Development, Evaluation and Refinement of a Body Mass Index Formula for Large Breed Canine Patients

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By

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The current method of quantifying obesity in the veterinary patient is the subjective body condition score; however, scant research has focused on the development of an objective measurement. The present two part study evaluates the ability to create and refine an objective body mass index (BMI) formula for the large breed canine patient. In the first part of this study, seven morphometric measurements were obtained from seventy large breed dogs allowing the creation of five BMI formulas. In the second part of this study, computed tomography images were obtained from twenty-two dogs and the total percent body fat (TBF) was calculated. Results from the five formulas were compared to the calculated TBF to evaluate their accuracy. A final BMI formula was developed that has a very strong correlation with the TBF, and provides an objective measurement of obesity in the large breed canine patient.

DEDICATION

I would like to dedicate this research to my parents, Don and Linda Lodato, for their faithful support of my pursuit of education even though my father cannot be here to share in my achievement.

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NOMENCLATURE

BCS	*Body condition score*
BMI	*Body mass index*
BMI-BCS	*Modified BCS according to BMI value*
CARPUS	*Circumference just proximal to the right carpus*
CT	*Computed tomography*
DEXA	*Dual-energy X-ray absorptiometry*
D_2O	*Deuterium oxide dilution*
H-S	*Length from tuber calcanei to mid-patella*
HT	*Height*
IV	*Intravenous*
LN1	*Length from the occipital protuberance to the base of the tail*
LN2	*Length from the thoracic inlet to ischiatic tuberosity*
TBF	*Total percent body fat*
TBF-BCS	*Modified BCS according to TBF*
WAIST	*Circumference at the level of the umbilicus*
WT	*Weight*

CHAPTER I

INTRODUCTION

Background

Obesity is the most common nutritional disorder in companion animals, and current estimates indicate 25-40% of pets in the United States are overweight or obese (1-6). Specifically, 40% of dogs, ages 6 to 10 years, are considered overweight or obese (7). Generally speaking, animals that are 1-9% above their ideal weight are thought of as above optimal, while clinically overweight dogs are considered to be 5-19% above ideal body weight, and dogs more than 20% above ideal body weight are classified as obese (2,5,8,9).

The current method of estimating body fat in the veterinary patient is the previously described body condition score (BCS) (1,10). This is a nine point scale, with one being emaciated and nine considered grossly obese (1,10). The BCS is determined by an examiner subjectively assigning a numerical value that corresponds to the scale. One of the problems with this method is that it has been shown to take 2 to 4 months for the BCS to change one increment, and as much as an 8% body mass change must occur in order to be detected (11). This makes the BCS a good estimator of body condition, but a poor method for monitoring long term weight management and body mass due to its lack of sensitivity to subtle changes. Another problem is the subjectivity of the score assignment. What one examiner deems an appropriate BCS, may be challenged by another. Furthermore, an examiner's experience with BCS assignment influences the resultant score (12). This further indicates a need for an objective, accurate assessment of body mass to aid in weight management plans.

In human medicine, the body mass index (BMI) is defined as the weight in kilograms divided by the height in meters squared (13). This provides a numeric value that can be compared to the International Classification of Adults chart that classifies an individual as underweight, normal, overweight, or obese (13). Unfortunately, there is no such objective formula in veterinary medicine. Providing a similarly numbered objective scale of the overall physical condition of the pet that an owner could relate to would be a significant step towards client education, preventative health care and the strengthening of the human-animal bond. A BMI formula would give owners and veterinarians a way to see progress or failures more quickly than the BCS. Changes could be made in nutritional or activity management, or congratulations given to reinforce the health management of our canine companions.

Obesity

Unfortunately, obesity is prevalent in today's pet population and continues to be a growing concern. Deciding if an animal is at an optimal weight, underweight, overweight, or obese is a daily challenge faced by veterinarians. Numerous factors may play a role in a patient being obese, including genetics (breed), neutering, increasing age, decreased activity level, and diet (1,3,4,6-9).

For example, gonadectomy predisposes pets to weight gain by decreasing the resting metabolic rate through loss of estrogen and androgen influence and reduction in activity level through the subsidence of roaming behavior (1,9). Moreover, estrogens also suppress appetite so gonadectomy can lead to increased food consumption (9,14). This was demonstrated in a study by Jeusette et al where *ad libitum* feeding of female Beagle dogs after ovariohysterectomy led to overconsumption of food and resultant obesity (14).

Also, the age of the animal has been linked to obesity. It has been shown that very few animals less than two years of age are considered overweight (9). After two years of age, the incidence of excess body weight increases and peaks at six to eight years (9). At that time, weight reaches a plateau or slightly decreases until 12 years of age when the prevalence appears to significantly decrease (9). The reason behind this has been debated in the literature. Some suggest that the reason for this is a decrease in energy requirement secondary to loss of lean body tissue associated with aging (9). Weight gain follows if an animal's energy intake does not concurrently decrease (9). Others propose that as dogs and cats age past 10 to 12 years, they naturally become thinner but may actually be in less than optimal body condition (9). Another theory purports that overweight pets die sooner than their thinner counterparts because excess weight impacts overall health (6,9). This has been demonstrated in rodents but remains unconfirmed in dogs and cats (9).

Type of food and feeding regime has also been tied to obesity. Offering highly palatable foods free choice to dogs and cats may encourage caloric consumption that surpasses daily energy requirements (9). Manufacturer recommendations offered on the food label are often above the energy requirement of many pets (9). The reason for this is because those recommendations are based on the average caloric requirement for that body weight (9). However, these averages are determined from population means and the energy requirements within these means vary widely (9). In addition to the amount, the type of food plays a role in excessive weight (9). The proportion of different nutrients, including protein, fat, and soluble carbohydrates, constitutes a food's caloric density (9). Many light, lean, reduced calorie and reduced fat products available have decreased fat content and increased fiber, air, or moisture content (9). This effectively reduces the caloric density of the food (9). Using this type of commercially available food ensures that the diet remains balanced (9). By simply decreasing the amount of the maintenance diet currently being fed, there is a serious risk of energy and nutritional deficiencies that will impact the dog or cats' overall health (9).

The main concern with obese patients is the predisposition to a multitude of medical problems and decreased longevity. Ongoing research and evidence-based reviews have shown obese dogs are more prone to a variety of disease processes including but not limited to arthritis, traumatic and degenerative orthopedic disorders, diabetes mellitus, lipid metabolism disorders, cardiovascular and respiratory disease, urinary disorders, reproductive disorders, neoplasia, dermatologic diseases, decreased heat tolerance, decreased immune function, and anesthetic complications (1,5-7,9,12,14-20). There is also scientific evidence that weight loss can help reverse or slow some of these diseases. Blanchard et al were able to demonstrate a regain of insulin sensitivity in diabetic dogs with weight loss and proper body mass maintenance (21). Proper weight management has also been shown to play a vital role in improving mobility and comfort in arthritic canine patients (20).

As veterinarians, our job is to not only care for animals, but educate their owners. In some instances, particularly when an animal is obese, educating owners can prove challenging and require a delicate conversation. Studies have shown that less active and overweight owners tend to have less active and overweight dogs (8,15). This stresses the importance of owner education and eliminating the conversation being personal and distressing to the owner. Owner compliance and monthly monitoring are keys to successful weight management and maintenance (22).

Evaluating body mass

In order to determine an objective way of measuring body mass composition, several different methods have been evaluated, including dual-energy X-ray absorptiometry (DEXA), bioelectric impedance, deuterium oxide dilution (D_2O), and computed tomography (CT). DEXA is employed in human and veterinary medicine to assess bone density and whole body composition (2). This method uses two x-rays of differing energies to determine the bone and soft tissue compositions (2). DEXA has been validated in dogs in previous studies, and has been found to have a high correlation with the BCS ($r^2 = 0.92$) (2,5,23,24). The downfall of this method is that it requires expensive equipment and special facilities not available to the general practitioner.

Another method of estimating body fat percentage is by use of a hand-held bioelectric impedance device (5). This device employs a low-voltage, high-frequency current that is conducted through electrodes placed on the surface of the animal (5). The methodology behind this device is based on the ability of electrolyte-containing body fluid, namely extra- and intra-cellular fluid, to conduct electricity (5). Resistance to this conduction is due to the capacitance of cell membranes and tissue resistance (5). This resistance is perceived as a diminished current, and is translated into a measure of body composition (5). Different tissues have different conduction abilities (5). For instance, adipose tissue is well-hydrated allowing less current to be conducted (5). As the amount of adipose tissue increases, so does the impedance to the current (5). When this device was used in one study, the results obtained were compared to the BCS and a good correlation was found ($r_s = 0.844$); however, this correlation was not as strong as the correlation between DEXA and BCS (2,5). The disadvantages of this method of body composition measurement is that it also requires specialized equipment not easily accessible to the general practitioner, and the effect of haircoat length, texture, and density are currently unknown (5).

The D_2O technique is based on the fact that body water is typically associated with nonfat tissue, so measuring total body water is an indirect method of measuring lean body (i.e., fat free) mass (25). Deuterium oxide is a stable, nontoxic tracer given intravenously (IV) that is freely exchanged with water (25,26). Dogs are weighed and blood samples drawn before and two hours after administration (25). Blood samples are then analyzed and the amount of D_2O present in the blood is determined (25). These values are then entered into several previously described equations that calculate the total body water content and percent body fat (25,27). Mawby et al found a good correlation (r^2=0.78) between measurements of percent body fat gathered from the D_2O method and those found using DEXA (25). A second study compared values obtained using D_2O and DEXA, and found an excellent relative agreement (r^2=0.84) between these two modalities (28). However, the values obtained with DEXA were on average 13-15.8% higher than those obtained with the D_2O method (5,28). This technique is not freely accessible to the general practitioner since it requires access to the tracer and analysis equipment.

Computed tomography is considered the gold standard in human medicine at assessing body composition (20). A study that involved human subjects found that there was a fairly strong correlation between CT and DEXA ($r = 0.70 - 0.75$) when several measurements, including total subcutaneous fat, superficial subcutaneous fat, deep subcutaneous fat, and visceral fat, were assessed (20). Another study also found strong correlations between body composition analysis when results from MRI and DEXA were compared to CT (29). Ishioka et al described the use of CT to determine fat area in Beagles (26). This study described the CT analysis of one image obtained at the level of L3 (to L5) with the range of -135/-105 Hounsfield units had the best correlation ($r = 0.98$) with body fat content estimated using the D_2O method (26). Since CT is available at our institution and is considered the gold standard in human medicine, this modality was used in the present study to determine body composition.

Management of Obesity

Obesity is combatted using three equally important strategies (9). The first is developing an appropriate feeding plan (9). The second is constructing an exercise plan (9). Lastly, a consistent recheck plan should be instituted (9). Eliminating just one of these strategies risks serious compromise to a successful weight loss and management plan (9).

Feeding a reduced amount of a food that is not calorie restricted is unlikely to result in weight loss without creating protein, vitamin, mineral and energy deficits (9). When evaluating a diet, both fat content and total calories are instrumental in determining if an animal gains, loses or maintains their current body weight (9). It is important that the amount of food offered to the pet is measured and adjusted based on the amount of weight the animal loses during the plan (9). This requires complete owner commitment and understanding of the impact that this has on overall weight loss and management (9). Also, the addition of soluble and especially insoluble fiber, contribute to satiety by prolonging the gastrointestinal tract distention and increasing the total transit time through the gastrointestinal tract (4,9). Fiber also decreases pancreatic enzyme activity and pancreatic lipase secretion, and increases fecal excretion of bile acids and fat (9). It has also been shown that fiber increases the amount of fecal material and defecation frequency (9). Additionally, if treats are included in the weight loss plan, their caloric content must be factored into the total daily calories allotted (9).

Exercise must also be introduced into the pet's daily routine to aid in weight reduction (9). Initially, any exercise that the animal is able to tolerate is instituted (9). This amount is increased gradually every day to a final goal of 20 to 60 minutes per day of leash walking or its equivalent (9). A particular challenge is faced by the cat owner when it comes to exercise (9). Some creative options include training a cat to walk on a leash, or encouraging play using string, balls, laser toys, other toys, or other pets (9).

Recheck examinations are also needed to monitor the amount and rate of weight loss, and ensure that it is steady (9,22). There are three critical time periods during a weight loss plan (9). These are at the initiation of the plan, when the goal weight is reached, and at any point in between when weight loss slows or a plateau is reached (9). In the beginning of the weight loss regime, recheck examinations should be scheduled every two weeks, then every four to six weeks as the rate of weight loss is steady (9). When the diet is being changed or increased to maintain the goal weight, the rechecks should be increased to every one to two weeks (9). Recheck examinations serve several functions, including reinforcement of the importance of weight loss, encouraging owner commitment, providing an opportunity to adjust the feeding plan and exercise recommendations (9). Successful weight loss will enhance surgical and pharmacologic treatment benefits, and is necessary to attain maximal benefits from these treatment modalities (9). It is during these recheck examinations that an objective measurement of obesity, such as a BMI formula, would be implemented. Scales can vary and individual assessments may not be in agreement. A BMI value is indisputable and its similarity with the human BMI scale will aid owners in their understanding on the impact obesity has on their pet.

References

[1] Elliot DA. The obesity epidemic: causes, risks and diagnosis in pets. *Banfield Journal* 2010;6(3):7-14.

[2] Jeusette I, Greco D, Aquino F, et al. Effect of breed on body composition and comparison between various methods to estimate body composition in dogs. *Res in Vet Sci* 2010;88:227-232.

[3] Wolfsheimer KJ. Obesity. In: Ettinger SJ, Feldman EC, eds. *Textbook of Veterinary Internal Medicine: Diseases of the Dog and Cat*. 5th ed. Philadelphia: WB Saunders; 2000:70-72.

[4] Hand MS, Armstrong PJ, Allen TA. Obesity: occurrence, treatment, and prevention. *Vet Clin North Am Small Anim Pract* 1989;19:447-474.

[5] Stone R, Berghoff N, Steiner JM, et al. Use of a bioelectric impedance device in obese and lean healthy dogs to estimate body fat percentage. *Vet Thera* 2009;10(1-2): 59-70.

[6] German AJ. The growing problem of obesity in dogs and cats. *J Nutr* 2006;136(7):1940S-1946S.

[7] Lund EM, Armstrong PJ, Kirk CA, Klauser JS. Prevalence and risk factors for obesity in adult dogs from private US veterinary practices. *Int J Apply Res Vet Med* 2006;4:177-186.

[8] Gossellin J, Wren JA, Sunderland SJ. Canine obesity: an overview. *J Vet Pharmacol Ther* 2007;30:1-10.

[9] Burkholder WJ, Toll PW. Obesity. In: Hand MS, Thatcher CD, Remillard RL, *et al.*, eds. Small Animal Clinical Nutrition. 4th ed. Topeka: Mark Morris Institute, 2000;401-430.

[10] Laflamme DP. Development and validation of a body condition score system for dogs. *Canine Pract* 1997;22:10-15.

[11] Dorsten CM, Cooper DM. Use of body condition scoring to manage body weight in dogs. *Contemp Top Lab Anim Sci* 2004;43(3):34-7.

[12] Burkholder WJ. Use of body condition scores in clinical assessment of the provision of optimal nutrition. *J Am Vet Med Assoc* 2000;217:650-654.

[13] World Health Organization website. Global Database on Body Mass Index. Available at: apps.who.int/bmi/index.jsp?introPage=intro_3.html. Accessed Nov 22, 2011.

[14] Jeusette I, Detilleux J, Cuvelier C, et al. Ad libitum feeding following ovariectomy in female beagle dogs: effect on maintenance energy requirement and on blood metabolites. *J Anim Physiol Anim Nutr* 2004;88:117-121.

[15] Chan CB, Spierenburg M, Ihle SL, Tudor-Locke C. Use of pedometers to measure physical activity in dogs. *J Am Vet Med Assoc* 2005;226:2010-2015.

[16] Martin LM, Siliart B, Dumon HJ, Nguyen PG. Hormonal disturbances associated with obesity in dogs. *J Anim Physiol Anim Nutr* 2006;90:355-360.

[17] Ellmerer M, Hamilton-Wessler M, Kim SP, et al. Reduced access to insulin-sensitive tissues in dogs with obesity secondary to increased fat intake. *Diabetes* 2006;55:1769-1775.

[18] Gayet C, Leray V, Saito M, et al. The effects of obesity-associated insulin resistance on mRNA expression of peroxisome proliferator-activated receptor-gamma target genes, in dogs. *Br J Nutr* 2007;98:497-503.

[19] Bergman RN, Kim SP, Catalano KJ, et al. Why visceral fat is bad: mechanisms of metabolic syndrome. *Obesity* 2006;14:16S-19S.

[20] Blanchard G, Nguyen P, Gayet C, et al. Rapid weight loss with high-protein low-energy diet allows the recovery of ideal body composition and insulin sensitivity in obese dogs. *J Nutr* 2004;134(8):2148S-2150S.

[21] Mlacnik E, Bockstahler BA, Muller M, et al. Effects of caloric restriction and a moderate or intense physiotherapy program for treatment of lameness in overweight dogs with osteoarthritis. *J Am Vet Med Assoc* 2006;229:1756-1760.

[22] Roudebush P, Schnoenherr WD, Delaney SJ. An evidence-based review of the use of therapeutic foods, owner education, exercise, and drugs for management of obese and overweight pets. *J Am Vet Med Assoc* 2008;233:717-725.

[23] Lauten SD, Cox NR, Brawner WR Jr, et al. Use of dual energy x-ray absorptiometry for noninvasive body composition measurements in clinically normal dogs. *Am J Vet Res* 2001;62:1295-1301.

[24] Munday HS, Booles D, Anderson P, et al. The repeatability of body composition measurements in dogs and cats using dual energy x-ray absorptiometry. *J Nutr* 1994;124:2619S-2621S.

[25] Mawby DI, Bartges JW, d'Avignon A, et al. Comparison of various methods for estimating body fat in dogs. *J Am Anim Hosp Assoc* 2004;40:109-114.

[26] Ishioka K, Okumura M, Sagawa M, et al. Computed tomographic assessment of body fat in beagles. *Vet Radiol Ultrasound* 2005;46(1):49-53.

[27] Burkholder WJ, Thatcher CD. Validation of predictive equations for use of deuterium oxide dilution to determine body composition of dogs. *Am J Vet Res* 1998;59:927-937.

[28] Son HR, d'Avignon DA, Laflamme DP. Comparison of dual-energy x-ray absorptiometry and measurement of total body water content by deuterium oxide dilution for estimating body composition in dogs. *Am J Vet Res* 1998;59(5):529-32.

[29] Kullberg J, Brandberg J, Angelhed J-E, et al. Whole-body adipose tissue analysis: comparison of MRI, CT and dual energy x-ray absorptiometry. *Brit J of Radiol* 2009;82:123-130.

CHAPTER II

PART I: DEVELOPMENT OF A BODY MASS INDEX FORMULA FOR LARGE BREED CANINE PATIENTS

Objectives

The objective of this part of the study was to develop potential BMI formulas based on morphometric measurements obtained from large breed dogs (1). Results from these formulas were then compared to the traditional BCS classification to establish if a canine BMI calculation is feasible.

Materials and Methods

Study population

Seventy client-owned large breed dogs were included in this study. Use of these animals was performed in accordance with the Mississippi State University guidelines for animal research. Patients with a disagreeable temperament, pre-existing underlying metabolic or neoplastic disease, notable skeletal growth abnormality (angular limb deformity or chondrodystrophic breeds), or dogs less than one year of age were excluded from the study population. Previously described morphometric measurements were obtained from awake dogs in the standing position (Figure 1) (1,2). These included weight in kilograms (WT), height at the top of the scapula in centimeters (HT), length from the occipital protuberance to the base of the tail in centimeters (LN1), pelvic circumference at the level of the umbilicus in centimeters (WAIST), and hock-to-stifle length from tuber calcanei to mid-patella in centimeters (H-S) (1,2). Mawby et al originally described measuring from a midpoint between the cranial scapulae to the base of the tail (1). In the current study, this was modified to the length from the thoracic inlet to the base of the tail in cm (LN2) to aid in landmark consistency. In addition, the circumference just proximal to the right carpus in cm (CARPUS) was included in our study as described in human medicine.

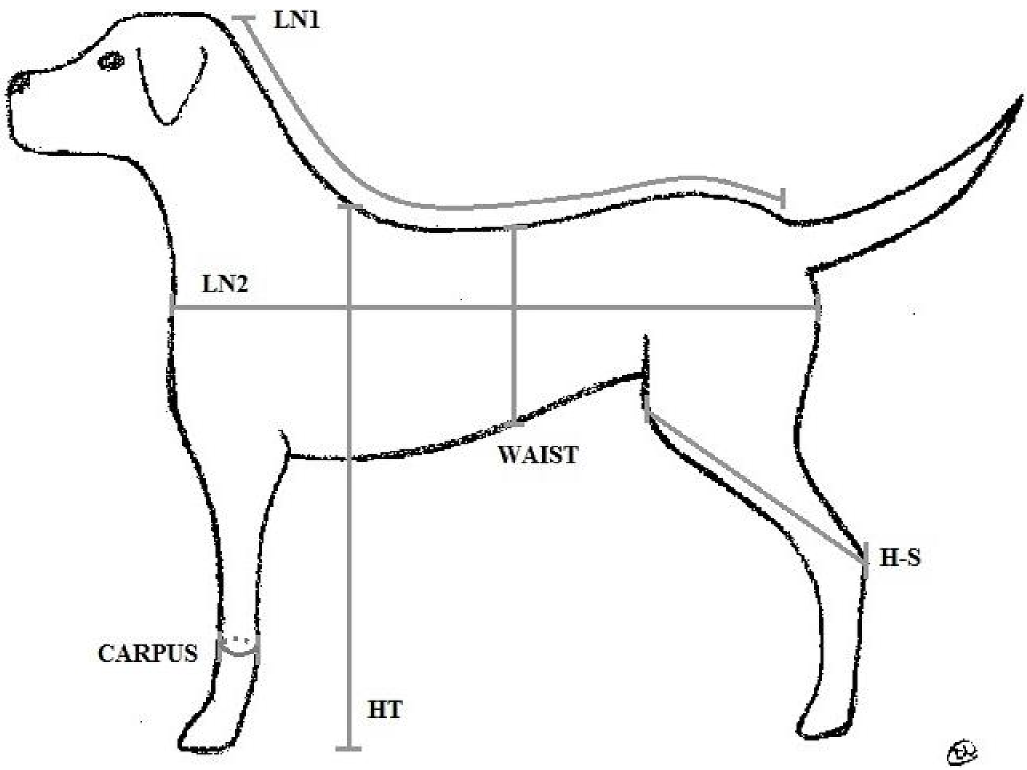

Figure 1 Morphometric measurement locations on the dog

Following the morphometric measurements, a subjective body score assessment using the previously described nine-point BCS scale, with 1 being emaciated to 9 being grossly obese, was assigned by one of two investigators to maintain consistency (3). Scores were based on both visual examination and palpation. Dogs were then classified into one of four categories; the underweight category contained dogs with a BCS of 1 to 3, the normal weight category contained dogs with a BCS of 4 or 5, the overweight category contained dogs with a BCS of 6 or 7, and the obese category contained dogs with a BCS of 8 or 9.

Statistical analysis

The potential for using the seven measurement variables to develop BMI formulas for large breed dogs was assessed using a stepwise discriminant analysis program (PROC STEPDISC from SAS[a]). The measurement variables determined to be the best set of linear discriminators were used to develop formulas with the stipulation that the resultant BMI numerical values would classify the dogs in a manner similar to the currently used human BMI numerical classes (underweight, ideal or normal weight, overweight, and obese). These classes were assigned to a modified BCS (BMI-BCS) (Table 1). The BMI-BCS was then compared to the traditional subjective BCS classification. Dogs that were classified differently between the BCS and BMI-BCS were assessed using discriminant analysis (PROC DISCRIM from SAS). The classification agreement between each BMI-BCS classification and the BCS classification was determined in two-way frequency tables.

Table 1 Classification of dogs based on their BMI values and correlating BMI-BCS

Classification	BMI	BMI-BCS
Underweight	<18.5	1 to 3
Normal	18.5 to <25.0	4 to 5
Overweight	25.0 to 30.0	6 to 7
Obese	>30.0	8 to 9

Results

Study population

Seventy dogs fit the inclusion criteria and had objective measurements obtained, along with a subjective BCS assigned. The study population consisted of Labrador Retrievers (23), Golden Retrievers (13), mixed breed dogs (9), Boxers (7), German Shepherd dogs (3), Weimaraners (3), German Short Haired Pointers (2), Doberman Pinschers (2), a Chesapeake Bay Retriever (1), a Dalmatian (1), an Australian Cattle dog (1), a Treeing Walker Coonhound (1), a Rottweiler (1), a Catahoula (1), a Border Collie (1), and an American Pitt Bull Terrier (1). There were 22 neutered males, 17 intact males, 22 spayed females, and 9 intact females. Body weight ranged from 17.2 kg to 70.7 kg with a mean weight of 31.93 kg. Ages ranged from one year to 13.6 years of age with a mean age of 5.12 years. The dogs ranged in BCS from 2 to 9. The relative frequency distribution of BCS values for the seventy dogs in the study are displayed in Figure 2. None of the examined dogs were assessed as having a BCS of 1. There were 2 dogs with a BCS of 2, 7 with a BCS of 3, 7 with a BCS of 4, 15 with a BCS of 5, 21 with a BCS of 6, 8 with a BCS of 7, 8 with a BCS of 8, and 2 with a BCS of 9

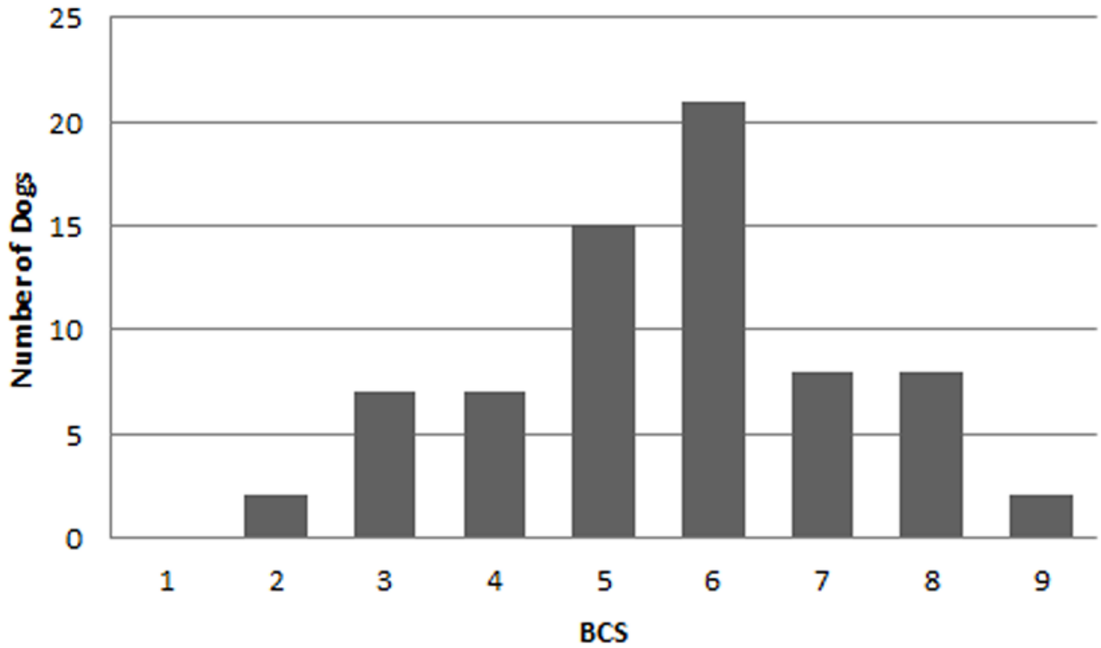

Figure 2 Relative frequency histogram of dogs by BCS

Correlation of morphometric measurements and BCS

When the morphometric measurements were compared to the BCS (Table 2), the WAIST measurement had the highest correlation (r=0.73), whereas WT had a moderate correlation (r=0.46).

Table 2 Correlation of the BCS to measurement values

Measurement variable	Correlation to BCS
WT	0.46
HT	-0.06
LN1	0.26
LN2	0.25
WAIST	0.76
CARPUS	0.26
H-S	-0.16

Creation of BMI formulas

The stepwise discriminant analysis (PROC STEPDISC from SAS) indicated that the best set of linear discriminators consisted of the HT, H-S, and WAIST variables. Based on these findings, the following five formulas were developed for large breed dogs:

$$\text{BMI \#1} = (\text{HT} / \text{H-S}) + (\text{WAIST} / 3) \quad (1)$$

$$\text{BMI \#2} = 2/3\ \text{WT} + (\text{HT} / \text{H-S}) \quad (2)$$

$$\text{BMI \#3} = 0.5\ (\text{WT} / (\text{LN1} / 100)^2) \quad (3)$$

$$\text{BMI \#4} = (\text{WT} / (\text{HT} / \text{H-S})^2) + (\text{WAIST} / 3) \quad (4)$$

$$\text{BMI \#5} = (\text{WT} / (\text{HT} / \text{H-S})) + (\text{WAIST} / 4) \quad (5)$$

Based on the BMI value computed from each formula, dogs were assigned to the underweight, normal weight, overweight, or obese class (Table 1). A comparison of the BMI formulas #1 through #5 to BCS based on their joint classification of the dogs into one of the four classes is given in Table 3. BMI #1 classified 10 dogs higher and 25 dogs lower than their BCS classification with a 50% classification agreement. BMI #2 classified 15 dogs higher and 26 dogs lower than their BCS classification with a 41.4% classification agreement. BMI #3 assigned values that were higher for 15 dogs and lower for 22 dogs in comparison to their BCS classification, resulting in a total of 37/70 discrepancies in the joint classification and a 41.7% classification agreement. BMI #4 classified 25 dogs higher and 12 dogs lower than their BCS classification, with a 47.1% classification agreement. And finally, BMI #5 classified 39 dogs higher and 9 dogs lower than their BCS classification with a 31.4% agreement in classification.

Table 3 Frequency distribution for BCS classes and BMI formula calculation assigned classes

BMI Class				
BCS Class	**Underweight**	**Normal**	**Overweight**	**Obese**
BMI Formula #1 Classification				
Underweight	1	8	0	0
Normal	1	20	1	0
Overweight	0	17	11	1
Obese	0	0	7	3
BMI #1 Totals	2	45	19	4
BMI Formula #2 Classification				
Underweight	3	6	0	0
Normal	4	13	5	0
Overweight	6	10	9	4
Obese	1	2	3	4
BMI #2 Totals	14	31	17	8
BMI Formula #3 Classification				
Underweight	1	7	1	0
Normal	2	14	5	1
Overweight	2	12	14	1
Obese	1	0	5	4
BMI #3 Totals	6	33	25	6
BMI Formula #4 Classification				
Underweight	1	5	3	0
Normal	1	10	10	1
Overweight	0	7	16	6
Obese	0	0	4	6
BMI #4 Totals	2	22	33	13
BMI Formula #5 Classification				
Underweight	0	4	4	1
Normal	1	6	12	3
Overweight	0	6	8	15
Obese	0	0	2	8
BMI #5 Totals	1	16	26	27

When the BMI formula values were compared to the BCS, BMI #1 had the strongest correlation at 0.73, whereas BMI #2, BMI #3, BMI #4, and BMI #5 were found to have smaller correlations (r=0.47, 0.42, 0.64, and 0.57, respectively). BMI #1 also had the highest percentage of classification agreement when compared to BCS.

Discussion

The purpose of developing a BMI formula tailored to dogs was to offer the general practitioner a means of tabulating an objective measurement versus the traditional insensitive, subjective BCS. The goal was also to create the canine BMI formula to mirror the same numerical outcome categories as the human scale, so owners would understand the information. This was intentional so that clients would be able to better understand the impact of their animal's BMI class. By enabling a clinician to take a limited number of measurements quickly and turn them into an objective numerical BMI value that an owner can relate to may allow for an unemotional evaluation of an animal's physical condition. An additional goal of developing a BMI formula is for it to be more sensitive and specific than the traditional BCS classification. Since a change in the BCS may take several months and mean a difference of 8% body mass, the BMI formula would potentially allow for earlier detection of weight loss or gain based on their morphometric measurements (4).

In this part of the study, five BMI formulas were developed using objective measurements obtained from 70 large breed dogs. When compared to the subjective BCS, BMI #1 had the strongest correlation (r=0.73), while the remaining formulas had moderate correlations (r=0.42-0.64). Overall, it appears that the majority of the discrepancies in classification for BMI #1, BMI #2, and BMI #3 underestimated the dogs "size" when compared to their subjective BCS classification. In contrast, the classification results from both BMI #4 and BMI #5 tended to overestimate the dogs "size" when compared to the subjective BCS classification. These results are comparable to those found in human medicine, where BMI results are strongly correlated with total fat mass in both men and women (r^2=0.78 and r^2=0.92, respectively) (5). Although our formula results are approaching this correlation strength, they are not as strong. It is important to note that the formulas developed during this part of the study were compared to the imperfect BCS, which is subjective in nature and at risk of having variable results. Since it was shown that a correlation can be made between these BMI formulas and the BCS, the next step in this study was to use a controlled study population where these BMI formulas were compared to the percent body fat determined using one of the previously described objective "gold standard" methods. In doing this, each formula's accuracy was evaluated and refined so that the most accurate formula could be created.

In human medicine, the BMI formula is a ratio between weight and height (6). The results then enable a person to be categorized as underweight, normal, overweight, or obese (6). The problem with trying to extrapolate this formula to canine species is the wide range of conformations and body types/sizes found in dogs, and also the difference between bipeds and quadrupeds. By creating a BMI formula for large breed dogs only, we evaluated one particular body type/size in order to see if it was possible to create a formula(s). The hope is to develop a single BMI formula, or a few formulas, applicable to the wide range of body types/sizes seen in our canine patients.

Mawby et al used of the morphometric measurements utilized during this part of the study and determined percent body fat using previously described formulas (both gender neutral and sex specific formulae) (1). They then compared those results to the percent body fat determined via DEXA (1). These authors found that there was a significant correlation between the percent body fat calculated using the measurements and the percent body fat determined using DEXA (1). Additionally, Mawby et al reported a BMI formula that included body weight, height, and length from the occipital protuberance to the base of the tail (1). Values obtained from their BMI formula were also compared to the percent body fat calculated using DEXA (1). They found that the correlation between their BMI formula and DEXA was significant; however, there was a lack of absolute agreement (1). When they compared the correlation between their BMI formula and the percent body fat to the correlation between the measurements and the percent body fat, they found that the correlation was less when their BMI formula was used (1). They concluded that their BMI formula was not useful which further supports the need to investigate and develop additional formulas that have a stronger correlation to an objective body mass assessment such as DEXA or CT; hence the purpose of our follow-up study (1).

During this part of the study, data collection was performed over numerous months to assure a broad range of patients and the largest sample of dogs possible. This allowed for a study sample that was representative of the general large breed canine population seen at our institution. However, this also is one of the major limitations. The study population appears normally distributed with the majority of the dogs falling in the ideal and overweight categories. Due to the lack of dogs with a BCS of 1, and the limited number of dogs with a BCS of 2 and 9, measurements from dogs with these BCS classifications were not available to contribute to the BMI formula development. Logically, it was extremely difficult to locate healthy emaciated or grossly obese dogs. Most dogs that were at the extreme ends of the BCS typically had health issues that precluded their inclusion in the study sample. If additional healthy emaciated or grossly obese dogs were included in the study population used to develop the formulas, the results may be more sensitive and specific. This could be the reason for the discrepancies calculated with our BMI formulas when compared to their subjective BCS; however, this could also be due to the inaccuracies of the BCS scale.

A second limitation is that there may not necessarily be agreement between evaluators on BCS assignment. The variation in score assignment during this part of the study was minimized by using only two individuals. These two individuals were also the only ones collecting the objective measurements. Having only two data collectors lowered the risk of major variation between BCS assessments, as well as limited any inconsistencies in the locations where the measurements were obtained.

Footnotes

[a] SAS, version 9.2, SAS Institute Inc., Cary, NC.

[b] Hawthorne A, Butterwick RF. Predicting the body composition of cats: development of a zoometric measurement for estimation of percentage body fat in cats [abstract]. *J of Vet Inter Med* 2000;14:365.

References

[1] Mawby DI, Bartges JW, d'Avignon A, et al. Comparison of various methods for estimating body fat in dogs. *J Am Anim Hosp Assoc* 2004;40:109-114.

[2] Burkholder WJ. Use of body condition scores in clinical assessment of the provision of optimal nutrition. *J Am Vet Med Assoc* 2000;217:650-654.

[3] Laflamme DP. Development and validation of a body condition score system for dogs. *Canine Pract* 1997;22:10-15.

[4] Dorsten CM, Cooper DM. Use of body condition scoring to manage body weight in dogs. *Contemp Top Lab Anim Sci* 2004;43:34-37.

[6] World Health Organization website. Global Database on Body Mass Index. Available at: apps.who.int/bmi/index.jsp?introPage=intro_3.html. Accessed Nov 22, 2011.

[5] Janssen I, Heymsfield SB, Allison DB, Kotler DP, Ross R. Body mass index and waist circumference independently contribute to the prediction of non abdominal, abdominal subcutaneous, and visceral fat. *Am J Clin Nutr* 2002;75:683-688.

CHAPTER III

PART II: EVALUATION AND REFINEMENT OF BODY MASS INDEX FORMULAS FOR LARGE BREED CANINE PATIENTS

Objectives

The purpose of this part of the study was to test the five potential BMI formulas, created in the first part of this study, to determine formula accuracy with CT scans and develop a simple and precise formula for use in large breed dogs.

Materials and Methods

Study population

All animal procedures were approved by the Mississippi State University Institutional Animal Care and Use Committee. Twenty-two healthy adult large breed dogs were included in the study. Owner consent was obtained before study inclusion. A complete blood count, blood chemistry profile, heartworm test and urinalysis were performed to ensure minimal risk with sedation for the CT scans. Patients with a diagnosed underlying metabolic or neoplastic disease, or notable skeletal growth abnormality (angular limb deformity or chondrodystrophic breeds) were excluded from the study. Morphometric measurements were obtained by the primary investigator (D.L.), and included weight in kilograms (WT), height at the shoulder in centimeters (HT), length from the occipital protuberance to the base of the tail in centimeters (LN1) and from the thoracic inlet to ischiatic tuberosity in centimeters (LN2), pelvic circumference at the level of the umbilicus in centimeters (WAIST), hock-to-stifle length from tuber calcanei to mid-patella in centimeters (H-S), and the circumference just proximal to right carpus in centimeters (CARPUS) (1). A BCS was also assigned by one individual (D.L.), using the previously described nine-point scale (2). Scores were based on visual examination and palpation (2). Dogs were then divided into one of five categories based on the BCS: thin (BCS 1-2/9), underweight (BCS 3/9), normal (BCS 4-5/9), overweight (BCS 6-7/9), and obese (BCS 8-9/9).

Computed tomography

The dogs were fasted for 12 hours before they were sedated for the procedure. Each dog had an intravenous catheter placed in one of the cephalic veins and was sedated with dexmedetomidine[a] (5μg/kg) and butorphanol[b] (0.2 mg/kg) administered intravenously. All dogs were placed in dorsal recumbency, head first into the gantry. All dogs were scanned using a 4 slice Toshiba Aquilion[c] CT scanner. The following acquisition parameters were used in all dogs: 120 kVp, 300 mA, 5 mm helical collimation, and a 500 mm field of view to accommodate the largest dogs. Images were acquired from the cardiac apex, caudally to the sacrum. After the scans were completed, the sedation was reversed with half intramuscular and half intravenous atipamezole[d] (volume equivalent to dexmedetomidine volume).

Body fat assessment

The CT images were evaluated using the ImageJ[e] program. Transverse CT images at the level of the third lumbar vertebra were selected for body fat analysis. Body fat area was determined by counting the numbers of pixels in the range between -135 and -105 Hounsfield units according to the method described by Ishioka et al (3). A region of interest was drawn around the entire body to include all body fat (Figure 3). A separate region of interest was drawn around the visceral cavity and the pixels within the same attenuation range counted for visceral fat area calculation (Figure 4). All regions of interest were drawn by the primary investigator (D.L.). The subcutaneous fat area was determined by subtracting the visceral fat area from the total body fat area. The total percent body fat (TBF) was determined by taking the total fat area, as defined by the limited attenuation values, and dividing it by the total area of the body. Based on these results, dogs had their BCS corrected according to the dog's actual objective TBF values (TBF-BCS) based on previously published results (Table 4) (4).

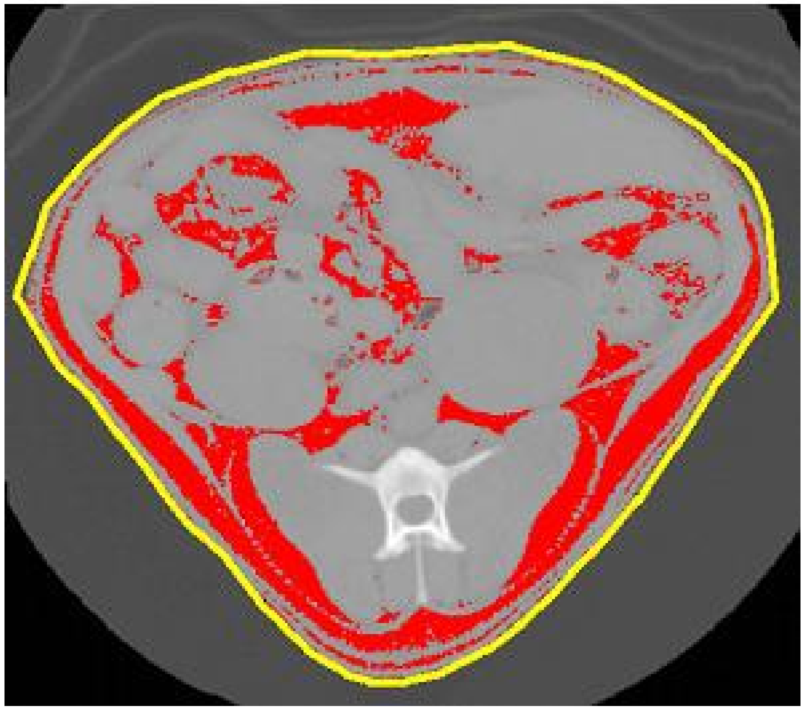

Figure 3 First region of interest drawn

A region of interest was drawn around the entire body to include all body fat indicated by the yellow line. The area in red represents adipose tissue.

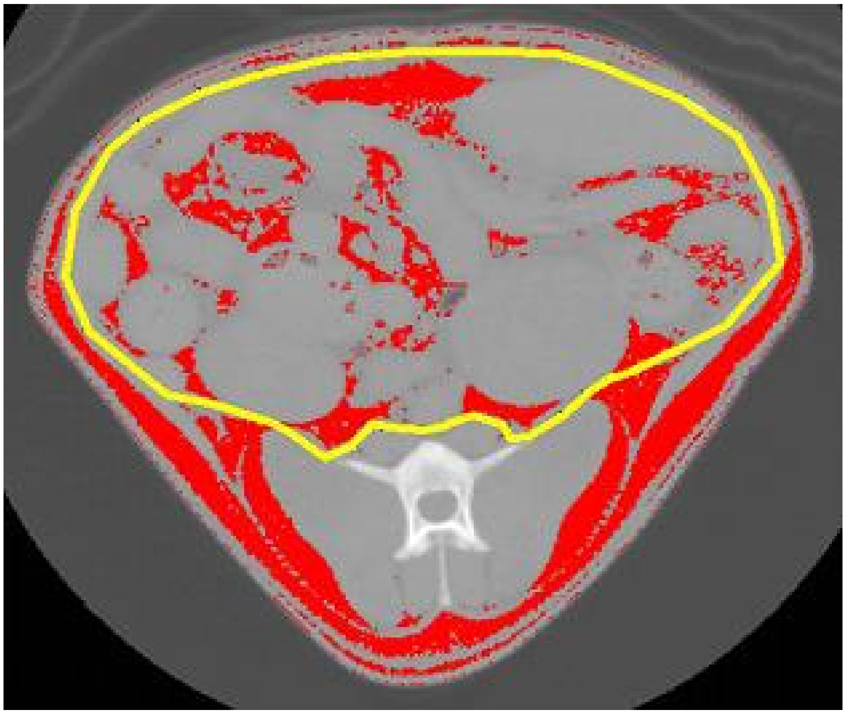

Figure 4 Second region of interest

A second region of interest was drawn around the visceral cavity only indicated by the yellow line in order to calculate the visceral fat area.

Table 4 TBF-BCS classification based on TBF calculated from CT images

TBF	TBF-BCS
<5 to 15%	1 to 3
16 to 25%	4 to 5
26 to 35%	6 to 7
>35%	8 to 9

Statistical analysis

The utility and correctness of the derived scores from the previously determined BMI formulas from the pilot study were based on three measurements. Pearson correlation, Spearman rank correlation, and the inspection of a plot[f] of the generated BMI results from each formula were compared to the TBF obtained for the test animals. The

Pearson correlation measured the linear associations of the calculated BMI results from each formula and the TBF of the animal. The Spearman rank correlation measured the similarity in the rankings of the dogs based on TBF and a calculated BMI value from each of the formulas. Significance was set at a $P < 0.05$.

BMI formula creation

A BMI was calculated for each dog using the created formulas and the dogs were then classified based on their BMI value into one of the following four classes used in human medicine – underweight, normal weight, overweight, and obese. These categories corresponded with a modified BCS (BMI-BCS) (Table 5). The BMI-BCS scores were then correlated to the CT scan determined TBF-BCS for each of the formulas to evaluate their accuracy. The BMI formula results were then compared to the subjectively assigned BCS to see the relationship between them as well. Additionally, the CT scan determined TBF was compared to our BMI formula results and the subjective BCS that was originally assigned.

Table 5 Classification of dogs based on their BMI values and corresponding BMI-BCS

Classification	BMI-BCS	BMI
Underweight	1 to 3	<18.5
Normal weight	4 to 5	18.5 to <25.0
Overweight	6 to 7	25.0 to 30.0
Obese	8 to 9	>30.0

Results

Study population

Twenty-two dogs fit the inclusion criteria and had morphometric measurements obtained, along with a subjective BCS assigned. The study population consisted of the following breeds: Labrador Retriever (6), mixed breed (3), Boxer (3), Golden Retriever (2), Weimaraner (1), German shorthaired pointer (1), Doberman Pinscher (1), Dalmatian (1), Rottweiler (1), Catahoula Cur (1), Border Collie (1), and American Pitt Bull Terrier (1). There were 5 neutered males, 7 intact males, 9 spayed females, and 1 intact female. Body weight ranged from 20.7 kg to 50.9 kg with a mean weight of 33.82 kg. Ages ranged from one year to 13 years of age with a mean age of 3.26 years. The dogs ranged in BCS from 2 to 9. There were two dogs with a BCS of 2, five with a BCS of 3, two with a BCS of 4, three with a BCS of 5, four with a BCS of 6, one with a BCS of 7, three with a BCS of 8, and two with a BCS of 9. None of the examined dogs were assessed as having a BCS of 1. Two dogs were classified as thin (BCS 1-2), five were classified as underweight (BCS 3), five were classified as ideal (BCS 4-5), five were classified as overweight (BCS 6-7), and five were classified as obese (BCS 8-9). The two dogs with a BCS of 2 were added to the group of five dogs that had a BCS of 3. This created an underweight category with seven dogs in it, versus separate thin and underweight categories with five dogs each. By doing this, it also allowed our BMI results to mirror the human BMI classification scheme that contains only four categories.

TBF compared to BCS

Computed tomography images were evaluated and the TBF determined. The TBF ranged from 0.77 to 14.8 with a mean of 5.67 for the underweight category. For the normal category, TBF values ranged from 11.31 to 30.03 with a mean of 18.3. Dogs in the overweight category had TBF values between 16.3 and 30.58 with a mean of 25.47. When the obese category dogs were evaluated, the TBF values fell between 26.56 and 35.34 with a mean of 31.03. According to Table 5, all of the dogs in the underweight category were considered underweight, along with three dogs that were included in the normal category. One dog from the normal category along with two dogs from the overweight category had TBF values that classified them as normal. TBF values determined that one dog in the normal category, three dogs from the overweight category, and 4 dogs from the obese category were considered overweight. Lastly, one dog that was in the obese category was also considered obese by the TBF value. When the BCS was compared to the TBF, a correlation of 0.9 was found.

BMI formulas compared to TBF

The following BMI formulas previously derived during the first part of the study were compared to the TBF values:

$$\text{BMI \#1} = (\text{HT} / \text{H-S}) + (\text{WAIST} / 3) \tag{6}$$

$$\text{BMI \#2} = 2/3\ \text{WT} + (\text{HT} / \text{H-S}) \tag{7}$$

$$\text{BMI \#3} = 0.5\ (\text{WT} / (\text{LN1} / 100)^2) \tag{8}$$

$$\text{BMI \#4} = (\text{WT} / (\text{HT} / \text{H-S})^2) + (\text{WAIST} /3) \tag{9}$$

$$\text{BMI \#5} = (\text{WT} / (\text{HT} / \text{H-S})) + (\text{WAIST} / 4) \tag{10}$$

The Pearson correlations between these BMI formulas and the TBF calculations determined by the CT images were 0.81, 0.81, 0.80, 0.76, and 0.77 for BMI #1, BMI #2, BMI #3, BMI #4 and BMI #5, respectively. The Spearman rank correlations between

TBF and BMI #1, BMI #2, BMI #3, BMI #4, and BMI #5 were 0.80, 0.83, 0.79, 0.75, and 0.79, respectively.

Morphometric measurements compared to TBF

The morphometric measurements were compared to the TBF and their correlations determined. According to the Pearson correlation, it was found that WT and WAIST had strong relationships to TBF with each having a value of 0.80. Moderate relationships were found between LN1, LN2, and the CARPUS ($r = 0.40$, 0.49, and 0.38, respectively). The HT and H-S had non-significant relationships to the TBF. The Spearman rank correlation found strong relationships between TBF and the WT and WAIST measurements ($r_S = 0.81$ and 0.79, respectively), moderate relationships with LN1, LN2, and CARPUS ($r_S = 0.39$, 0.50, and 0.44, respectively), and a non-significant relationships with HT and H-S. Based on these findings, a new formula was derived by testing all combinations of weight to a body size morphological measurement to find the best estimator of the TBF. The formula was further modified so the scale of the derived BMI scores had the same approximate range of percentages found with TBF and which approximated the slope of the TBF. The best estimator was

$$\text{BMI \#6} = \{\log [(WT/H\text{-}S) + 0.2]\} \times 100 \qquad (11)$$

According to BMI #6, 4 of the 22 dogs were misclassified in relation to their TBF. In all four cases, BMI #6 considered them as a lower category than the TBF classification. The plot in Figure 5 shows the relationships of all 6 BMI formulas and measured TBF.

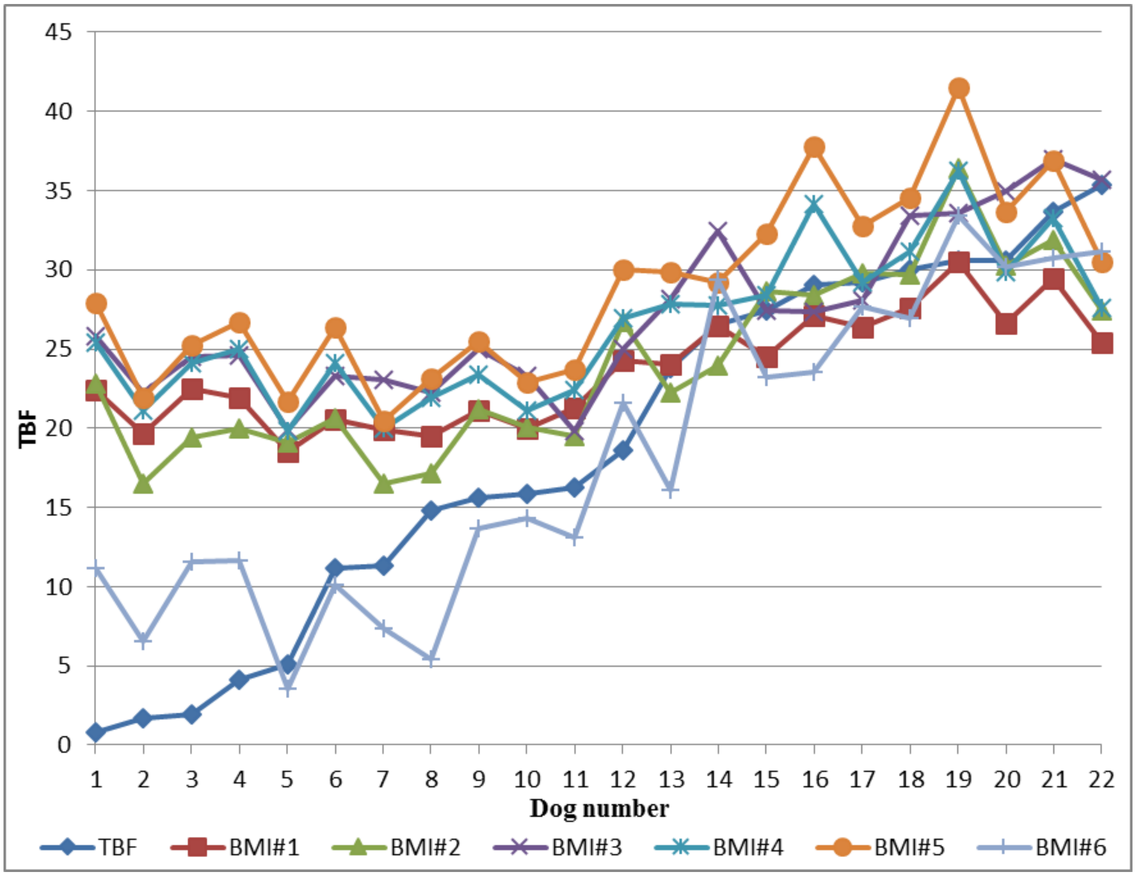

Figure 5 Plot of the five original BMI formulas and BMI #6 compared to TBF

This plot depicts the five original body mass index (BMI) formulas, along with the formula that was created during this part of the study (BMI#6) compared to the TBF by CT. It demonstrated the relationships of all six BMI formulas to the measured TBF. A TBF of less than 15, 16 to 25, 26 to 35, and greater than 35 was considered underweight, normal weight, overweight and obese, respectively.

Discussion

In this part of the study, a BMI formula was derived as an estimator of canine fat that paralleled the human BMI calculation. The human BMI formula is a ratio of weight to height. The desirability of our BMI formula is that the components of the equation are easily measured and it is an accurate assessment of physical condition. Thus, estimation of a similar measure in the canine utilized the weight divided by a size measurement. The BMI #6 formula was found to satisfy these parameters with strong correlations to the measured TBF. Our formula results do show some variation from the dogs that had a very low TBF. The majority of the dogs whose formula results show the greatest deviation were below 15% total body fat. Because we set the upper limit of the underweight category as 15% total body fat, the dogs' classification did not change regardless of the deviation. In human medicine, BMI results have been found to have a strong correlation with total fat mass in both men and women (0.78 and 0.92, respectively) (5). The formula developed during this part of the study has results that are comparable to these (0.89 and 0.91 for the Pearson and Spearman correlations, respectively).

The original study protocol called for five categories containing five dogs each. These categories were thin, containing dogs with a BCS or 1 or 2, underweight, with dogs having a BCS of 3, normal, with dogs having a BCS of 4 or 5, overweight, including dogs with a BCS of 4 or 5, and obese, having dogs with a BCS of 8 or 9. During the study, the pursuit of healthy emaciated dogs proved fruitless, with only two dogs with a BCS of 2 falling in the thin category. Several dogs with a BCS of 1 were evaluated but were excluded because they were considered unhealthy and therefore did not fit the inclusion criteria. In an attempt to compensate for the lack of emaciated dogs, the thin and underweight categories were combined, allowing the underweight category to contain seven dogs. By combining these categories, it allowed us to conform to the human BMI classification of four categories (underweight, normal, overweight and obese). The BMI #6 formula was more accurate than the other five BMI formulas for this study population. The first five BMI formulas were created based on a patient population that appeared normally distributed. These initial morphometric formulas were created based on the subjective BCS scale and did not have the CT scans to calculate exact TBF. In this part of the study, the number of dogs in each of the categories was similar. In addition, we calculated the TBF using CT as our gold standard which allowed us to determine the accuracy of the subjective BCS. Therefore, we were able to refine a better formula than in the first part of the study, due to the improved sensitivity of our CT model as our control.

In this part of the study, there were several measurements that correlated with TBF (for example the weight and waist measurements were found to have strong relationships); however, not all of them helped in the accuracy or simplicity of the BMI calculation. Furthermore, correlation does not necessarily indicate a cause and effect relationship. The human BMI formula uses the weight divided by some function that characterizes a person's size, namely height. In our formula, we also needed a measurement that estimated an animal's size. The H-S measurement provides this, since this measurement will change with increasing height. This can be demonstrated by comparing H-S measurements from large and small breed dogs. By using the WT and H-S measurements, we were able to develop a formula that has a strong correlation (0.89 and 0.91 for Pearson and Spearman correlations, respectively) with the TBF.

Factors other than an excess of body fat will influence an animal's weight. Two examples include muscle hypertrophy and fluid accumulation (4). These factors are also a problem faced by medical doctors when the human BMI formula is used. Additionally, the human BMI values have been found to be influenced by ethnicity (6). In veterinary medicine, the equivalent to varied ethnicities would be different breeds. To further complicate the situation, these breeds have a wide size variety, and can be considered anywhere from a toy to a giant. In an attempt to reduce the error that may be factored in, due to the wide array of canine confirmations, only large breeds were included in the present study. It is unclear whether the H-S value used in our formula will accurately account for different conformations or body types without substantial modification. Further studies evaluating different conformations and body types, such as chondrodystrophic, smaller or giant breeds, will need to be conducted in order to determine this.

A major limitation in this part of the study as well is the subjective BCS assignment to the dogs in the test population and potential lack of agreement between evaluators on score assignment (4). Variations in score assignment during this part of the study were decreased by having only one individual assign the subjective BCS and collect the morphometric measurements (D.L.). In this study, correlation between BCS and TBF was strong ($r = 0.9$); however, this correlation merely reflects the accuracy of the individual assigning the scores. It is not to say that a different observer would assign the same scores, ultimately having either a stronger or weaker correlation (1). Another limitation is the potential for inconsistencies in measurement location. This was addressed by having only one individual (D.L) take the measurements to limit differences in where the measurements were obtained. Choosing anatomic landmarks that were easily palpated and shown to be consistent were chosen to decrease variability (1). A third limitation was the small study population size. Perhaps by increasing the number of animals enrolled in the study, we could have gathered more information to further modify the BMI #6 to have a stronger correlation to TBF.

Footnotes

[a] Dexdomitor ® Orion Corporation. Espoo, Finland. Distributed by Pfizer Animal Health. Div. of Pfizer Inc. NY, NY 10017.

[b] Torbugesic ® Fort Dodge Animal Health. Fort Dodge, Iowa, USA.

[c] Toshiba Aquilion 4, Toshiba American Medical Systems Inc., Tustin, CA.

[d] Antisedan ® Orion Corporation. Espoo, Finland. Distributed by Pfizer Animal Health. Div. of Pfizer Inc. NY, NY 10017.

[e] ImageJ, NIH Image, United States Government, http://rsb.info.nih.gov/ij/

[f] SAS, version 9.2, SAS Institute Inc., Cary, NC.

References

[1] Mawby DI, Bartges JW, d'Avignon A, et al. Comparison of various methods for estimating body fat in dogs. *J Am Anim Hosp Assoc* 2004;40:109-114.

[2] Laflamme DP. Development and validation of a body condition score system for dogs. *Canine Pract* 1997;22:10-15.

[3] Ishioka K, Okumura M, Sagawa M, et al. Computed tomographic assessment of body fat in beagles. *Vet Radiol Ultrasound* 2005;46(1):49-53.

[4] Burkholder WJ, Toll PW. Obesity. In: Hand MS, Thatcher CD, Remillard RL, *et al*., eds. Small Animal Clinical Nutrition. 4th ed. Topeka: Mark Morris Institute, 2000;401-430.

[5] Janssen I, Heymsfield SB, Allison DB, et al. Body mass index and waist circumference independently contribute to the prediction of non abdominal, abdominal subcutaneous, and visceral fat. *Am J Clin Nutr* 2002;75:683-688.

[6] World Health Organization website. Global Database on Body Mass Index. Available at: apps.who.int/bmi/index.jsp?introPage=intro_3.html. Accessed Nov 22, 2011.

[7] Dorsten CM, Cooper DM. Use of body condition scoring to manage body weight in dogs. *Contemp Top Lab Anim Sci* 2004;43(3):34-7.

CHAPTER IV

CONCLUSION

In conclusion, a BMI formula for large breed dogs was created based on two morphometric measurements and TBF determined on CT images. The formula created during the present study was found to have a correlation of 0.89 and 0.91 for Pearson and Spearman correlations, respectively. The BMI formula correlation and BCS correlation to TBF were similar in this study; however, by using this formula, the clinician will be able to make two measurements and calculate an objective measure of an animal's physical condition versus a subjective evaluation. This formula is potentially more sensitive to changes in body mass than the BCS, since as much as an 8% change in body mass must occur to be detected using BCS. Additionally, this objective value will be more meaningful to clients since we use the same BMI scale utilized in human medicine. Future studies are needed to evaluate the effect of weight loss on the BMI #6 formula accuracy. Additionally, formulas for small, median and giant breeds may be needed, and age or sex might also have to be included in the BMI as is seen in human medicine.