited the higher fiber content of the weight loss foods enhanced satiety, reducing incidents of begging, compared to the standard foods.

Evidence supporting physical activity as a primary strategy for weight loss in dogs is less compelling than caloric restriction. Research indicates the type of physical activity may influence canine weight status. Dogs allowed to run freely off-leash demonstrated a reduced risk of obesity (Bjørnvad et al., 2019). Conversely, Wakshlag et al. (2012) observed no significant correlation between BCS and number of steps recorded using a pedometer. The study did find dogs with higher step counts consumed more energy while achieving similar rates of weight loss. More active dogs had a mean daily energy intake approximately 27% higher than their less active counterparts, suggesting increased physical activity might permit elevated caloric consumption while still facilitating effective weight management.

Currently, no approved pharmaceutical interventions to treat obesity in canines are on the market. Dirlotapide “Slentrol” and mitratapide “Yarvitan,” once authorized in Europe, are no longer approved substances. Slentrol was the only FDA-approved medication for canine obesity in the United States (*Freedom of Information Summary - Food and Drug Administration Slentrol*, 2006). Dirlotapide and mitratapide function as microsomal triglyceride transfer protein (MTP) inhibitors, designed to promote weight loss by suppressing appetite and reducing food intake (Dobenecker et al., 2009; Wren et al., 2007). In a four-month study with client-owned

obese dogs, 97.8% of participants on Slentrol experienced weight reductions averaging 11.8% of body weight (*Freedom of Information Summary - Food and Drug Administration Slentrol*, 2006).

Similarly, Yarvitan produced a decrease in body fat mass by approximately 41.6% in an eight-week treatment period (Dobenecker et al., 2009). Despite their effectiveness, the drugs were plausibly removed from the market due to side effects such as vomiting and diarrhea. In trials with dirlotapide, 18.9% of dogs experienced vomiting and 14.9% had diarrhea (Wren et al., 2007). Additionally, Wren et al. (2007) reported a severe reduction in food intake of up to 42% of the total daily food intake.

Achieving weight loss in household dogs is a challenging endeavor. Adopting a one-health approach may prove beneficial. Evidence suggests active weight loss efforts in either a dog or its human caregiver can result in passive weight loss for the other (Niese et al., 2021). Pearl et al. (2020) revealed veterinarians and veterinary students express negative emotions such as disgust and frustration toward obese dogs and their owners. Veterinarians are also more pessimistic about compliance if both the dog and owner are obese. Reframing obesity as a disease may help owners appreciate its seriousness and the impact on the life span of the dog.

Obesity in dogs is a significant health concern, extending beyond aesthetic implications to contribute to various medical conditions. A cross-sectional study conducted in veterinary clinics identified a higher prevalence of conditions such as hypothyroidism, diabetes mellitus, pancreatitis, ruptured cruciate ligament, and neoplasia among obese dogs (Lund et al., 2006). Osteoarthritis (OA) is prevalent in overweight dogs and is characterized by the degradation of cartilage surpassing its production. Primary causes of OA include mechanical stress from excessive weight, aging, and genetic predisposition, while secondary causes may involve injury

or abnormal joint loading (Frye et al., 2016). Obesity exacerbates OA through mechanical stress as well as the release of inflammatory mediators from adipose tissue. A decade-long study subjected dogs to treadmill exercise adding an additional 30% of the dog's body weight using a weighted vest (Newton et al., 1997), revealing no significant effects on stifle cartilage in the weighted vest group when compared to the control group. This suggests that inflammation from obesity may have a more pronounced impact on OA than mechanical stress alone.

Obesity has also been linked to increased cancer risk, particularly in female dogs predisposed to mammary cancer and tumors (Marchi et al., 2022). The link between obesity and cancer is potentially due to changes in the endocrine functions of adipose tissue, which can promote carcinogenesis. Although the correlation between cancer and obesity in dogs is established, the causal relationship remains ambiguous. Obesity significantly affects canine metabolism, with hypothyroidism being one of the most prevalent metabolic disorders in dogs strongly associated with obesity (Dixon et al., 1999). Dixon et al. (1999) found approximately 44% of dogs diagnosed with hypothyroidism also presented with obesity or recent weight gain. Such comorbidities, including cancer, OA, and diabetes, underline obesity has severe health implications and is associated with a shorter health span in dogs (Kealy et al., 2002).

Addressing canine obesity is essential for dog owners. Despite the increasing obesity rates among dogs in the U.S., there remains a gap in research concerning the current demographics of overweight dogs, feeding habits, and variations in blood parameters across different weight classifications.

The Geo Study chapter aims to provide updated statistics on the demographics of overweight and obese dogs. Detailing common breeds, sex differences, comorbidities, and including owner demographics and perceptions regarding the health of the dog and activity

levels. The research intends to enhance dialogues between owners and veterinarians about the weight status of the dog.

Additionally, the 1000 Dog Chapter will analyze how the demographics of overweight and obese dogs differ from those of dogs with ideal weight, focusing on factors such as age, intact status, and comorbidities. The 1000 dog chapter will also explore feeding patterns and blood parameter variations across weight classifications. The chapter aims to better equip veterinarians to understand the influence of feeding habits on canine weight and to recognize clinical presentations of overweight or obese dogs based on demographics and laboratory blood values.

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Chapter 2 - Chapter 2 - Overweight and Obese Status in Healthy

Older Dogs Visiting General Veterinary Practices in the U.S.:

Results of the 1,000 Dog Survey

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Wernimont

Introduction

Obesity in domestic dogs is increasingly prevalent in the United States. The disease represents the most common form of malnutrition for modern day dogs in the region. Overweight and obese status are characterized by an increase in adipose tissue above the ideal body fat range of 15% to 20% (Hand, Thatcher, Remillard , et al., 2010). Dogs are classified as overweight when the body fat percentage of the dog is between 25% and 35% (Witzel et al., 2014). Dogs with a body fat percentage exceeding 35% are classified as obese. A recent survey by the Association for Pet Obesity Prevention (APOPOP) estimated 59% of dogs in the United States are overweight or obese (APOPOP, 2022). Obese dogs are predisposed to experience adverse health outcomes which lead to decreased lifespan, increased health care costs for pet owners, and diminish quality of life for dogs (Kealy et al., 2002; Lund et al., 2006). The cause of obesity is multifactorial, with overfeeding as a prominent contributor. One study found obese dogs consumed significantly more "other food" with homemade, semi-moist, or canned foods as a major dietary component (Lund et al., 2006). Other food was defined as meat, other food products, commercial treats, or table scraps. Bray et al. (2022) found dogs fed once per day exhibited improved health outcomes including lower mean scores on a cognitive dysfunction scale, as well as lower odds of having gastrointestinal, dental, orthopedic, kidney/urinary, and

liver/pancreas disorders. However, Bjørnvad et al. (2019) found dogs fed two meals per day had a lower risk of being overweight compared to dogs fed once per day. The study also found ad libitum feeding was negatively correlated with body condition score (BCS). In contrast, Kealy et al. (2002) indicated portion-controlled foods are necessary to prevent weight gain. Data suggest some dogs may self-regulate intake when fed ad libitum; no clear feeding pattern has been identified to reduce the risk of obesity in dogs.

Obesity increases the likelihood of other medical conditions. A cross-sectional study conducted in veterinary clinics found obese dogs were more frequently diagnosed with hypothyroidism, diabetes mellitus, pancreatitis, ruptured cruciate ligament, or neoplasia (Lund et al., 2006). Osteoarthritis (OA) is also common among overweight dogs, occurring when cartilage degradation outpaces production. The primary causes of OA include weight-loading stress, aging, and genetic predisposition (Frye et al., 2016). While secondary causes include injury or abnormal joint loading. Hoffman et al. (2022) found larger, older dogs with a history of being overweight were more commonly diagnosed with OA compared to younger, smaller dogs without a history of being overweight.

Overweight and obesity present significant challenges for senior dogs. A study conducted by Kealy et al. (2002) demonstrated dogs with lower BCS, achieved through caloric restriction, not only had extended lifespans but also required intervention for chronic conditions at more advanced ages. Another study conducted on client-owned dogs found similar results, where all surveyed breeds had shorter lifespans if they were overweight status (Salt et al., 2019). However, smaller dogs experienced the greatest impact, with a reduction in lifespan of two years. Further research by Fleming et al. (2011) identified age as a significant predictor of disease development in dogs, with types of diseases varying by age. Obesity in senior dogs elevates the risk of disease

onset, posing a serious threat to overall health and well-being. Additionally, as highlighted by Wallis et al. (2023), the disease risk is compounded by the tendency of owners to attribute health changes to aging rather than investigating underlying causes in older dogs. The demographics of overweight senior dogs, encompassing factors such as geographical location, age, spay/neuter status, breed, and American Kennel Club (AKC) classification, remain under-researched. While comorbidities have been documented in obese dogs of all ages, research specifically focusing on obese senior dogs without chronic conditions is scarce. Furthermore, detailed feeding patterns of senior obese dogs have not been thoroughly compared with dogs of underweight and healthy-weight, nor have blood parameters results been contrasted among weight status in dogs.

The study aims to describe demographics, feeding patterns, comorbidities and blood parameters results of overweight/obese senior dogs compared to underweight and ideal-weight senior dogs. Despite many known health risks, obesity rates in dogs continue to rise. More detailed knowledge of the characteristics associated with overweight status and obesity has the potential to help veterinarians and pet owners understand how to establish more healthy feeding practices and identify potential causes of obesity and identify prevention strategies.

Methods

Subject Enrollment

The study was a multicenter cross-sectional observational study involving 21 veterinary clinics throughout the continental United States conducted between June 2016 and March 2017 enrolling 485 dogs. Identity of the sponsor (Hill's Pet Nutrition) was kept confidential throughout the study. The study entailed a single visit to a veterinary clinic where investigators performed a comprehensive health history assessment of previous and current health conditions

and diagnoses, an assessment of a nutrition history, a cheek swab for genetic analysis, collection of a whole blood sample, and collection of a fecal sample for microbiome analysis. In accordance with ethical guidelines, all animal procedures were performed in compliance with institutional and national standards. For detailed methods, please refer to Hollar et al. (in preparation), which provides a more comprehensive overview of the study.

Eligible participants included adult purebred and mixed-breed dogs aged five years or older. No dietary restrictions were imposed on dogs during the study. Exclusion criteria included dogs whose owners' lacked knowledge of previous medical history or had ownership for less than three years, dogs who required hospitalization, were dehydrated and in need of intravenous fluids, or had an active infectious disease, dogs whose behavior precluded collection of blood, cheek cells, or fecal samples, and dogs with a history of an undiagnosed illness or a current illness unlikely to receive a diagnosis.

Dogs were eligible for analysis if they passed a clinical veterinary exam and health history screening without identification of significant chronic conditions. Dogs with mild or moderate dental/gum disease, benign tumors, sebaceous cysts, arthritis of the elbow, stifle, back and/or neck, chronic constipation (if inflammatory bowel disease or adverse reactions to food had been ruled out), otitis (if atopic dermatitis was ruled out), mitral valve insufficiency, urinary tract infection, and/or incontinence were included in the analysis. Overweight or obese (O/O) dogs were included if they met other inclusion criteria. A more detailed description of enrolled dogs is provided in Hollar et al. (in preparation)

Clinics were encouraged to screen dogs who met enrollment criteria and for which the clinic had a comprehensive medical history of the dog to prevent enrollment of dogs with incomplete medical records. Clinics were advised to review medical files for potential candidates

and to conduct phone interviews to preliminarily assess eligibility. During interviews, owners were instructed to bring digital photos of packaging for all foods currently offered to the dog, including treats, to the appointments. Information regarding concomitant medications and prior unscheduled physical examinations was collected. Concomitant medications administered in the 60 days prior to enrollment through time of last sample collection were documented. Prescribed medications and vaccinations initiated at time of last sample collection were not included. Dogs belonging to clinic staff were allowed to participate if they satisfied the study enrollment criteria. On the study visit day, owners provided informed consent, eligibility was confirmed, and clinic staff conducted a medical history review, physical examination, and dietary history assessment. Veterinarians documented medical histories of the dogs and performed physical exams, including a Body Fat Index (BFI) assessment (Witzel et al., 2014). Owners completed a nutrition survey, estimating the proportions of dry food, wet food, human food, treats, and other foods (including homemade pet foods) given to the dogs during the previous day.

Sample Analysis

Laboratory samples were obtained during the study visit; dogs were not required to be fasted before the samples were collected. If required samples were not collected on visit day, owners were asked to return to the clinic within seven days for a second attempt. Blood samples were taken for a complete blood count, serum chemistry profile, and thyroid (T4) analysis. A whole blood sample was collected using an FTA Micro Card (blood card). Samples were sent to Marshfield Laboratories for analysis immediately after collection. The complete blood count (CBC) results were conducted using a CBC analyzer at Marshfield Laboratories, which is presently known as Idexx Laboratories Inc. Fecal samples were collected and analyzed using COSMOS ID for microbiome analysis. The cheek swab was sent to Neogen for DNA

sequencing. Adverse events, defined as any unfavorable and unintended observation, undesirable experience, reaction, or side effect, were recorded from time of informed consent signing through completion of the study visit.

Data Collection

Study data was captured using the Prelude Electronic Data Capture (EDC) System. In the event of EDC system unavailability, data were collected on paper forms and subsequently entered into the EDC system when access was restored. Both EDC and paper data were reviewed by a study monitor, who coordinated corrections and resolved queries with study site personnel.

Statistical Analysis

Descriptive statistics of dog characteristics are presented as means and standard deviations, medians and interquartile ranges, and frequencies for healthy ideal-weight versus healthy overweight/obese dogs. For normally distributed continuous data, two-sample t-tests were used to determine significant differences between the means of healthy underweight, healthy ideal-weight, and healthy overweight/obese dogs. Skewed continuous data was analyzed using the Wilcoxon-Mann-Whitney test to compare groups. Proportions were compared using either the chi-square test or Fisher's exact test, depending on the expected frequencies. Examples of proportion data in the study include percentage of males, percentage of obese dogs, and percentage of giant breeds. The significance level was adjusted for multiple testing within outcome categories: weight category, state, region, sex and intact status, age, breed, commodities, medication, supplements, wet food, dry food, wet/dry food, treats, people food, and food categorization using the Benjamini-Hochberg false discovery rate (FDR) (Benjamini & Hochberg, 1995). A *P* -value of less than 0.05 was considered statistically significant. Analyses

were conducted using SAS version 9.4 (SAS Institute Inc., Cary, NC) and R version 4.2.2, and plots were produced in R.

Results

Demographics

Body Fat Index (BFI) was a primary classification criterion for the enrolled subject population. Of dogs ($n = 485$) enrolled, 7.0% ($n = 34$) were underweight with less than 20% BFI, 45.2% ($n = 219$) of dogs were of ideal weight with 20% BFI, 27.4% ($n = 133$) of enrolled dogs were overweight with 30% BFI, and 20.4% ($n = 99$) of dogs were obese with a BFI ranging from 40% to 70% (Table 2.1). For subsequent analyses, overweight and obese dogs were combined into one group.

Dogs were enrolled from 15 states, and states were categorized into regions representing geographic distribution across different parts of the country (Hollar et al, in prep). When comparing states, no significant differences were observed after adjustment between underweight and ideal-weight dogs, as well as ideal-weight and O/O dogs in most states. However, in New York (NY), a significantly higher percentage of underweight dogs 64.7% ($n = 22$) was observed compared to ideal weight dogs 13.7% ($n = 30$), $\chi^2 (1, N = 219) = 46.89$, $P < 0.0001$, adjusted $P < 0.0001$. In Virginia (VA), 10.3% ($n = 24$) of O/O dogs were enrolled, which was significantly more than the ideal weight dogs enrolled in VA 1.8% ($n = 4$), $\chi^2 (1, N = 28) = 14.04$, $P < 0.0002$, adjusted $P = 0.0051$.

Body weight categorization in dogs is based on adult body weight and takes into account growth rate variations across different breed sizes: Small: ≤ 25 lbs., Medium: $> 25 < 55$ lbs., Large: $\geq 55 < 110$ lbs., and Giant: ≥ 110 lbs. (Hawthorne et al., 2004). When comparing current

body weight categories (Figure 1), a significant difference was found in the proportion of small dogs within weight categories; 58.8% (n = 20) of underweight dogs and 40.6% (n = 89) ideal weight were categorized as small dogs. Small dogs had an increased likelihood of being considered underweight, $\chi^2 (1) = 3.9690$, $P = 0.0464$. However, the significance of the comparison was no longer true after adjusting for multiple comparisons (adjusted $P = 0.1420$). The analysis also found medium-weight dogs were more likely to be of ideal weight; 25.1% (n = 55) of ideal weight were classified as medium while 8.8% (n = 3) of underweight dogs were classified as medium, $\chi^2 (1) = 4.4200$, $P = 0.0355$. However, significance did not hold after adjustment for multiple comparisons (adjusted $P = 0.1420$). In the giant weight classification, dogs were more likely to be O/O [8.2% (n = 19) of O/O dogs] when compared to 2.3% (n = 5) of ideal weight dogs, $\chi^2 (1) = 7.8010$, $P = 0.0052$, (adjusted $P = 0.0416$).

In this study, weights were recorded at a veterinary clinic and veterinarians assessed BFIs, the objective was to determine if discrepancies existed in weight category classifications. The assessment was possible as the necessary data was available to calculate ideal body weights of the dogs. Dogs were classified into weight groups based on current weights: Small (≤ 25 lbs.), Medium (> 25 lbs. and < 55 lbs.), Large (≥ 55 lbs. and < 110 lbs.), and Giant (≥ 110 lbs.) (Table 2.2). Ideal body weight was then calculated using a veterinarian-assessed BFI of the dog, and then dogs were subsequently re-categorized into small, medium, large, and giant weight groups. No significant difference between the distributions of current versus ideal body weight groupings were found, but the study observed more dogs were considered small and medium-sized while fewer dogs were considered large and giant in the current weight distribution as compared to ideal. The discrepancy between the current and ideal weight of a dog can lead to

misclassification into a weight category. Such misclassification may result in an incorrect dietary recommendation which does not align with the actual body size of the dog.

No significant differences were found between the proportions of ideal vs. underweight dogs and ideal vs. O/O dogs across age brackets: under 7 years, 7-11 years, and 11+ years. Additionally, no significant difference was found in the mean (SD) age of different weight categories: underweight (< 20 BFI): 9.9 (2.14) years, ideal weight (20 BFI): 9.3 (1.98) years, and O/O combined: 9.3 (1.77) years (Table 2.3). Intact males were more probable to be ideal weight at 6.4% (n = 14) of ideal weight dogs compared to intact male being only 1.7% (n = 4) of the O/O dog population, $\chi^2 (1) = 6.41$, $P = 0.0114$. However, this no longer significant after adjustment for multiple comparisons (adjusted $P = .1117$). No other significant sex differences between groups were identified.

The top 10 breeds of eligible dogs enrolled in the study were Labrador Retriever, Golden Retriever, Other (none of the listed breeds), Shih Tzu, German Shepherd Dog, Dachshund, Yorkshire Terrier, Beagle, Bichon Frise, Jack Russell Terrier, and Pug. For a full list of breeds, refer to Hollar et al. (in preparation). No significant differences were found between breeds and the likelihood of being O/O after adjusting for multiple comparisons. However, before adjustment, Pugs had an increased tendency to be O/O. Specifically, 3.9% (n = 9) of the O/O dog population were Pugs, compared to only 0.5% (n = 1) of the ideal weight dogs being Pugs, $\chi^2 (1) = 5.02$, $P = 0.0206$; adjusted $P = 0.1722$. Similarly, Dachshunds were more likely to be O/O, with 6.0% (n = 14) of O/O dogs being Dachshunds compared to 1.4% (n = 3) of ideal weight dogs being Dachshunds, $\chi^2 (1) = 6.76$, $P = 0.0093$; adjusted $P = 0.0972$. It is important to note results may be influenced by the small number of enrolled dogs within a breed or dogs classified in “other” breed.

Medication and Supplements

No significant differences in medication usage were observed between underweight and ideal-weight dogs or between ideal-weight and O/O dogs. The majority of dogs in the study received medication 60 days prior to enrollment: 85.3% (n = 29) of underweight dogs, 75.8% (n = 166) of ideal weight dogs, and 81.5% (n = 189) of O/O dogs. No significant differences were found in medication classes between ideal weight and O/O dogs, including antibiotics, dietary supplements, non-steroidal anti-inflammatory drugs, parasiticides (including heartworm), steroids, thyroid medications, vaccines, and other medications. The study found 20.6% (n = 7) of underweight dogs consumed dietary supplements containing chondroitin compared to 4.6% (n = 10) of ideal weight dogs, $P = 0.0031$; adjusted $P = 0.0104$ (Appendix Figure A.1). There were no significant differences in supplement consumption between underweight and ideal-weight dogs or between ideal-weight and O/O dogs.

24 hr. Food Recall

In addition to asking dog owners for a 24-hour food recall from the previous day, owners were also asked if the recall represented a normal day for the dogs. Only 1.6% of owners reported the last 24 hours of food recall did not represent a normal day of food consumption for the dog. Owners were asked to assign a percentage to each category: dry food, wet food, human food, treats, and other based on daily consumption, ensuring the total equaled 100%, Hollar et al. (in preparation). When analyzing food consumption, there was no significant difference in total daily consumption levels of wet food, people food, and treats between underweight, ideal weight, and O/O dogs. No significant differences were found in dry food consumption at thresholds of $\geq 60\%$, $\geq 70\%$, $\geq 80\%$, and $\geq 90\%$ of total food consumed between underweight and ideal-weight dogs or between ideal-weight and O/O dogs. The study found 26.5% (n = 58) of ideal weight

dogs consumed 100% dry food compared to 17.2% (n = 40) of O/O dogs, $\chi^2 (1) = 5.66$, $P = 0.0174$. The difference was no longer significant after adjustment for multiple comparisons ($P = 0.0979$).

Similarly, no significant difference was found in the consumption of wet and/or dry food at thresholds of $\geq 60\%$, $\geq 70\%$, $\geq 80\%$, and $\geq 90\%$ between underweight and ideal-weight dogs or between ideal-weight and O/O dogs. The study found that significantly more ideal weight dogs, 32.0% (n = 70) consumed 100% commercial wet and/or dry food than 14.7% (n = 5) underweight dogs (5, 14.7%), $\chi^2 (1) = 4.20$, $P = 0.0404$, adjusted $P = 0.1933$. The study also found that significantly more ideal weight dogs, 32.0% (n = 70) consumed 100% commercial wet and/or dry food than 23.3% of O/O dogs (n = 54), $\chi^2 (1) = 4.27$, $P = 0.0389$ adjusted $P = 0.1891$. P -values were no longer significant after adjustment for multiple comparisons.

There were no significant differences in the consumption of therapeutic, wellness, adult, all life stage, puppy, senior, popular, premium, high protein, traditional protein and grain-free, or traditional grain foods among underweight, ideal weight, and O/O dogs (Hollar et al. (in preparation) for full definitions). Additionally, no significant differences were found in the number of brands and types of brands consumed relative to weight status (Appendix Figure A.1). Free fed dogs were not significantly more likely to be obese: 0% (n = 0) of underweight dogs, 8.7% (n = 19) of ideal weight dogs, and 6.5% (n = 15) of O/O dogs were free fed. There were also no significant differences in number of feedings of any food type, including wet, dry, people food, or treats. Additionally, the intervals between feeding meals (commercial wet and/or dry food) did not significantly affect weight status of the dog, whether the intervals were 0-2 hours, 3-6 hours, 7-10 hours, or >10 hours. No significant difference between weight status and the number of times the dog was fed treats and human food was observed in the study.

Comorbidities

A significant difference was found in the mean (SD) number of individual overall comorbidities between O/O dogs (2.9 ± 1.09) and ideal weight dogs (1.8 ± 1.04), $t(448.85) = -10.49$, $P < 0.0001$, adjusted $P < 0.0001$, with O/O dogs having on average more comorbidities. Ideal weight dogs (39, 17.8%) were diagnosed with significantly more otitis than underweight dogs (1, 2.9%), $\chi^2(1) = 4.89$, $P = 0.0271$, adjusted $P = 0.0478$. Additionally, 26.5% ($n = 58$) of ideal weight dogs had a dermatological disorder, which was significantly higher when compared to 8.8% ($n = 3$) of underweight dogs, $\chi^2(1) = 5.02$, $P = 0.0251$, adjusted $P = 0.045$. No significant differences were found in the prevalence of oral disorders (mild/moderate dental/gum disease), neoplasia (such as benign neoplasia, benign tumors, lipomas), musculoskeletal disorders (such as arthritis of the elbow, stifle, back, and/or neck, intervertebral disc disease [IVDD]), cardiovascular disorders (such as mitral valve insufficiency, murmur), and urinary/renal disorders (such as urinary tract infection, incontinence) between underweight and ideal-weight dogs or between ideal-weight and O/O dogs.

Blood Parameters

The study found differences in mean triglyceride levels (TRIG, mg/dL) with underweight dogs (96.6 ± 74.64) having significantly lower levels than ideal body weight dogs (157.7 ± 176.28), $t = -3.50$, unequal DF = 103.19, $P = 0.0007$, adjusted $P = 0.0145$ (Table 2.4). Similarly, significant differences were observed between O/O dogs (213.6 ± 219.18) and ideal-weight dogs (157.7 ± 176.28), with ideal weight dogs having lower mean triglyceride levels, $t = -2.99$, unequal DF = 438.08, $P = 0.0029$, adjusted $P = 0.0407$. Ideal weight dogs (6.3 ± 0.50) had significantly lower mean total protein (TP, g/dL) than O/O dogs (6.5 ± 0.48), $t = -3.81$, unequal DF = 445.01, $P = 0.0002$, adjusted $P = 0.0051$. Significantly lower levels of mean calcium levels

(CA, mg/dL) were found in ideal weight dogs (9.7 ± 0.77) when compared to O/O dogs (10.1 ± 0.58), $t = -5.02$, unequal DF = 406.75, $P < 0.0001$, adjusted $P < 0.0001$. For mean white blood cell count (WBC, $\times 10^3/\mu\text{L}$), significantly lower values were found in ideal weight dogs (8.3 ± 2.02) versus O/O dogs (9.4 ± 3.24), $t = -4.71$, unequal DF = 390.15, $P < 0.0001$, adjusted $P = 0.0002$. A significantly lower mean platelet count (PLT, $\times 10^3/\mu\text{L}$) was noted in ideal weight dogs (312.5 ± 104.44) compared to O/O dogs (348.6 ± 119.73), $t = -3.04$, unequal DF = 350.91, $P = 0.0026$, adjusted $P = 0.0370$. Lastly, significantly lower values were found in mean segmented neutrophil count (SEG, $\times 10^3/\mu\text{L}$) between ideal weight dogs (67.8 ± 9.37) and O/O dogs (70.4 ± 9.08), $t = -3.08$, unequal DF = 445.47, $P = 0.0022$, adjusted $P = 0.0331$.

Free-Fed Dogs

The study found 19 dogs in the study population were free-fed and measured under or at ideal BFI when evaluated by a veterinarian. Of the 19 dogs, the sex distribution was as follows: Female Spayed 36.8% ($n = 7$) of free fed dogs, Female Intact 0% ($n = 0$) of free fed dogs, Male Intact 5.3% ($n = 1$) of free fed dogs, and Male Neutered 57.9% ($n = 11$) of free fed dogs. The largest AKC breed grouping represented was Toy at 42.1% ($n = 8$) of free fed dogs. Average age of free fed dogs was 9.88 (2.46) years. The weight distribution of free fed dogs was as follows: 63.2% ($n = 12$) Small (≤ 25 lbs.), 5.3% ($n = 1$) Medium (> 25 lbs. and < 55 lbs.), 31.6% ($n = 6$) Large (≥ 55 lbs. and < 110 lbs.), and 0% ($n = 0$) Giant (≥ 110 lbs.): 0 (0%). On average, dogs were fed predominantly dry food, constituting 98.1% of the daily food intake. Free-fed dogs consumed less than 2% of daily intake in treats (1.2%) or people food (0.9%), and none of the daily intake consisted of wet food or other foods for free fed dogs. In the ideal weight dog population, dietary consumption was composed of 88.1% dry food, 5.4% wet food, 1.7% human

food, and 2.7% treats, based on daily intake. For comprehensive demographic details pertaining to free-fed dogs studied, refer to Appendix Figure A.2.

Discussion

The study provides a comprehensive investigation into the health characteristics and feeding practices of senior dogs in the United States, with a particular focus on differences across weight statuses. Interestingly, the study uncovered overweight and obese dogs collectively accounted for 48% of the senior dogs enrolled. The proportion of senior dogs observed to be O/O in the present analysis (48%) is lower than the value previously reported by APOP (59%); though, the APOP value represented both adult and senior dogs (APOP, 2022). The differences suggest obesity might be more or less frequent in subgroups of dogs defined by age, breed, purebred status, owner lifestyle or other factors.

Although the prevalence of obesity in the present study at 48% is lower than the overall U.S. dog population, O/O dogs still constitute a sizeable portion of the study cohort. The observation underscores the ongoing concern regarding obesity within the senior dog demographic. The discrepancy in the reported percentage of O/O dogs may be attributed to the over-representation of purebred dogs, the senior age of the dogs in the study, and various owner lifestyle factors. Obese dogs might not reach the senior age group represented in the study, attributed to reduced life expectancy associated with obesity (Kealy et al., 2002; Salt et al., 2019). Additionally, the percentages in the study were derived from in person veterinarian evaluations of the dogs, whereas the APOP percentage was an estimate based on a recollection of dogs seen in practice by veterinarians. Percentages derived from in-person veterinarian

evaluations are likely to be more precise, as they are based on direct observations and assessments conducted during the study.

The study also highlighted that age and sex distribution across different weight categories did not exhibit significant differences. Findings suggest age and sex may not be primary factors determining weight status among senior dogs. Unlike other studies that found the spay and neuter status of dogs was positively correlated with being overweight status or obese (Benka et al., 2023; Bjørnvad et al., 2019), the study did not find such a correlation. Differences in characteristics of the dog populations included in studies, or the timing of the data collection periods, might help explain the lack of consistent findings. The dogs included in this study were of senior age, likely beyond their reproductive years, which minimizes the influence of their intact status on the likelihood of being O/O. Additionally, the enrolled dogs were required to have an extensive medical history, facilitating increased interactions with veterinary staff to discuss their weight status and implement measures to reduce obesity.

Another critical observation was the high prevalence of comorbidities among O/O dogs compared to ideal-weight dogs. Overweight/obese dogs exhibited significantly higher mean numbers of individual comorbid conditions, such as oral, dermatological, neoplastic, musculoskeletal, cardiovascular, urinary/renal, eye, and neurological disorders. The findings align with existing literature links obesity in dogs to numerous health complications, emphasizing the necessity of enhanced interventions to manage and prevent obesity among senior dogs (Frye et al., 2016; Kealy et al., 2002; Lund et al., 2006; Marchi et al., 2022). The study also found healthy, ideal-weight senior dogs consumed the majority of their daily food intake as commercial dry or wet food. The finding may be attributed to the ease of following a feeding guide and accurately measuring the amount of food provided when using commercial

foods, as well as the ability to adjust the feeding amount based on the weight of the dog. The study did not find a significant difference between overweight and ideal-weight dogs and supplement use, unlike Hoffman et al. (2022), who found older overweight dogs were more likely to receive a joint supplement.

The study fills a significant gap in the literature by providing a detailed analysis of weight status and its association with blood parameters, health conditions and feeding practices in senior dogs. Prior research has primarily focused on general feeding patterns and obesity prevalence without diving deep into the intricate connections within a senior dog population. The findings from the research have broader implications for managing and mitigating obesity in senior dogs. The prevalence of obesity and its associated comorbidities suggests the need for a multifaceted approach in addressing the obesity issue. Obesity may increase the likelihood of developing comorbidities, and conversely, the presence of certain comorbidities may elevate the risk of a dog becoming obese. Comprehensive veterinary care, combined with tailored dietary and lifestyle interventions, can significantly enhance the overall well-being of senior dogs. For instance, understanding the complex relationship between feeding practices and weight status can help veterinarians guide pet owners in developing more precise dietary recommendations.

Additionally, eliminating treats and food intended for human consumption from the daily intake of dogs, and feeding primarily commercial wet or dry dog foods, may help in maintaining a healthy weight. Feeding a commercial wet or dry food allows pet owners to more easily measure the amount of food and calories consumed by their dogs. When implementing a weight loss regimen in dogs, it is advisable to feed a food specifically formulated for weight loss. Relying on caloric restriction of a maintenance food not intended for weight loss could lead to nutrient deficiencies.

Although no significant difference was observed in current versus ideal weight classifications (Table 2.2), the study identified a reduction in the number of dogs classified as giant and large based on ideal weight. This discrepancy may lead veterinarians and pet owners to misclassify dog size categories when relying solely on current weight. This finding underscores the importance of recommending a food based on the ideal weight category of the dog. Additionally, the ideal weight of the dog should be taken into account when advising on feeding amounts, as most feeding recommendations on pet food labels are based on current weight rather than the ideal weight.

The study highlights notable differences in blood parameters among underweight, ideal weight, and O/O groups. The findings suggest body weight status significantly impacts physiological health markers. The laboratory values obtained in this study may be affected by the lack of a fasting protocol, potentially introducing variation in the blood parameters. The observation underweight dogs have significantly lower triglyceride levels compared to ideal-weight dogs may be attributed to lower body fat stores. Overweight/obese dogs exhibited higher triglyceride levels than ideal weight dogs, likely due to excessive caloric intake and subsequent fat accumulation. Gomez-Fernandez-Blanco et al. (2024) found higher triglyceride levels were associated with an increase in insulin and fructosamine concentrations, which may indicate early glucose intolerance. Jeusette et al. (2005) observed elevated total plasma cholesterol and triglyceride concentrations in obese dogs; however, when the food composition was altered and overall intake was reduced, they noted positive effects on plasma lipid and leptin concentrations even before any weight loss occurred. Regarding total protein and calcium levels, the finding ideal-weight dogs have lower mean total protein compared to O/O dogs may suggest increased adipose tissue influences nutrient metabolism. One study also indicated improved fat metabolism

in dogs fed the test food, with both caloric restriction and specifically formulated weight loss foods proving effective in a controlled research settings (Floerchinger et al., 2015). The hematological differences, such as higher white blood cell and neutrophil counts in O/O dogs, may imply an inflammatory or immune response associated with increased adiposity. Obesity is known to induce chronic low-grade inflammation, which might stimulate an immune system response (Bastien et al., 2015; Tvarijonaviciute et al., 2012).

Despite its strengths, the study has several limitations which warrant acknowledgment. One limitation is the reliance on owner-reported data on feeding patterns, which may lead to underreporting of food consumption. A 24-hour recall may result in owners forgetting what they specifically fed their dogs as treats or table scraps or overlooking what other household members fed the dog. However, participants were asked to capture images of the food fed to the dog at home before the visit. Images were then used to complete the feeding records, thereby minimizing the risk of information being forgotten or overlooked. In contrast, utilizing a food log might reveal relatively more of the daily intake for the dog consisting of treats and non-commercial pet food, particularly in O/O dogs. Additionally, an increase in treat and human food consumption might be more evident if the data were analyzed by the percentage of daily calories rather than by volume. As noted by Heuberger and Wakshlag (2011), pet owners often underreport food intake, potentially skewing results.

Due to the collection of genetic data during the study, both purebred and mixed breed dogs were recruited, resulting in a potential overrepresentation of purebred dogs in the analysis compared to the general population. Purebred dogs are often selected for specific purposes beyond companionship, such as sporting, showing, and breeding. This may lead to differences in owner behavior between purebred dog owners and those of mixed breed dogs. Owners of

purebred dogs may customize feeding practices to meet specific requirements, including breed-specific health considerations, training demands, or appearance-related goals. Additionally, the study protocol did not mandate fasting prior to blood sample collection, which is a limitation. The lack of fasting could introduce variability in blood parameters, potentially impacting the reported results and their subsequent interpretation.

Overweight status and obesity remain significant concerns in dog health today, contributing to many potentially avoidable conditions, such as osteoarthritis and diabetes. Montoya et al. (2025) identified the highest prevalence of obesity in mature dogs, noting the likelihood of a dog being obese in adulthood increases if obesity was recorded during the growth stage. Findings underscore the importance of early intervention by veterinarians. To assist pet owners in managing the weight status of their dog and health more effectively, future research is recommended to focus on refining dietary recommendations by incorporating detailed analyses of portion sizes and caloric requirements among senior dogs. Understanding the factors will enable the development of tailored dietary guidelines to better meet the needs of senior dogs. Furthermore, investigating genetic predispositions and metabolic rates across different breeds might provide insights into breed-specific weight gain tendencies. Educating pet owners on the importance of portion control and accurate reporting of feeding practices is crucial for long-term health of the dog. Implementing educational programs can empower owners to make well-informed decisions about the daily food consumption of the dog, ultimately reducing the prevalence of obesity.

In conclusion, this study provides significant insights into the prevalence and health risks associated with obesity in senior dogs. It identifies several areas for improvement in management practices, such as refining dietary recommendations for preventing obesity. By adopting an

integrated approach combining precise dietary guidelines and owner education, veterinarians can effectively manage the incidence of obesity and associated comorbidities in senior dogs.

The study protocol was reviewed and approved by the Institutional Animal Care and Use Committee (IACUC) at Hill's Pet Nutrition, under approval number (CP689.0.0.0-A-C-U-ADH-MULTI-365-OTH). All methods were carried out in accordance with relevant institutional, national, and international guidelines and regulations. Owners signed an informed consent form before the dog was enrolled and agreed to comply with the instructions given by the veterinarian.

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Competing Interests

EH, RH, DH, RT, and SW are all current or former employees of Hill's Pet Nutrition, Inc

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Table 2.1 Body Fat Index (BFI) Classification (Witzel et al., 2014) of dogs included in analyzed population of healthy senior dogs

Weight Category Classification (BFI)	n (% of total enrolled dogs 485)
Underweight (< 20)	34 (7.0%)
Ideal weight (20)	219 (45.2%)
Overweight (30)	133 (27.4%)
Obese (40)	64 (13.2%)
Obese (50)	26 (5.4%)
Obese (60)	7 (1.4%)
Obese (70)	2 (0.4%)

Figure 2.1 Violin Plot of Canine Weight Categories (Small: ≤ 25 lbs., Medium: $> 25 < 55$ lbs., Large: $\geq 55 < 110$ lbs., and Giant: ≥ 110 lbs.) of dogs included in analyzed population of healthy senior dogs

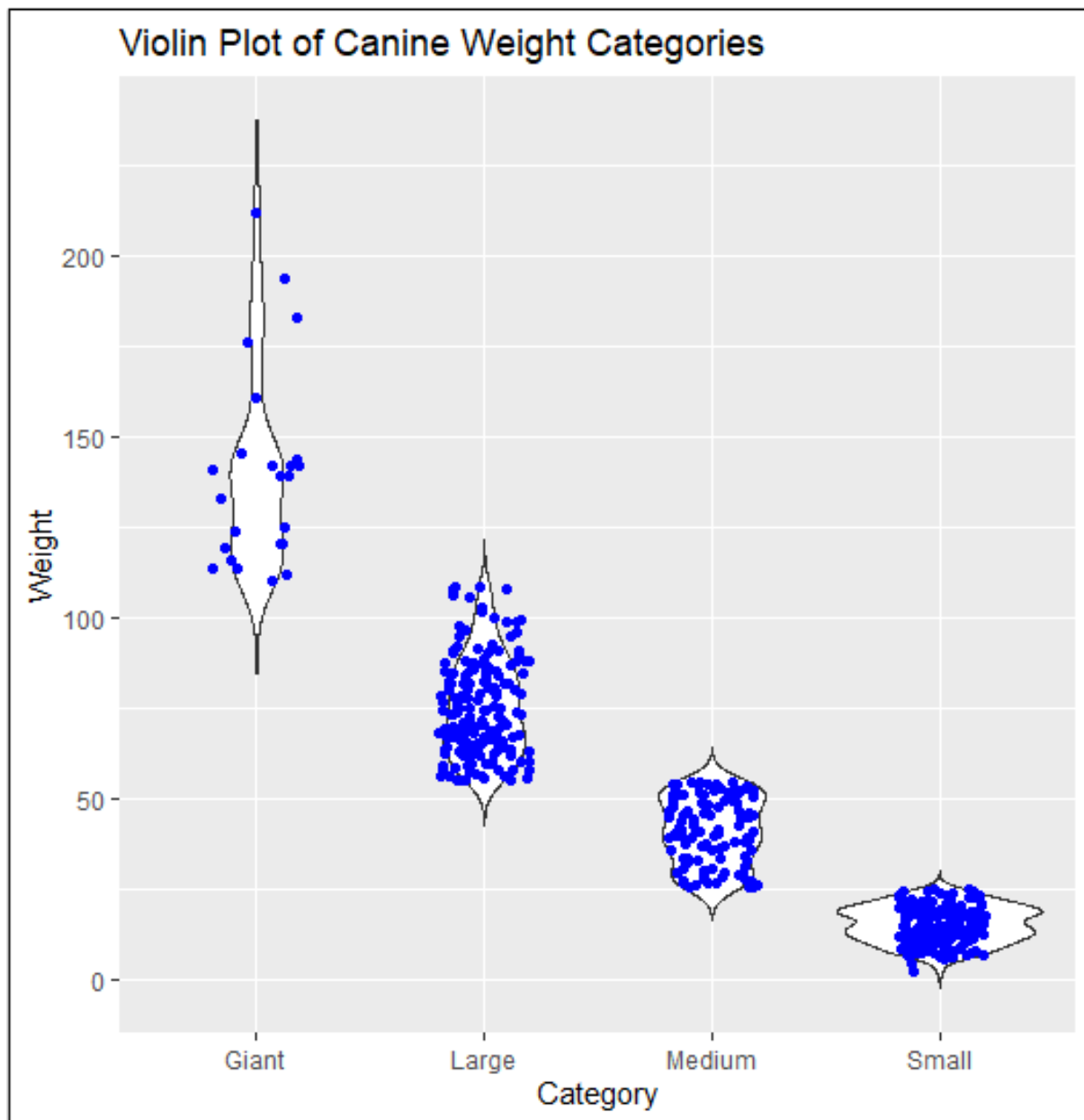


Table 2.2 Current vs Ideal Weight Classification of free feed underweight and ideal weight dogs included in analyzed population of healthy senior dogs

Weight Categories	Current Body Weight	Ideal Body Weight	χ^2 (1)	<i>adjusted P -value</i>
	n (%)	n (%)		
Small ≤ 25 lbs.	186 (38.4%)	201 (41.4%)	0.84265	0.3586
Medium > 25 lbs. - < 55 lbs.	109 (22.5%)	115 (23.7%)	0.14512	0.7032
Large ≥ 55 lbs. - < 110 lbs.	166 (34.2%)	155 (32.0%)	0.46561	0.495
Giant ≥ 110 lbs.	24 (4.9%)	14 (3.0%)	2.2185	0.1364

Table 2.3 Weight Classification based on body fat index (BFI), Sex/ Intact Status, and Age of dogs included in analyzed population of healthy senior dogs

	Underweight	Ideal Weight	Overweight/ Obese	Underweight vs. Ideal weight Dogs		Overweight/obese vs. Ideal weight Dogs	
	n (%)	n (%)	n (%)	χ^2 (1)	<i>adjusted P</i> -value	χ^2 (1)	<i>adjusted P</i> -value
Weight Classification							
Small ≤ 25 lbs.	20 (58.8%)	89 (40.6%)	77 (33.2%)	3.97	0.14	2.69	0.20
Medium > 25 lbs. - < 55 lbs.	3 (8.8%)	55 (25.1%)	51 (22.0%)	4.42	0.14	0.61	0.58
Large ≥ 55 lbs. - < 110 lbs.	11 (32.4%)	70 (32.0%)	85 (36.6%)	<0.01	1.00	1.09	0.47
Giant ≥ 110 lbs.	0 (0.0%)	5 (2.3%)	19 (8.2%)	NA	1.00	7.80	0.04
Sex and Intact Status							
Male Intact	4 (11.8%)	14 (6.4%)	4 (1.7%)	NA	0.75	6.41	0.11
Male Neutered	15 (44.1%)	91 (41.6%)	92 (39.7%)	NA	1.00	0.17	1.00
Female Intact	0 (0.0%)	7 (3.2%)	5 (2.2%)	NA	1.00	0.47	0.98
Female Spayed	15 (44.1%)	107 (48.9%)	131 (56.5%)	0.26	1.00	2.62	0.48
Age Grouping (Years)							
<7	0 (0.0%)	4 (1.8%)	9 (3.9%)	NA	1.00	NA	0.64
7 – 11	23 (67.7%)	173 (79.0%)	190 (81.9%)	1.00	0.56	1.00	0.94
> 11	11 (32.4%)	42 (19.2%)	33 (14.2%)	1.00	0.41	1.00	0.59
	Mean (SD)	Mean (SD)	Mean (SD)	χ^2 (1)	<i>adjusted P</i> -value	χ^2 (1)	<i>adjusted P</i> -value
Age (Years)	9.9 (2.14)	9.3 (1.98)	9.3 (1.77)	NA	0.47	NA	1.00

Table 2.4 Weight Classification based on body fat index (BFI); blood parameters of dogs included in analyzed population of healthy senior dogs

	Underweight	Ideal Weight	Overweight/Obese	Underweight vs. Ideal weight Dogs		Overweight/obese vs. Ideal weight Dogs	
	Mean (SD)	Mean (SD)	Mean (SD)	t ² (DF)	<i>adjusted P -value</i>	t ² (DF)	<i>adjusted P -value</i>
Laboratory Values							
TRIG, mg/dL	96.6 (74.64)	157.7 (176.28)	213.6 (219.18)	-3.50 (103.19)	0.01	-2.99 (438.08)	0.04
TP, g/dL	6.1 (0.40)	6.3 (0.50)	6.5(0.48)	-2.09 (251)	0.26	-3.81 (445.01)	0.01
CA, mg/dL	9.8 (0.61)	9.7 (0.77)	10.1 (0.58)	0.45 (251)	1.00	-5.02 (406.75)	<0.01
WBC, x 10 ³ /μL	8.3 (2.40)	8.3 (2.02)	9.4 (3.24)	0.14 (251)	1.00	-4.71 (390.15)	0.00
PLT, x 10 ³ /μL	335.8 (123.09)	312.5 (104.44)	348.6 (119.73)	1.11 (0.2667)	0.74	-3.04 (350.91)	0.04
SEG, x 10 ³ /μL	69.8 (8.60)	67.8 (9.37)	70.4 (9.08)	1.19 (251)	0.71	-3.08 (445.47)	0.03

Chapter 3 - A Geographical Analysis of Owner and Dog Demographics: Comparing Overweight/Obese and Non- Overweight/Obese Dogs Across 150 Major Metropolitan Areas

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Wernimont

Introduction

Prevalence of obesity in dogs is a growing concern within the field of veterinary medicine. Obesity significantly impacts canine health and longevity. Overweight status and obesity are defined as an increase in adipose tissue above the ideal body fat range of 15% to 20% (Hand, Thatcher, Remillard , et al., 2010). An estimated 59% of dogs in the United States are overweight or obese (APOP, 2022). Studies have sought to understand risk factors contributing to obesity in dogs, revealing a multifaceted issue influenced by demographic, physiological, and environmental factors.

Obesity is a chronic disease associated with the onset of other medical conditions. Obese dogs face increased risks of developing medical conditions, including mammary cancer in females, diabetes mellitus, pancreatitis, and osteoarthritis (Dixon et al., 1999; Frye et al., 2016; Lund et al., 2006; Marchi et al., 2022). Mechanical and inflammatory burdens of excess body weight exacerbate other medical conditions, leading to a complex interplay of health challenges.

Age and sex have both been found to have a strong relationship with canine obesity. Older age has been associated with higher body condition scores (BCS) in female dogs regardless of intact status (Bjørnvad et al., 2019). Male dogs in the study did not have an increased probability of being obese due to age. Montoya et al. (2025) identified dogs recorded

as overweight or obese during puppyhood or adulthood exhibited greater odds of being diagnosed as overweight or obese in later stages of life. Findings suggested a high likelihood of dogs previously diagnosed as overweight or obese remain in such a condition over time. Intact status of dogs can also influence the likelihood of a dog developing obesity. Benka et al. (2023) found spayed and neutered dogs are at twice the risk of developing obesity.

Dietary factors influence the risk of obesity in dogs, underscoring food as a major environmental determinant in canine weight management. Lund et al. (2006) highlighted obese dogs tend to consume "other food" items such as table scraps, commercial treats, and homemade foods more frequently. Surprisingly, Webb et al. (2020) found no association between treat feeding and obesity risk in dogs. In contrast, Bjørnvad et al. (2019) reported owners who gave their dogs treats during non-active periods (e.g., as snacks or while owners ate) were notably more probable to have obese dogs.

Genetic predispositions also contribute to the risk of obesity in dogs. Research has identified polymorphisms in the TNF and ADCY3 genes related to increased body fat (Sypniewski & Szydlowski, 2023). Labradors with specific genetic mutations, such as the POMC gene, have been shown to exhibit lower resting energy rates, predisposing dogs with the mutation to weight gain (Dittmann et al., 2024). Owner characteristics and behaviors can further influence a dog's weight status, although the strength of bond between owner and dog does not appear to be a direct factor (Bjørnvad et al., 2019; Webb et al., 2020). Interestingly, owners who perceive higher costs associated with dog care were significantly more likely to have overweight dogs (Webb et al., 2020). However, more research is needed to understand the potential owner demographics associated with obese dogs.

The study provides a comprehensive examination of a large population of dogs and owners across the top 150 major metropolitan areas of the U.S. and Canada. The study examined differences in sex, intact status, housing, weight categories, veterinarian visit frequency, food, supplements, and medical conditions across overweight/obese (O/O) dogs compared to dogs without an O/O diagnosis. The paper also described differences between dogs without an O/O diagnosis owners and O/O dog owners in terms of owners' age, profession, marital status, children, income, location, perception, and concerns. By better understanding demographic, physiological, and environmental factor differences between dogs without an O/O diagnosis and O/O dogs, veterinarians may be able to better identify and educate owners of dogs at greater risk of developing obesity.

Methods

Subject Enrollment

Hill's Pet Nutrition commissioned M/A/R/C® Research to conduct interviews with pet-owning households in the United States to assist in identifying geographic clusters of pets with relevant conditions. Identity of the sponsor (Hill's Pet Nutrition) was kept confidential throughout the survey. The survey was conducted from May 21 to June 21, 2020. The cross-sectional, non-interventional study involved owners of 33,326 dogs. A segment of the study explored the willingness of pet owners to participate in future research involving wearable technology. Respondents who expressed a willingness or potential interest in future participation were profiled to discern differences in pet characteristics, demographics, and geographic locations compared to other pet owners. The survey encompassed the top 150 major metropolitan areas, see (Appendix Figure B.4) for full list. Due to COVID-19 lockdowns, participants were

instructed to respond to survey questions based on their typical pre-pandemic behavior.

Additionally, owners were asked to exclude any dogs or cats temporarily fostered due to the pandemic.

Respondents completed a detailed survey for up to four dogs and four cats per person, answering questions focused on lifestyle factors and current and future health concerns. Data was captured using an online survey from M/A/R/C Research. Owners with more than four cats or four dogs were excluded from the sample population. Owners under 18 years of age were also excluded.

Owners were directed to answer health modules about conditions owners expressed concern about regarding their dogs. Owners who did not express concerns about their dogs were excluded from the study. In the questionnaire, comorbidities were categorized into ten distinct buckets for owners to address when expressing concerns about their dog's conditions: Mobility, Weight, Dermatology (Skin & Coat), Digestion, Aging, Stress, Oral (Teeth & Mouth), Urinary, Cancer, and Liver. Within each bucket, owners were asked, "Has a veterinarian ever diagnosed your pet with any of the following? (Select all that apply)," and were provided with a dropdown list of conditions specific to each category.

Dogs were excluded from the study if owners reported the animals had never undergone veterinary evaluation. If owners answered "yes" to whether a veterinarian had ever diagnosed their dog as overweight, obese, or severely obese, the dog was categorized as obese. If the dog owner answered that a vet had not diagnosed their dog with a weight condition, the dogs were then categorized as dogs without an O/O diagnosis. Dogs were included in the analysis if classified as O/O or had no diagnosed weight conditions. All other dogs were eliminated from the data set, including underweight dogs and dogs whose owners did not know if the dogs had

been diagnosed as O/O. After applying all exclusion criteria, 1,306 dogs were used for the analysis.

Statistical Analysis

A p-value of 0.05 was considered statistically significant. All analyses were conducted using R version 4.2.2, and plots were produced in R. Dog demographics and responses of owners were characterized by number and percentage of total dogs or, in cases where inferential tests are presented, the percentage relevant to the comparison. To assess the association between categorical variables, chi-square tests of independence were conducted. The analysis was used to determine whether there was a significant association between variables of interest. For cases where the assumptions of the chi-square test were violated, Fisher's Exact Test was employed which is suitable for small sample sizes. A simulated p-value approach was employed for certain analyses in the study, particularly in the context of complex models where the exact distribution of the test statistic is not readily known. The significance level was adjusted for multiple testing within outcome categories using the Benjamini-Hochberg false discovery rate (FDR) (Benjamini & Hochberg, 1995). The False Discovery Rate (FDR) was used to adjust p-values within categories, including age grouping, sex and age, intact status, housing status, Dog Activity Level Owner Reported, Owner Reported Dog Weight Perception, breed, mobility, weight, dermatology, digestive, aging, stress, oral, urinary, cancer, liver, owner age, profession, employment status, income, marital status, gender, children, number of dogs, and number of cats.

To explore the relationship between a binary outcome and multiple predictors, binary logistic regression analysis was conducted. The analysis was used to provide insights into the likelihood of O/O occurring in relation to various predictor variables. The logistic regression was performed using `dplyr glm()` function in R with a binomial family specification. Model fit was

assessed using Akaike Information Criterion (AIC), and the significance of individual predictors was evaluated through the Wald test, providing p-values, odds ratios, and 95% confidence intervals.

Results

Dog Demographics

In the study, data from 1,306 dogs were analyzed to assess weight status. The analysis revealed a significantly larger proportion of dogs, 60.7% (n = 793), were diagnosed by a veterinarian as O/O compared to dogs classified as dogs without an O/O diagnosis, which accounted for 39.3% of dogs (n = 513), $\chi^2 (1, N = 1,306) = 60.03, (P < 0.001)$. No significant difference was found between O/O and puppies less than one year old without an O/O diagnosis, with 60.0% of puppies (n = 3) being O/O and 40.0% of puppies (n = 2) without an O/O diagnosis, (adjusted $P = 0.40$). However, a significant difference was detected within the adult age group (1 to less than 7 years), where a higher number of dogs were overweight/obese (O/O), with 62.6% of adult dogs (n = 405) compared to 37.4% of adult dogs without an O/O diagnosis (n = 242), $\chi^2 (1, N = 647) = 41.07, (adjusted P < 0.001)$. Similarly, a significant difference was observed among senior dogs, with 58.9% of senior dogs being O/O compared to 41.1% of dogs without an O/O diagnosis (n = 269), $\chi^2 (1, N = 654) = 20.58, (adjusted P < 0.001)$.

Spayed females were more prone to having an O/O diagnosis, with 60.5% of spayed female dogs (n = 357) having a diagnosis of O/O compared to 39.5% of spayed female dogs without an O/O diagnosis (n = 233), $\chi^2 (1, N = 590) = 51.28, (adjusted P < 0.001)$. A significant disparity was also found among neutered males, with a higher O/O prevalence of 64.7% of neutered male dogs (n = 383) compared to 35.3% of neutered male dogs without an O/O

diagnosis ($n = 209$), $\chi^2 (1, N = 592) = 101.11$, (adjusted $P < 0.001$). Additionally, 69.0% of intact females were shown to be without an O/O diagnosis ($n = 29$) compared to 31.0% of intact females being O/O ($n = 13$), (adjusted $P = 0.002$). However, no significant difference was detected in weight status among intact males (Table 3.1). The analysis also revealed significant differences when comparing age and sex. Specifically, both male and female dogs in the adult and senior age classifications were more frequently classified as overweight status or obese compared to dogs without an O/O diagnosis, (adjusted $P < 0.05$).

In the survey, purebred dogs were shown to be more likely overweight/obese (O/O), with 57.4% of purebred dogs ($n = 468$) being diagnosed with O/O compared to 42.6% of purebred dogs without an O/O diagnosis ($n = 348$), $\chi^2 (1, N = 816) = 17.65$, (adjusted $P < 0.001$). Mixed breeds were also more probable to be O/O, with 66.3% of mixed breed dogs ($n = 325$) compared to 33.7% of mixed breed dogs without an O/O diagnosis ($n = 165$), $\chi^2 (1, N = 490) = 52.24$, (adjusted $P < 0.001$). The study found a higher percentage of mixed breeds dogs 66.3% ($n = 325$) were diagnosed with O/O compared to purebred dogs 57.4% ($N = 468$). Among the breeds studied, Australian Shepherd, Bernese Mountain Dog, and German Shorthair Pointer were found to have a significantly higher rate of O/O diagnosis compared to dogs without an O/O diagnosis, (adjusted $P < 0.05$) (Appendix Figure B.1). However due to a small sample size with in the breed further research is needed to determine the link between the breeds and overweight/ obesity. The study also found O/O dogs were common among indoor-only, mostly indoor, and indoor/outdoor dogs, but there was no significant difference for outdoor dogs (Table 3.1).

Food Type and Supplements

A logistic regression analysis was conducted to evaluate the influence of different food types on the weight status of dogs in the survey. Participants reported the types of food regularly

provided to their dogs, categorized as dry food, wet food, table food/leftovers, raw food, home-cooked pet food, and store-bought treats. Food types were used as independent variables in the analysis, which applied a binomial logistic regression model. The results revealed that dry food demonstrated a significant negative association with weight status (adjusted $P = 0.005$), indicating dogs consuming dry food had reduced odds of being classified as overweight status or obese compared to dogs fed other types of food. In contrast, dogs fed home-cooked pet food were significantly more probable to fall into the overweight or obese category rather than dogs without an O/O diagnosis ($P = 0.049$). However, the comparison is no longer significant after adjusting for multiple comparisons (adjusted p - values = 0.147). Wet food, table food/leftovers, and store-bought treats had no significant impact on weight status. Study findings underscore the impact of feeding practices on canine weight status and suggest potential dietary interventions for weight management.

A binary logistic regression analysis was conducted to explore the relationship between various predictors specifically, vitamins/minerals, omega-3/omega-6 fatty acids, prebiotics, probiotics, multivitamins, supplements for anxiety/calming, supplements for digestion, supplements for immune boosting/antioxidants, supplements for skin/coat/nails, CBD oil, supplemental food, other supplements/vitamins, and the absence of supplements—and the weight status of subjects. Dog owners were asked to indicate all types of supplements their pets received. Dogs who did not receive supplements were less probable to be O/O ($P = 0.029$); though, the finding no longer reached significance after adjustment for multiple comparisons (adjusted p - values = 0.408). In contrast, the remaining predictors did not show significant associations with weight status, indicating no strong link between supplements and the weight classification of the dogs.

Comorbidities

Dog owners reported any health conditions their pets had been diagnosed with by a veterinarian, focusing on concerns of mobility, weight, skin/coat, digestion, aging, stress, oral health, bladder, cancer, and liver health. If an owner expressed any concern, they were directed to a more detailed health module for specific conditions (Appendix Figure B.2). Results from the mobility module indicated O/O dogs were shown to be diagnosed significantly more often with conditions such as hip dysplasia (adjusted $P = 0.003$), elbow dysplasia (adjusted $P < 0.001$), osteoarthritis or degenerative joint disease (adjusted $P = 0.042$), and other bone or joint issues (adjusted $P = 0.005$) than dogs without an O/O diagnosis. Dogs also had an increased chance of being diagnosed with diabetes (adjusted $P < 0.001$) and other weight-related concerns (adjusted $P < 0.001$).

In the dermatology module, O/O dogs were more frequently diagnosed with atopic dermatitis or atopy (adjusted $P < 0.001$), ear infections (adjusted $P < 0.001$), adverse reactions to food (adjusted $P = 0.001$), and other skin or coat issues (adjusted $P = 0.003$). However, there was no significant difference in diagnosis of acne (adjusted $P = 0.409$) when compared to dogs without an O/O diagnosis.

Regarding digestive health, O/O dogs were diagnosed more often with short-term diarrhea or dietary indiscretion (adjusted $P = 0.003$), chronic diarrhea with (adjusted $P = 0.022$) and without weight loss (adjusted $P = 0.012$), constipation or megacolon (adjusted $P = 0.018$), liver or bile duct disease (adjusted $P = 0.003$), and colitis (adjusted $P = 0.022$) when compared to dogs without an O/O diagnosis. There was no significant difference for irritable bowel syndrome (IBS) or inflammatory bowel disease (IBD) (adjusted $P = 0.185$) and other digestive issues (adjusted $p = 0.154$) between O/O dogs and dogs without an O/O diagnosis.

For the aging category, O/O dogs were shown to be diagnosed with cognitive dysfunction (adjusted $P < 0.001$) and other aging concerns (adjusted $P < 0.001$) more than their dogs without an O/O diagnosis counterpart. Stress-related conditions also varied significantly, with O/O dogs facing higher incidences of separation anxiety (adjusted $P = 0.032$), thunderstorm phobia (adjusted $P = 0.044$), aggression (adjusted $P = 0.014$), obsessive compulsive disorder (OCD) (adjusted $P = 0.031$), and compulsive over-grooming (adjusted $P = 0.008$) than dogs without an O/O diagnosis. No significant differences were found for noise phobia (adjusted $P = 0.095$) and other stress-related issues (adjusted $P = 0.527$) between O/O and dogs without an O/O diagnosis.

The oral health module revealed O/O dogs were more frequently diagnosed with plaque (adjusted $P = 0.015$), gingivitis (adjusted $P < 0.001$), periodontal disease (adjusted $P < 0.001$), and other teeth and mouth conditions (adjusted $P < 0.001$) than dogs without an O/O diagnosis. Within the urinary module, O/O dogs were more probable to be diagnosed with bladder stones (adjusted $P = 0.021$) compared to non-O/O diagnosis counterparts. However, no significant differences were observed for urinary tract infections (adjusted $P = 0.071$), bladder infections (adjusted $P = 0.066$), cancer of the bladder or kidneys (adjusted $P = 0.071$), urinary bladder inflammation (adjusted $P = 0.071$), chronic kidney disease (adjusted $P = 0.185$), kidney stones (adjusted $P = 0.146$), and related conditions between dogs without an O/O diagnosis and O/O dogs. In the cancer module, O/O dogs had higher diagnoses of leukemia (adjusted $P = 0.019$) when compared to dogs without an O/O diagnosis. There were no significant differences found for melanoma, mass cell tumor, hemangiosarcoma, lymphoma, sarcoma, carcinoma and other cancer-related conditions among O/O as compared to dogs without an O/O diagnosis.

Lastly, in the liver module no significant differences were noted for other liver-related conditions, including hepatitis, fibrosis, poisons affecting the liver, liver bacterial infection,

canine chronic hepatitis, leishmaniasis metastasis, cholangiohepatitis, cancers of the liver, liver failure, acute liver failure or chronic liver failure, gallbladder disease, chronic Hepatitis, liver metastasis of cancer, liver disease, triaditis, pancreatitis, gallstones, bile disorder, liver shunt, and urate bladder stones between O/O and dogs without an O/O diagnosis.

Owner Perceptions

Dog owners were surveyed to gather their perceptions of the activity level of their dogs. The study identified significant differences (adjusted $P < 0.001$), indicating dogs were more likely to be O/O than dogs without an O/O diagnosis across all activity level options: Very Active (Daily runs/High intensity activity), Active (Daily walks/Play time), Moderately Active (Occasional walks/activities), and Very Inactive (Minimal activity/Couch potato). However, the finding may not be relevant and is plausible due to a higher proportion of dogs in the study being categorized as O/O (Table 3.2).

The survey asked owners to evaluate the body condition of their dog with answer choices including much too skinny, a bit too skinny, just right, a bit heavy, and much too heavy. Owners of O/O dogs were significantly more probable to evaluate their dogs as “much too skinny,” with 82.0% ($n = 50$) doing so compared to 18.0% ($n = 11$) of owners of dogs without an O/O diagnosis, $\chi^2 (1, N = 61) = 47.34$, (adjusted $P < 0.001$). Conversely, 59.1% ($n = 62$) of owners of dogs without an O/O diagnosis were highly likely to evaluate their dogs as “a bit too skinny” compared to 41.0% ($n = 43$) of owners of O/O dogs, $\chi^2 (1, N = 105) = 6.17$, (adjusted $P = 0.013$). In addition, 56.1% ($n = 124$) of owners of dogs without an O/O diagnosis assessed their dogs as “just right,” compared to 43.9% ($n = 97$) of O/O dog owners, $\chi^2 (1, N = 221) = 6.12$, (adjusted $P = 0.013$). For options “a bit heavy,” $\chi^2 (1, N = 832) = 123.870$, ($P < 0.001$), and “much too

heavy,” $\chi^2 (1, N = 87) = 77.33$, (adjusted $P < 0.001$), owners of O/O dogs were more inclined to select a bit heavy or much to heavy descriptions than owners of dogs without an O/O diagnosis.

Owner Demographics

The study analyzed household demographics to compare owners of dogs with and without an O/O diagnosis. Significant differences in O/O prevalence were found among owner age groups. For ages 25-34, 65.2% of dogs were O/O compared to 34.9% without an O/O diagnosis ($\chi^2 = 23.05$, $P < 0.001$). In the 35-49 age group, 63.6% were O/O versus 36.4% without ($\chi^2 = 60.45$, $P < 0.001$). For ages 50-54, 58.7% were O/O compared to 41.3% without ($\chi^2 = 7.667$, $P = 0.010$). Among 55-69-year-olds, 58.1% were O/O against 41.9% without ($\chi^2 = 24.22$, $P < 0.001$). Lastly, in owners 70 or older, 58.8% were O/O versus 41.2% without an O/O diagnosis ($\chi^2 = 6.723$, $P = 0.013$).

The study also examined the employment status of owners. Owners who were recently unemployed or temporarily laid off due to the COVID-19 pandemic were less probable to have dogs without an O/O diagnosis at 40.0% ($n = 48$) compared to O/O dogs at 60.0% ($n = 72$ dogs), $\chi^2 (1, N = 120) = 8.82$, (adjusted $P = 0.007$). Owners employed full-time for an employer were significantly more probable to have O/O dogs at 60.9% ($n = 365$) than dogs without an O/O diagnosis at 39.1% ($n = 234$), $\chi^2 (1, N = 599) = 56.43$, (adjusted $P < 0.001$). Part-time employed owners were also significantly more probable to have O/O dogs, with 75.3% ($n = 55$) compared to 24.7% ($n = 18$) without an O/O diagnosis, $\chi^2 (1, N = 73) = 35.51$, (adjusted $P < 0.001$).

Owners who were permanently sick, disabled, or unable to work were less probable to have dogs without an O/O diagnosis at 37.5% ($n = 18$) compared to O/O dogs at 62.5% ($n = 30$), $\chi^2 (1, N = 48) = 5.04$, (adjusted $P = 0.050$). Retired owners were also less probable to have dogs without an O/O diagnosis, with 40.1% ($n = 112$) compared to O/O dogs at 59.9% ($n = 167$), $\chi^2 (1, N = 279)$

= 20.90, (adjusted $P < 0.001$). There was no significant difference for owners who were unemployed or laid off not due to COVID-19, self-employed, homemakers, full-time students, or owners who preferred not to answer (Appendix Figure B.3). When examining the owners' professions, no significant difference was found between O/O and dogs without an O/O diagnosis after adjusting for multiple comparisons. Dogs whose owners earned over \$45,000 per year were shown to be overweight or obese than dogs without an O/O diagnosis ($P < 0.05$; see Appendix Figure B.3).

Gender of owners did not seem to play a role in the probability of O/O in dogs, as both male and female owners were shown to have O/O dogs compared to dogs without an O/O diagnosis, (adjusted $P < 0.001$) (Appendix Figure B.3). The study examined the relationship between marital status of dog owners and the weight status of their dogs. Owners who were single and never married had a significantly higher likelihood of having O/O dogs at 64.4% ($n = 96$) compared to owners with dogs without an O/O diagnosis at 35.6% ($n = 53$), $\chi^2 (1, N = 149) = 23.68$, (adjusted $P < 0.001$). Similarly, married owners were more probable to have O/O dogs at 61.1% ($n = 547$) than dogs without an O/O diagnosis at 38.9% ($n = 348$), $\chi^2 (1, N = 895) = 87.61$, (adjusted $P < 0.001$). Divorced owners also showed a higher prevalence of O/O dogs at 60.2% ($n = 62$) compared to dogs without an O/O diagnosis at 39.8% ($n = 41$), $\chi^2 (1, N = 103) = 7.77$, (adjusted $P = 0.012$). No significant differences in dog weight status were observed among owners in a domestic partnership, separated, widowed, or owners who prefer not to answer. The study also examined the impact of having children under 18 in the household. Households with children were shown to have O/O dogs at 64.3% ($n = 303$) compared to dogs without an O/O diagnosis at 35.7% ($n = 168$), $\chi^2 (1, N = 471) = 76.25$, (adjusted $P < 0.001$). Similarly, in childless households, O/O dogs were more prevalent at 58.7% ($n = 485$) than dogs without an

O/O diagnosis at 41.3% ($n = 341$), $\chi^2 (1, N = 826) = 49.51$, (adjusted $P < 0.001$). No significant differences were found where respondents preferred not to disclose the presence of children.

Discussion

The study provides a comprehensive analysis of the weight status of dogs within a sizable sample, offering significant insights into factors associated with O/O in canines, including age group, sex, comorbidities, owner demographics, and owner perceptions. The survey found 60.7% of the dogs had a history of a vet diagnosis of being overweight and/or obese. The finding aligns with the 2022 APOP survey, which reported 59% of dogs in the U.S. were overweight status or obese (APOP, 2022). Adult and senior dogs were significantly more probable to be overweight or obese, largely consistent with findings by Bjørnvad et al. (2019), who noted an association between higher body condition scores and increased age in female dogs but not in males. However, the study observed higher rates of O/O diagnoses in both male and female adult and senior dogs than Bjørnvad et al. (2019). There was no significant difference in puppies between O/O and dogs without an O/O diagnosis.

Sex and reproductive status further elucidated discrepancies in weight status among dogs. Spayed females and neutered males exhibited a markedly higher prevalence of O/O, consistent with findings by Benka et al. (2023), which indicated spayed/neutered dogs were twice as probable to be overweight or obese. Interestingly, intact females were less probable to be O/O, suggesting the potential for hormonal influences on weight stability. There was no significant difference between O/O and dogs without an O/O diagnosis in intact male dogs.

The analysis of dietary influences revealed significant associations between feeding practices and weight status. Notably, dry food consumption was linked to a reduced prevalence

of O/O diagnosis, while home-cooked foods correlated positively with being overweight or obese. Results align with broader narratives in veterinary nutrition, indicating comprehensive dietary management is crucial in canine weight control. Commercial dry dog foods may allow pet owners to more effectively measure and feed the appropriate number of calories compared to homemade foods, in which caloric content may be more difficult for owners to calculate.

Results from the analyses of how supplement use relates to O/O status were mixed, with most showing no significant association with weight status, except for the absence of supplements, which was associated with reduced O/O risk. However, it was no longer significant after adjusting for multiple comparisons. In contrast to the findings of the study, Hoffman et al. (2022) observed a significant correlation between overweight dogs and an increased likelihood of supplement consumption. Most commercial dog foods are formulated to be complete and balanced, meeting the essential nutritional requirements for dogs. The study found that not providing dietary supplements was associated with a reduced prevalence of O/O in dogs, suggesting supplements may be unnecessary when a complete and balanced commercial food is consumed. Owners of overweight or obese dogs, which are more prone to health conditions, may also have an increased propensity to administer dietary supplements to their pets.

The study also explores the relationship between weight status and various health conditions. O/O dogs were at significantly increased risk to present with various mobility issues, dermatological conditions, digestive problems, stress-related disorders, and oral health complications. Results are largely similar to previous studies noted associations with osteoarthritis, hypothyroidism, diabetes mellitus, pancreatitis, ruptured cruciate ligament, neoplasia, and cancer (Frye et al., 2016; Lund et al., 2006; Marchi et al., 2022). Reported comorbidities underscore the risk associated with O/O status and emphasize the importance of

mitigating risk due to detrimental health effects. Further research is recommended to investigate effective communication strategies for veterinarians to convey the importance of maintaining an ideal weight to dog owners. Owner perceptions of body condition further highlight an educational gap, as discrepancies between perceived and actual weight status were evident, emphasizing the need for initiatives focused on accurate body condition assessment to improve weight management practices.

The study investigated the relationship between household demographics and the prevalence of O/O versus dogs without an O/O diagnosis. Significant associations were found between various demographic factors and dog weight status. Among age groups, owners over the age of 25 were shown to have significantly more O/O dogs. Employment status also influenced dog weight, with full-time and part-time employed owners having a higher likelihood of owning O/O dogs, while no significant difference was observed for owners unemployed not due to COVID-19 or in other specified categories. A notable finding was owners earning over \$45,000 annually tended to have O/O dogs more frequently than dogs without an O/O diagnosis. Gender did not significantly affect the likelihood of having O/O dogs; both male and female owners were more probable to have O/O animals ($P < 0.05$). Marital status revealed that single, married, and divorced owners were more probable to have O/O dogs, whereas no significant differences were found for other marital categories. The presence of children under 18 in the household further correlated with a higher likelihood of owning O/O dogs, highlighting the complex interplay of socioeconomic factors in dog obesity see (Appendix Figure B.3) for further details. Study insights suggest nuanced socio-economic and occupational influences on dog weight management practices, warranting further investigation. Further studies are recommended to

explore lifestyle factors, such as nutritional habits and exercise routines of dog owners, to determine if any correlations exist with the weight status of dogs.

Survey results provide insights into how dog owners perceive the body conditions of their dogs and highlight a significant discrepancy between perceived and actual weight classifications. Owners of O/O dogs were notably more probable to describe their dogs as "much too skinny," despite medical indicators of being overweight. Suggesting a potential lack of awareness or denial regarding the actual body condition of their dogs. Interestingly, owners of dogs without an O/O diagnosis tended to classify their dogs as "a bit too skinny" or "just right" more frequently, which may indicate a greater accuracy in assessing the weight status of their dogs. The preferences for descriptions "a bit heavy" and "much too heavy" among owners of O/O dogs point to some level of recognition of the weight issue. However, the overall findings underscore the need for comprehensive education efforts aimed at enhancing owner awareness about healthy body conditions in dogs. It is crucial to address both the misperceptions of dog owners unaware of obesity in their dogs and to encourage owners who recognize overweight status of dogs to understand the associated health risks. Emphasizing the importance of tailored educational strategies can effectively bridge the perception gap and promote healthier lifestyles for dogs.

The study has several limitations that should be considered when interpreting the results. One major limitation is the reliance on owner reports of veterinary diagnoses recollected from memory, without reviewing medical records. Owners were asked whether their dogs had ever been diagnosed with any health conditions. It is possible that some reported conditions had resolved, or new conditions may have developed since the last veterinary visit. If owners reported that their dogs had not been diagnosed with a weight condition, these dogs were categorized as dogs without an overweight or obese (O/O) diagnosis. However, dogs might have

been inaccurately categorized as having no O/O diagnosis even when they were, in fact, overweight or obese.

Potential misclassification could arise from various factors, including inadequate communication of weight-related issues by veterinarians to pet owners, omission of the diagnosis due to embarrassment or disagreement with the veterinarian's assessment, or owners failing to recall the diagnosis during the survey. These limitations underscore the necessity of interpreting the study results with the understanding that the data primarily reflects dogs formally diagnosed as O/O by veterinarians, rather than all dogs that might fall into the O/O category. Notably, the study findings align with the overweight/obese rates reported by the Association for Pet Obesity Prevention (APOP, 2022).

Furthermore, the study recognizes potential discrepancies between the actual weight status of the dogs and their classification based on veterinary input. There were instances where a dog may have been overweight or obese, but the veterinarian did not convey this information to the owner, or the owner did not recall the diagnosis at the time of the survey. Changes in a dog's weight status since their last veterinary visit might also have led to incorrect classification as dogs without an O/O diagnosis in the analysis. Some pet owners might have refrained from reporting a diagnosis of overweight or obesity due to feelings of embarrassment or disagreement with the assessment. These considerations highlight the need for caution when interpreting the data under these limitations. Additionally, geographic limitations are present as the survey was conducted exclusively in the United States. Consequently, the owner demographic data and animal husbandry practices identified may not be applicable to other countries.

In summary, the study highlights the complexity underlying canine obesity, influenced by hereditary, dietary, health, and owner-perceived factors. Emphasizing the necessity of early

diagnosis and intervention for overweight dogs to mitigate potential health risks. Veterinary guidance is needed to educate owners about obesity as a preventable disease through proper nutrition and lifestyle changes.

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Competing Interests

EH, JV, DH, RT, and SW are all current or former employees of Hill's Pet Nutrition, Inc

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Table 3.1 Demographics of Dogs Enrolled from U.S. and Canadian Households, Including Weight Status, Age, Sex, Intact Status, and Housing

	Non- Overweight/ Obese	Overweight/ Obese	χ^2 (1)	<i>adjusted P -value</i>
	n (%)	n (%)		
Weight Status				
	513 (39.3%)	793 (60.7%)	60.03	NA
Age Grouping (Years)				
Puppy < 1	2 (40.0%)	3 (60.0%)	NA	0.40
Adult 1 - < 7	242 (37.4%)	405 (62.6%)	41.07	<0.01
Senior 7 +	269 (41.1%)	385 (58.9%)	20.58	<0.01
Sex and Age				
Female Puppy	1 (100%)	0 (0%)	NA	0.01
Female Adult	119 (41.5%)	168 (58.5%)	8.37	0.01
Female Senior	149 (41.5%)	210 (58.5%)	10.37	0.00
Male Puppy	1 (25.0%)	3 (75.0%)	NA	1.00
Male Adult	123 (34.2%)	237 (65.8%)	36.10	<0.01
Male Senior	120 (40.7%)	175 (59.3%)	10.25	0.00
Intact Status				
Spayed Female	233 (39.5%)	357 (60.5%)	51.29	<0.01
Intact Female	29 (69.0%)	13 (31.0%)	NA	0.00
Unknown Female	7 (46.7%)	8 (53.3%)	NA	1.00
Neutered Male	209 (35.3%)	383 (64.7%)	101.11	<0.01
Intact Male	31 (53.4%)	27 (46.6%)	NA	0.87
Unknown Male	4 (44.4%)	5 (55.6%)	NA	1.00
Housing Status				
Indoor Only	67 (32.7%)	138 (67.3%)	24.59	<0.01
Mostly Indoor	293 (38.8%)	463 (61.2%)	38.23	<0.01
Indoor/ Outdoor	137 (43.6%)	177 (56.4%)	5.10	0.03
Outdoor Only	16 (51.6%)	15 (48.4%)	0.03	0.86

Table 3.2 Owner Perception of Activity Level and Weight Status of Dogs Enrolled from U.S. and Canadian Households

	Non- Overweight/ Obese	Overweight/ Obese		<i>adjusted P -value</i>
	n (%)	n (%)	χ^2 (1)	
Owner Reported Dog Activity Level				
Very Active (Daily runs/High intensity activity)	63 (35.2%)	116 (64.8%)	30.21	<0.01
Active (Daily walks/Play time)	182 (42.2%)	249 (57.8%)	20.21	<0.01
Moderately Active (Occasional walks/activities)	171 (38.7%)	271 (61.3%)	44.35	<0.01
Inactive (Infrequent walks/Activities)	61 (39.4%)	94 (60.7%)	13.21	<0.01
Very Inactive (Minimal activity/Couch potato)	36 (36.4%)	63 (63.6%)	13.66	<0.01
Owner Reported Dog Weight Perception				
Much too skinny	11 (18.0%)	50 (82.0%)	47.34	<0.01
A bit too skinny	62 (59.1%)	43 (41.0%)	6.17	0.01
Just right	124 (56.1%)	97 (43.9%)	6.12	0.01
A bit heavy	302 (36.3%)	530 (63.7%)	123.87	<0.01
Much too heavy	14 (16.1%)	73 (83.9%)	77.33	<0.01

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Appendix A - 1000 Dog

Medication, supplements, and food

Appendix Figure A.1 Medication, supplements, and food consumed by dogs included in analyzed population of healthy senior dogs

	Underweight	Ideal Weight	Overweight/Obese	Underweight vs. Ideal weight Dogs		Overweight/obese vs. Ideal weight Dogs	
	n (%)	n (%)	n (%)	χ^2 (1)	adjusted P-value	χ^2 (1)	adjusted P-value
Medication reported							
Received Medication	29 (85.3%)	166 (75.8%)	189 (81.5%)	1.00	0.38	1.00	0.28
Medication Class							
Antibiotic	1 (2.9%)	28 (12.8%)	24 (10.3%)	NA	0.29	1.00	0.58
Dietary Supplement	11 (32.4%)	36 (16.4%)	40 (17.2%)	1.00	0.07	1.00	0.95
Non-steroid anti-inflammatory	1 (2.9%)	11 (5.0%)	13 (5.6%)	NA	1.00	1.00	0.93
Parasiticide (including heartworm)	28 (82.4%)	139 (63.5%)	166 (71.6%)	1.00	0.08	1.00	0.15
Steroid	1 (2.9%)	8 (3.7%)	8 (3.5%)	NA	1.00	NA	1.00
Thyroid Medication	0 (0.0%)	0 (0.0%)	0 (0.0%)	NA	NA	NA	NA
Vaccine	7 (20.6%)	46 (21.0%)	64 (27.6%)	1.00	1.00	1.00	0.22
Other	7 (20.6%)	38 (17.4%)	32 (13.8%)	1.00	0.83	1.00	0.46
Other Medications							
Allergy Medications	3 (8.8%)	6 (2.7%)	3 (1.3%)	NA	0.22	NA	0.48
Antacid	0 (0.0%)	4 (1.8%)	1 (0.4%)	NA	1.00	NA	0.36
Anxiety Medications	0 (0.0%)	3 (1.4%)	2 (0.9%)	NA	1.00	NA	0.86

Antiemetic	0 (0.0%)	2 (0.9%)	2 (0.9%)	NA	1.00	NA	1.00
Antiepileptic	0 (0.0%)	1 (0.5%)	4 (1.7%)	NA	1.00	NA	0.53
Antifungal	1 (2.9%)	10 (4.6%)	9 (3.9%)	NA	1.00	1.00	0.88
Antihistamine	3 (8.8%)	5 (2.3%)	3 (1.3%)	NA	0.17	NA	0.67
Dietary Supplements							
Any Dietary Supplement	11 (32.4%)	36 (16.4%)	40 (17.2%)	1.00	0.07	1.00	0.95
Dietary Supplements (nutritional benefit)	7 (20.6%)	22 (10.0%)	25 (10.8%)	NA	0.19	NA	0.94
Dietary Supplements (no nutritional benefit)	6 (17.7%)	22 (10.0%)	27 (11.6%)	NA	0.40	NA	0.78
Dietary Supplements							
Essential Fatty Acid	4 (11.8%)	18 (8.2%)	21 (9.0%)	NA	0.69	1.00	0.91
Mineral	3 (8.8%)	10 (4.6%)	5 (2.2%)	NA	0.55	1.00	0.30
Vitamin	5 (14.7%)	12 (5.5%)	13 (5.6%)	NA	0.14	1.00	1.00
Other	7 (20.6%)	26 (11.9%)	25 (10.8%)	NA	0.32	1.00	0.88
Other Supplements							
Probiotic	0 (0.0%)	7 (3.2%)	10 (4.3%)	NA	0.79	1.00	0.72
Prebiotic	0 (0.0%)	0 (0.0%)	1 (0.4%)	NA	-	NA	1.00
Herbal	4 (11.8%)	11 (5.0%)	10 (4.3%)	NA	0.26	1.00	0.88
CBD	0 (0.0%)	1 (0.5%)	0 (0.0%)	NA	1.00	NA	0.66
Glucosamine	7 (20.6%)	20 (9.1%)	21 (9.0%)	NA	0.15	1.00	1.00

Chondroitin	7 (20.6%)	10 (4.6%)	12 (5.2%)	NA	0.01	1.00	0.91
Unspecified	1 (2.9%)	15 (6.9%)	13 (5.6%)	NA	0.88	1.00	0.78
Food Classifications							
Therapeutic	5 (14.7%)	13 (5.9%)	13 (5.6%)	NA	0.29	NA	1.00
Wellness	29 (85.3%)	203 (92.7%)	215 (92.7%)	NA	0.48	NA	1.00
Adult	27 (79.4%)	192 (87.7%)	203 (87.5%)	NA	0.50	NA	1.00
All Life Stage	2 (5.9%)	11 (5.0%)	13 (5.6%)	NA	1.00	NA	1.00
Puppy	0 (0.0%)	1 (0.5%)	2 (0.9%)	NA	1.00	NA	1.00
Senior	4 (11.8%)	14 (6.4%)	14 (6.0%)	NA	0.63	NA	1.00
Popular	19 (55.9%)	130 (59.4%)	152 (65.5%)	NA	1.00	NA	0.48
Premium	13 (38.2%)	103 (47.0%)	95 (41.0%)	NA	0.71	NA	0.51
High Protein	0 (0.0%)	13 (5.9%)	17 (7.3%)	NA	0.57	NA	0.92
Traditional Protein	32 (94.1%)	198 (90.4%)	209 (90.1%)	NA	1.00	NA	1.00
Grain Free	32 (94.1%)	209 (95.4%)	222 (95.7%)	NA	1.00	NA	1.00
Traditional Grain	0 (0.0%)	4 (1.8%)	0 (0.0%)	NA	1.00	NA	0.24

Free-Fed Dogs: Underweight and Ideal Weight

Appendix Figure A.2 Demographics of free feed underweight and ideal weight dogs included in analyzed population of healthy senior dogs

Breed	n (% of free fed population)
AMERICAN PIT BULL TERRIER	1 (5.3%)
AMERICAN STAFFORDSHIRE TERRIER	1 (5.3%)
BEAGLE	1 (5.3%)
BERNESE MOUNTAIN DOG	1 (5.3%)
BICHON FRISE	2 (10.5%)
GERMAN SHEPHERD DOG	1 (5.3%)
GERMAN SHORTHAIRED POINTER	2 (10.5%)
LABRADOR RETRIEVER	1 (5.3%)
MALTESE	3 (15.8%)
MINIATURE PINSCHER	1 (5.3%)
MINIATURE POODLE	1 (5.3%)
RAT TERRIER	1 (5.3%)
SHIH TZU	1 (5.3%)
TOY POODLE	1 (5.3%)
YORKSHIRE TERRIER	1 (5.3%)
Giant	n (% of free fed population)
Yes	1 (5.3%)
No	18 (94.7%)
Sex and Intact Status	n (% of free fed population)
Female Intact	0 (0.0%)
Female Spayed	7 (36.8%)
Male Intact	1 (5.3%)
Male Neutered	11 (57.9%)
AKC 2020 Grouping	n (% of free fed population)
Herding	1 (5.3%)
Hound	1 (5.3%)
n/a	1 (5.3%)
Non-Sporting	2 (10.5%)
Sporting	3 (15.8%)

Terrier	2 (10.5%)
Toy	8 (42.1%)
Working	1 (5.3%)
Age	Age (SD)
Average Age (Years)	9.88 (2.46)
Weight Categories	n (% of free fed population)
Small ≤ 25 lbs.	12 (63.2%)
Medium > 25 lbs. - < 55 lbs.	1 (5.3%)
Large ≥ 55 lbs. - < 110 lbs.	6 (31.6%)
Giant ≥ 110 lbs.	0 (0.0%)
Food Type	n (average % of total daily intake)
Dry Food	98.10%
Wet Food	0.00%
People Food	0.90%
Treats	1.20%
Other	0.00%

Appendix B - Geo Study

Breeds

Appendix Figure B.1. Breeds of Dogs Enrolled from U.S. and Canadian Households

Breed	Non- Overweight/ Obese	Overweight/ Obese	χ^2 (1)	<i>adjusted P -value</i>
	n (%)	n (%)		
Mixed Breed	165 (33.7%)	325 (66.3%)	52.25	<0.01
Purebred	348 (42.6%)	468 (57.4%)	17.65	<0.01
Australian Shepherd	10 (28.6%)	25 (71.4%)	NA	0.00
Basset Hound	1 (14.3%)	6 (85.7%)	NA	<0.01
Beagle	13 (39.4%)	20 (60.6%)	NA	0.86
Bernese Mountain Dog	1 (16.7%)	5 (83.3%)	NA	0.01
Border Collies	5 (41.7%)	7 (58.3%)	NA	0.39
Boston Terrier	5 (71.4%)	2 (28.6%)	NA	0.55
Boxer	7 (50.0%)	7 (50.0%)	NA	0.37
Brittany Spaniel	0 (0.0%)	1 (100.0%)	NA	0.21
Bulldog	8 (34.8%)	15 (65.2%)	NA	0.27
Cane Corso	0 (0.0%)	1 (100.0%)	NA	0.55
Cavalier King Charles Spaniel	4 (36.4%)	7 (63.6%)	NA	0.97
Chihuahua	36 (40.0%)	54 (60.0%)	NA	0.98
Cocker Spaniel	4 (33.3%)	8 (66.7%)	NA	0.48
Collie	3 (100%)	0 (0.0%)	NA	1.00
Dachshund	19 (33.3%)	38 (66.7%)	NA	0.27
Doberman Pinscher	3 (60.0%)	2 (40.0%)	NA	0.48

English Spaniel	3 (33.3%)	6 (66.7%)	NA	0.19
French Bulldog	2 (28.6%)	5 (71.4%)	NA	0.73
German Shepherd	18 (58.1%)	13 (41.9%)	NA	1.00
German Shorthair Pointer	1 (33.3%)	2 (66.7%)	NA	0.05
Golden Retriever	14 (45.2%)	17 (54.8%)	NA	0.48
Great Dane	0 (0.0%)	2 (100.0%)	NA	0.64
Havanese	5 (55.6%)	4 (44.4%)	NA	1.00
Labrador Retriever	33 (40.7%)	48 (59.3%)	NA	0.73
Maltese	3 (50.0%)	3 (50.0%)	NA	0.71
Mastiff	5 (62.5%)	3 (37.5%)	NA	0.73
Miniature American Shepherd	0 (0.0%)	2 (100.0%)	NA	0.86
Miniature Schnauzer	1 (100.0%)	0 (0.0%)	NA	1.00
Newfoundland	0 (0.0%)	0 (0.0%)	NA	0.62
Pembroke Welsh Corgi	5 (38.5%)	8 (61.5%)	NA	0.86
Pomeranian	4 (30.8%)	9 (69.2%)	NA	0.75
Poodle	6 (75.0%)	2 (25.0%)	NA	0.86
Pug	4 (17.4%)	19 (82.6%)	NA	0.16
Rottweiler	6 (42.9%)	8 (57.1%)	NA	0.19
Shetland Sheepdog	5 (50.0%)	5 (50.0%)	NA	0.64
Shih Tzu	15 (55.6%)	12 (44.4%)	NA	1.00
Siberian Husky	3 (30.0%)	7 (70.0%)	NA	0.25
Vizsla	0 (0.0%)	2 (100.0%)	NA	0.91
Weimaraner	0 (0.0%)	3 (100.0%)	NA	0.21
Yorkshire Terrier	11 (61.1%)	7 (38.9%)	NA	0.91

Other	88 (50.3%)	87 (49.7%)	NA	0.07
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Medical Conditions

Appendix Figure B.2. Medical Conditions of Dogs Enrolled from U.S. and Canadian Households

	Non- Overweight/ Obese	Overweight/ Obese	<i>adjusted P - value</i>
	n (%)	n (%)	
Mobility			
Hip dysplasia	9 (16.1%)	47 (83.9%)	0.00
Elbow dysplasia	1 (2.8%)	35 (97.2%)	<0.01
Osteoarthritis / degenerative joint disease	19 (24.1%)	60 (75.9%)	0.04
Other mobility (bone & joint) issue(s)	22 (22.2%)	77 (77.8%)	0.01
Don't know / not sure	9 (42.9%)	12 (57.1%)	0.48
None	88 (46.1%)	103 (53.9%)	<0.01
Weight			
Diabetes	0 (0.0%)	41 (100.0%)	<0.01
Other weight issue(s)	0 (0.0%)	17 (100.0%)	<0.01
Dermatology			
Acne	5 (22.7%)	17 (77.3%)	0.41
Atopic dermatitis / atopy	4 (8.0%)	46 (92.0%)	<0.01
Ear infection	14 (15.6%)	76 (84.4%)	<0.01
Adverse reaction to food, food sensitivity, food intolerance or food allergy	9 (15.5%)	49 (84.5%)	0.00
Other skin or coat issue	12 (18.2%)	54 (81.8%)	0.00
Don't know / not sure	3 (30.0%)	7 (70.0%)	1.00
None	65 (55.6%)	52 (44.4%)	<0.01
Digestive			
Short term diarrhea / dietary indiscretion	3 (11.5%)	23 (88.5%)	0.00
Chronic diarrhea with weight loss	3 (15.0%)	17 (85.0%)	0.02
Chronic diarrhea without weight loss	1 (6.7%)	14 (93.3%)	0.01

Constipation / obstipation / megacolon	3 (14.3%)	18 (85.7%)	0.02
Pancreatic insufficiency / pancreatitis	5 (23.8%)	16 (76.2%)	0.14
Liver or bile duct disease	0 (0.0%)	13 (100.0%)	0.00
Colitis	3 (15.0%)	17 (85%)	0.02
Irritable Bowel Syndrome (IBS)/ Inflammatory Bowel Disease (IBD)	6 (26.1%)	17 (73.9%)	0.19
Other digestion issue(s)	2 (18.2%)	9 (81.8%)	0.15
Don't know / not sure	4 (50.0%)	4 (50.0%)	0.72
None	45 (60.8%)	29 (39.2%)	<0.01
Aging			
Cognitive dysfunction	4 (9.8%)	37 (90.2%)	<0.01
Other aging issue	12 (19.7%)	49 (80.3%)	<0.01
Don't know / not sure	5 (33.3%)	10 (66.7%)	0.79
None	96 (50.8%)	93 (49.2%)	<0.01
Stress			
Separation anxiety	16 (23.2%)	53 (76.8%)	0.03
Thunderstorm phobia	18 (24.3%)	56 (75.7%)	0.04
Noise phobia	9 (22.5%)	31 (77.5%)	0.10
Aggression	4 (12.5%)	28 (87.5%)	0.01
Obsessive compulsive disorder (OCD)	3 (12.0%)	22 (88.0%)	0.03
Compulsive or over-grooming	2 (7.7%)	24 (92.3%)	0.01
Other stress issue(s)	11 (40.7%)	16 (59.2%)	0.53
Don't know / not sure	2 (22.2%)	7 (77.87%)	0.53
None	46 (51.7%)	43 (48.3%)	<0.01
Oral			
Plaque	42 (29.6%)	100 (70.4%)	0.02
Gingivitis	13 (19.4%)	54 (80.6%)	<0.01
Periodontal disease	11 (16.7%)	55 (83.3%)	<0.01
Other teeth and mouth issue(s)	8 (15.4%)	44 (84.6%)	<0.01
Don't know / not sure	7 (35.0%)	13 (65.0%)	1.00
None	64 (56.6%)	49 (43.4%)	<0.01
Urinary			

Chronic kidney (renal) disease	2 (14.3%)	12 (85.7%)	0.19
Urinary tract infection	4 (15.4%)	22 (84.6%)	0.07
Kidney (renal) stones	1 (9.1%)	10 (90.9%)	0.15
Bladder stones	1 (5.3%)	18 (94.7%)	0.02
Bladder infections	3 (12.5%)	21 (87.5%)	0.07
Kidney disease/ chronic kidney disease	1 (7.7%)	12 (92.3%)	0.10
Urethral obstruction or "blocked"	2 (16.7%)	10 (83.3%)	0.40
Cancer of the bladder or kidneys	0 (0.0%)	9 (100.0%)	0.07
Inflammation in the urinary bladder	2 (11.1%)	16 (88.9%)	0.07
Other bladder/urinary issue	1 (14.3%)	6 (85.7%)	0.42
Don't know / not sure	3 (50.0%)	3 (50.0%)	0.42
None	31 (55.4%)	25 (44.6%)	<0.01
Cancer			
Mast Cell Tumor	1 (5.6%)	17 (94.4%)	0.06
Melanoma	1 (7.1%)	13 (92.9%)	0.16
Lymphoma	2 (14.3%)	12 (85.7%)	0.39
Leukemia	0 (0.0%)	16 (100.0%)	0.02
Bone Cancer /Osteosarcoma	1 (10.0%)	9 (90.0%)	0.40
Hemangiosarcoma	0 (0.0%)	10 (100.0%)	0.12
Mammary gland carcinoma	1 (16.7%)	5 (83.3%)	0.76
Non- Cancerous Tumors (Ex. lipoma)	6 (23.1%)	20 (76.9%)	0.61
Hypercalcemia	0 (0.0%)	6 (100.0%)	0.35
Bone Cancer /Osteosarcoma	1 (10.0%)	9 (90.0%)	0.40
Vaccine related sarcoma	0 (0.0%)	8 (100.0%)	0.23
Other sarcoma	0 (0.0%)	9 (100.0%)	0.16
Carcinoma	1 (16.7%)	5 (83.3%)	0.76
A mass	4 (23.5%)	13 (76.5%)	0.82
Don't know / not sure	1 (25.0%)	3 (75.0%)	1.00
None	16 (55.2%)	13 (44.8%)	0.01
Liver			
Hepatitis	0 (0.0%)	12 (100.0%)	0.22
Fibrosis	0 (0.0%)	14 (100.0%)	0.17
Poisons affecting the liver	1 (7.7%)	12 (92.3%)	0.33

Liver bacterial infection	1 (11.1%)	8 (88.9%)	0.48
Canine Chronic Hepatitis	1 (14.3%)	6 (85.7%)	0.71
Leishmaniasis metastasis	1 (11.1%)	8 (88.9%)	0.48
Cholangiohepatitis	1 (9.1%)	10 (90.9%)	0.34
Cancers of the liver	1 (16.7%)	5 (83.3%)	1.00
Liver failure, acute liver failure or chronic liver failure	0 (0.0%)	8 (100.0%)	0.33
Gallbladder disease	1 (9.1%)	10 (90.9%)	0.34
Chronic Hepatitis	1 (7.7%)	12 (92.3%)	0.33
Liver metastasis of cancer	0 (0.0%)	9 (100.0%)	0.27
Liver disease	1 (9.1%)	10 (90.9%)	0.34
Triaditis	0 (0.0%)	7 (100.0%)	0.33
Pancreatitis	1 (9.1%)	10 (90.9%)	0.34
Gallstones	0 (0.0%)	9 (100.0%)	0.27
Bile disorder	0 (0.0%)	9 (100.0%)	0.27
Liver shunt	0 (0.0%)	9 (100.0%)	0.27
Urate bladder stones	0 (0.0%)	9 (100.0%)	0.27
Don't know / not sure	2 (50.0%)	2 (50.0%)	0.34
None	13 (61.9%)	8 (38.1%)	<0.01

Owner Demographics

Appendix Figure B.3 Owner Demographics of Dogs Enrolled from U.S. and Canadian Households, Including Age, Profession, Employment Status, Income, Marital Status, Gender, Children in Household, and Number of Cats and Dogs

	Non-Overweight/ Obese	Overweight/ Obese	χ^2 (1)	<i>adjusted P-value</i>
Owner Age	n (%)	n (%)		
18-24 years	9 (45.0%)	11 (55.0%)	NA	0.75
25-34 years	46 (34.9%)	86 (65.2%)	23.05	<0.01
35-49 years	151 (36.4%)	264 (63.6%)	60.45	<0.01
50-54 years	57 (41.3%)	81 (58.7%)	7.67	0.01
55-69 years	200 (41.9%)	277 (58.1%)	24.22	<0.01

70 or over	49 (41.2%)	70 (58.8%)	6.72	0.01
Prefer not to answer	1 (20.0%)	4 (80.0%)	NA	0.24
Profession				
An advertising agency or public relations firm	2 (0.2%)	11 (0.8%)	NA	0.20
Veterinarian, Veterinarian Clinic or Animal Hospital	7 (0.5%)	15 (1.2%)	NA	0.74
A marketing or market research company	1 (0.1%)	11 (0.8%)	NA	0.20
Work for a company that manufactures, distributes, or sells small animal pharmaceuticals (including food)	5 (0.4%)	11 (0.8%)	NA	0.77
Work for a company that manufactures, distributes, or sells small animal over-the-counter products (including food)	8 (0.6%)	14 (1.1%)	NA	0.83
A company that designs, manufactures, distributes or sells children's clothes	3 (0.2%)	10 (0.8%)	NA	0.45
A television, radio, magazine, or newspaper company	1 (0.1%)	9 (0.7%)	NA	0.20
Work for a restaurant or a distributor of food and beverage products	18 (1.7%)	31 (2.4%)	NA	0.83
Work in construction or commercial real estate	10 (0.8%)	31 (2.4%)	NA	0.20
None of these	471 (36.1%)	703 (53.8%)	NA	0.20
Employment Status				
Recently unemployed or temporarily laid off due to the Coronavirus (COVID-19) pandemic	48 (40.0%)	72 (60.0%)	8.82	0.01
Unemployed or laid off, but NOT due to the Coronavirus (COVID-19) pandemic	6 (35.3%)	11 (64.7%)	NA	0.21
Self-employed	44 (48.4%)	47 (51.7%)	0.09	0.85
Work full-time for an employer	234 (39.1%)	365 (60.9%)	56.43	<0.01
Work part-time for an employer	18 (24.7%)	55 (75.3%)	35.51	<0.01
Homemaker	25 (42.4%)	34 (57.6%)	2.17	0.20
Full-time student	4 (30.8%)	9 (69.2%)	NA	0.19
Permanently sick, disabled, or unable to work	18 (37.5%)	30 (62.5%)	5.04	0.05
Retired	112 (40.1%)	167 (59.9%)	20.90	<0.01
Prefer not to answer	4 (57.1%)	3 (42.9%)	NA	1.00
Income				

Under \$25,000	26 (41.3%)	37 (58.7%)	3.18	0.12
\$25,000 to under \$30,000	22 (48.9%)	23 (51.1%)	0.00	1.00
\$30,000 to under \$35,000	20 (46.5%)	23 (53.5%)	0.19	0.73
\$35,000 to under \$40,000	16 (41.0%)	23 (59.0%)	1.85	0.24
\$40,000 to under \$45,000	19 (43.2%)	25 (56.8%)	1.14	0.35
\$45,000 to under \$60,000	64 (41.0%)	92 (59.0%)	9.35	0.01
\$60,000 to under \$75,000	44 (32.4%)	92 (67.7%)	32.49	<0.01
\$75,000 to under \$100,000	89 (40.3%)	132 (59.7%)	15.96	<0.01
\$100,000 to under \$150,000	118 (38.2%)	191 (61.8%)	33.55	<0.01
\$150,000 or more	57 (36.3%)	100 (63.7%)	22.47	<0.01
Prefer not to answer	38 (40.9%)	55 (59.1%)	5.51	0.04
Marital Status				
Single, never married	53 (35.6%)	96 (64.4%)	23.68	<0.01
Living in a domestic partnership	37 (44.1%)	47 (56.0%)	1.93	0.23
Married	348 (38.9%)	547 (61.1%)	87.61	<0.01
Separated	9 (56.3%)	7 (43.8%)	NA	0.72
Divorced	41 (39.8%)	62 (60.2%)	7.77	0.01
Widowed	22 (45.8%)	26 (54.2%)	0.38	0.63
Prefer not to answer	3 (27.3%)	8 (72.7%)	NA	0.15
Gender				
Male	191 (38.3%)	308 (61.7%)	53.93	<0.01
Female	318 (39.8%)	481 (60.2%)	65.69	<0.01
Non-binary	1 (50.0%)	1 (50.0%)	NA	1.00
Prefer not to answer	3 (50.0%)	3 (50.0%)	NA	1.00
Children under 18 years living in the household				
Yes	168 (35.7%)	303 (64.3%)	76.25	<0.01
No	341 (41.3%)	485 (58.7%)	49.51	<0.01
Prefer not to answer	4 (44.4%)	5 (55.6%)	NA	1.00
Number of Dogs				
1	244 (39.6%)	373 (60.5%)	53.11	<0.01
2	184 (38.7%)	292 (61.3%)	48.11	<0.01
3	63 (37.1%)	107 (62.9%)	21.75	<0.01
4	22 (51.2%)	21 (48.8%)	0.00	1.00

Number of Cats					
1	298 (37.5%)	497 (62.5%)	98.63	<0.01	
2	141 (40.4%)	208 (59.6%)	24.96	<0.01	
3	54 (45.4%)	65 (54.6%)	1.68	0.26	
4	20 (46.5%)	23 (53.5%)	0.19	0.67	

Geographical Areas

Appendix Figure B.4 Geographical Area of Dogs Enrolled from U.S. and Canadian Households

Geographical Area (Metropolitan Statistical Area)	Non- Overweight/ Obese	Overweight/ Obese
	n (%)	n (%)
New York-Newark-Jersey City, NY-NJ-PA	10 (0.8%)	25 (0.2%)
Los Angeles-Long Beach-Anaheim, CA	6 (0.5%)	9 (0.7%)
Chicago-Naperville-Elgin, IL-IN-WI	5 (0.4%)	16 (1.2%)
Dallas-Fort Worth-Arlington, TX	8 (0.6%)	11 (0.8%)
Houston-The Woodlands-Sugar Land, TX	11 (0.8%)	8 (0.6%)
Washington-Arlington-Alexandria, DC-VA-MD-WV	1 (0.8%)	10 (0.8%)
Miami-Fort Lauderdale-West Palm Beach, FL	5 (0.4%)	7 (0.5%)
Philadelphia-Camden-Wilmington, PA-NJ-DE-MD	2 (0.2%)	7 (0.5%)
Atlanta-Sandy Springs-Roswell, GA	3 (0.2%)	10 (0.8%)
Boston-Cambridge-Newton, MA-NH	3 (0.2%)	5 (0.4%)
Phoenix-Mesa-Scottsdale, AZ	9 (0.7%)	10 (0.8%)
San Francisco-Oakland-Hayward, CA	8 (0.6%)	10 (0.8%)
Riverside-San Bernardino-Ontario, CA	8 (0.6%)	13 (1.0%)
Detroit-Warren-Dearborn, MI	3 (0.2%)	7 (0.5%)
Seattle-Tacoma-Bellevue, WA	8 (0.6%)	15 (1.1%)
Minneapolis-St. Paul-Bloomington, MN-WI	2 (0.2%)	8 (0.6%)
San Diego-Carlsbad, CA	5 (0.4%)	10 (0.8%)
Tampa-St. Petersburg-Clearwater, FL	5 (0.4%)	14 (1.1%)
Denver-Aurora-Lakewood, CO	5 (0.4%)	13 (1.0%)
St. Louis, MO-IL	7 (0.5%)	15 (1.1%)

Baltimore-Columbia-Towson, MD	10 (0.8%)	9 (0.7%)
Orlando-Kissimmee-Sanford, FL	5 (0.4%)	19 (1.5%)
Charlotte-Concord-Gastonia, NC-SC	9 (0.7%)	15 (1.1%)
San Antonio-New Braunfels, TX	4 (0.3%)	8 (0.6%)
Portland-Vancouver-Hillsboro, OR-WA	5 (0.4%)	11 (0.8%)
Sacramento--Roseville--Arden-Arcade, CA	15 (1.1%)	15 (1.1%)
Pittsburgh, PA	4 (0.3%)	10 (0.8%)
Las Vegas-Henderson-Paradise, NV	3 (0.2%)	15 (1.1%)
Cincinnati, OH-KY-IN	6 (0.5%)	11 (0.8%)
Austin-Round Rock, TX	11 (0.8%)	4 (0.3%)
Kansas City, MO-KS	6 (0.5%)	6 (0.5%)
Columbus, OH	5 (0.4%)	9 (0.7%)
Cleveland-Elyria, OH	7 (0.5%)	15 (1.1%)
Indianapolis-Carmel-Anderson, IN	8 (0.6%)	9 (0.7%)
San Jose-Sunnyvale-Santa Clara, CA	2 (0.2%)	8 (0.6%)
Nashville-Davidson--Murfreesboro--Franklin, TN	5 (0.4%)	7 (0.5%)
Virginia Beach-Norfolk-Newport News, VA-NC	8 (0.6%)	4 (0.3%)
Providence-Warwick, RI-MA	6 (0.5%)	2 (0.2%)
Milwaukee-Waukesha-West Allis, WI	3 (0.2%)	5 (0.4%)
Jacksonville, FL	9 (0.7%)	14 (1.1%)
Oklahoma City, OK	7 (0.5%)	8 (0.6%)
Raleigh, NC	8 (0.6%)	7 (0.5%)
Memphis, TN-MS-AR	3 (0.2%)	3 (0.2%)
Richmond, VA	4 (0.3%)	4 (0.3%)
Louisville/Jefferson County, KY-IN	4 (0.3%)	4 (0.3%)
New Orleans-Metairie, LA	2 (0.2%)	7 (0.5%)
Salt Lake City, UT	4 (0.3%)	5 (0.4%)
Hartford-West Hartford-East Hartford, CT	3 (0.2%)	6 (0.5%)
Birmingham-Hoover, AL	5 (0.4%)	4 (0.3%)
Buffalo-Cheektowaga-Niagara Falls, NY	2 (0.2%)	11 (0.8%)
Rochester, NY	6 (0.5%)	5 (0.4%)
Grand Rapids-Wyoming, MI	1 (0.8%)	3 (0.2%)
Tucson, AZ	5 (0.4%)	5 (0.4%)
Fresno, CA	3 (0.2%)	7 (0.5%)

Tulsa, OK	5 (0.4%)	8 (0.6%)
Urban Honolulu, HI	3 (0.2%)	3 (0.2%)
Worcester, MA-CT	4 (0.3%)	4 (0.3%)
Bridgeport-Stamford-Norwalk, CT	0 (0.0%)	4 (0.3%)
Omaha-Council Bluffs, NE-IA	4 (0.3%)	3 (0.2%)
Albuquerque, NM	3 (0.2%)	6 (0.5%)
Greenville-Anderson-Mauldin, SC	0 (0.0%)	2 (0.2%)
Bakersfield, CA	3 (0.2%)	5 (0.4%)
Knoxville, TN	3 (0.2%)	4 (0.3%)
Albany-Schenectady-Troy, NY	4 (0.3%)	4 (0.3%)
New Haven-Milford, CT	3 (0.2%)	6 (0.5%)
Oxnard-Thousand Oaks-Ventura, CA	3 (0.2%)	3 (0.2%)
El Paso, TX	2 (0.2%)	4 (0.3%)
Allentown-Bethlehem-Easton, PA-NJ	7 (0.5%)	5 (0.4%)
Columbia, SC	1 (0.8%)	3 (0.2%)
Baton Rouge, LA	0 (0.0%)	2 (0.2%)
North Port-Sarasota-Bradenton, FL	6 (0.5%)	5 (0.4%)
Charleston-North Charleston, SC	4 (0.3%)	3 (0.2%)
Greensboro-High Point, NC	2 (0.2%)	1 (0.8%)
Cape Coral-Fort Myers, FL	2 (0.2%)	5 (0.4%)
Stockton-Lodi, CA	4 (0.3%)	6 (0.5%)
Little Rock-North Little Rock-Conway, AR	4 (0.3%)	4 (0.3%)
Colorado Springs, CO	4 (0.3%)	5 (0.4%)
Boise City, ID	5 (0.4%)	7 (0.5%)
Lakeland-Winter Haven, FL	2 (0.2%)	3 (0.2%)
Akron, OH	2 (0.2%)	2 (0.2%)
Poughkeepsie-Newburgh-Middletown, NY	3 (0.2%)	4 (0.3%)
Ogden-Clearfield, UT	2 (0.2%)	0 (0.0%)
Winston-Salem, NC	0 (0.0%)	2 (0.2%)
Madison, WI	0 (0.0%)	3 (0.2%)
Deltona-Daytona Beach-Ormond Beach, FL	4 (0.3%)	3 (0.2%)
Des Moines-West Des Moines, IA	0 (0.0%)	1 (0.8%)
Syracuse, NY	2 (0.2%)	4 (0.3%)
Wichita, KS	0 (0.0%)	2 (0.2%)

Provo-Orem, UT	0 (0.0%)	1 (0.8%)
Springfield, MA	2 (0.2%)	5 (0.4%)
Augusta-Richmond County, GA-SC	1 (0.8%)	4 (0.3%)
Toledo, OH	1 (0.8%)	2 (0.2%)
Palm Bay-Melbourne-Titusville, FL	4 (0.3%)	8 (0.6%)
Durham-Chapel Hill, NC	1 (0.8%)	1 (0.8%)
Harrisburg-Carlisle, PA	2 (0.2%)	2 (0.2%)
Spokane-Spokane Valley, WA	4 (0.3%)	8 (0.6%)
Chattanooga, TN-GA	3 (0.2%)	2 (0.2%)
Scranton--Wilkes-Barre--Hazleton, PA	1 (0.8%)	4 (0.3%)
Modesto, CA	4 (0.3%)	2 (0.2%)
Lancaster, PA	1 (0.8%)	3 (0.2%)
Youngstown-Warren-Boardman, OH-PA	3 (0.2%)	2 (0.2%)
Portland-South Portland, ME	1 (0.8%)	1 (0.8%)
Lexington-Fayette, KY	1 (0.8%)	5 (0.4%)
Santa Rosa, CA	2 (0.2%)	5 (0.4%)
Pensacola-Ferry Pass-Brent, FL	5 (0.4%)	7 (0.5%)
Lafayette, LA	0 (0.0%)	1 (0.8%)
Port St. Lucie, FL	0 (0.0%)	1 (0.8%)
Lansing-East Lansing, MI	2 (0.2%)	1 (0.8%)
Reno, NV	2 (0.2%)	3 (0.2%)
Springfield, MO	2 (0.2%)	1 (0.8%)
Visalia-Porterville, CA	0 (0.0%)	1 (0.8%)
Huntsville, AL	1 (0.8%)	8 (0.6%)
Asheville, NC	2 (0.2%)	2 (0.2%)
Corpus Christi, TX	2 (0.2%)	3 (0.2%)
Killeen-Temple, TX	1 (0.8%)	1 (0.8%)
York-Hanover, PA	4 (0.3%)	1 (0.8%)
Vallejo-Fairfield, CA	5 (0.4%)	0 (0.0%)
Santa Maria-Santa Barbara, CA	1 (0.8%)	1 (0.8%)
Fort Wayne, IN	2 (0.2%)	2 (0.2%)
Shreveport-Bossier City, LA	2 (0.2%)	1 (0.8%)
Salinas, CA	3 (0.2%)	0 (0.0%)
Salem, OR	3 (0.2%)	3 (0.2%)

Reading, PA	2 (0.2%)	2 (0.2%)
Manchester-Nashua, NH	2 (0.2%)	4 (0.3%)
Mobile, AL	0 (0.0%)	2 (0.2%)
