Body Composition: 
How it is Assessed and its Relationship to Cranial Cruciate Ligament Disease in the Dog

by

Amanda Santarossa

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ABSTRACT

BODY COMPOSITION:
HOW IT IS ASSESSED AND ITS RELATIONSHIP TO CRANIAL CRUCIATE LIGAMENT DISEASE IN THE DOG

Amanda Santarossa
University of Guelph, 2017

Advisor:
Dr. Adronie Verbrugghe

In veterinary medicine, it is well documented that there can be negative consequences associated with having an abnormal body composition, either underweight, overweight, or obese. Thus, it is important to assess the body composition of animals as an indicator of health. This thesis is an investigation of how body composition is assessed in companion animals by the veterinary team, and how body composition may be related to cranial cruciate ligament disease in the dog. Veterinary teams most commonly use body weight and body condition scoring methods to assess body composition, however, veterinary teams do not always assess body composition in their patients, although this is recommended by current nutritional assessment guidelines. Dogs with cranial cruciate ligament disease were found to be more overweight or obese compared to a control group, but the association between obesity and the development of this disease is still unclear.
First and foremost, I would like to express my deepest gratitude to my wonderful advisor, Dr. Adronie Verbrugghe. Without her constant support, guidance, and expertise, this research would have not been possible. She was always available when I had questions, even when she was on maternity leave! I am forever grateful to her for giving me the opportunity to work on these research projects, with an amazing group of people, and for teaching me so many valuable lessons the last few amazing years. She has had a profound impact on my academic career, my personal growth, and my future aspirations. I could not have asked for a better advisor and mentor.

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<td>AAHA:</td>
<td>American Animal Hospital Association</td>
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<tr>
<td>ACL:</td>
<td>Anterior Cruciate Ligament</td>
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<td>ANOVA:</td>
<td>Analysis of Variance</td>
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<td>BIA:</td>
<td>Bioelectrical Impedance</td>
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<td>BCS:</td>
<td>Body Condition Score</td>
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<td>BF:</td>
<td>Body Fat</td>
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<td>Body Fat Index</td>
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<td>Body Fat Percentage</td>
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<td>BMC:</td>
<td>Bone Mineral Content</td>
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<td>BMD:</td>
<td>Bone Mineral Density</td>
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<td>BW:</td>
<td>Body Weight</td>
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<td>CT:</td>
<td>Computed Tomography</td>
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<td>CCL:</td>
<td>Cranial Cruciate Ligament</td>
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<td>CCLR:</td>
<td>Cranial Cruciate Ligament Rupture</td>
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<tr>
<td>DEXA:</td>
<td>Dual Energy X-ray Absorptiometry</td>
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<td>IBW:</td>
<td>Ideal Body Weight</td>
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<td>LSTM:</td>
<td>Lean Soft Tissue Mass</td>
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<td>MRI:</td>
<td>Magnetic Resonance Imaging</td>
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<td>MCS:</td>
<td>Muscle Condition Score</td>
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<tr>
<td>OVC-HSC:</td>
<td>Ontario Veterinary College Health Sciences Centre</td>
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<tr>
<td>QMR:</td>
<td>Quantitative Magnetic Resonance</td>
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<tr>
<td>S.H.A.P.E.:</td>
<td>Size, Health, And Physical Examination</td>
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<tr>
<td>S.E.:</td>
<td>Standard Error</td>
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<tr>
<td>VHT:</td>
<td>Veterinary Healthcare Team</td>
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<td>WSAVA:</td>
<td>World Small Animal Veterinary Association</td>
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CHAPTER 1:
LITERATURE REVIEW

CURRENT KNOWLEDGE ON ASSESSING BODY COMPOSITION AND ITS RELATIONSHIP TO CRANIAL CRUCIATE LIGAMENT DISEASE IN THE DOG

A Santarossa

Department of Clinical Studies, Ontario Veterinary College, University of Guelph, 50 Stone Road, Guelph, Ontario N1G 2W1, Canada
1.1 INTRODUCTION

Historically, the body composition of wild animals has been assessed as a way to determine an animal’s fitness in relation to its health and survival (1). For domesticated animals, body composition is assessed by veterinarians for a similar purpose, as an indicator of animal health (2). In canine and feline medicine, evaluating body composition has become of increasing importance as the prevalence of abnormal body condition is increasing in pets. Obesity is the most common form of malnutrition in cats and dogs, affecting longevity and quality of life (3–5). Meanwhile, an aging pet population and development of chronic diseases leads to an underweight body condition which can influence survival (6,7).

Body composition describes the sum of biological components that make up an animal’s body (1,2). These body components may be divided into different compartment models, but for the purposes of this review, the three-compartment model will be used (1). The three-compartment model divides the body into a body fat (BF) compartment, a bone compartment, and a lean soft tissue mass (LSTM) compartment (1). The LSTM compartment includes gut contents, water, muscle, organs, and other non-fat organic matter (1,2).

Various methods are available to veterinarians in private practice, referral clinics, or in research settings to assess body composition, which vary in their accuracy, practicality, and objectivity (2). Research has shown that companion animals that are overconditioned or underconditioned can have negative health consequences compared to those at a healthy body condition (8,9). Some of these implications include overconditioning influencing the progression
of osteoarthritis (10,11). While this has been evaluated extensively (12), body composition has only been minimally evaluated for another orthopedic condition which affects the adult dog, cranial cruciate ligament (CCL) disease (13–16). The function of the CCL, located in the stifle joint, is to prevent stifle instability by preventing cranial displacement and internal rotation of the tibia in relation to the femur. Rupture of the CCL is the most common cause of hind limb lameness in dogs, causing significant instability, inflammation and pain (13,17–19). Cranial cruciate ligament disease involves the degeneration of the cranial cruciate ligament, from stretching of the ligament, to a full ligament tear (19). Due to the prevalence of CCL rupture in dogs, the relationship between body composition and this disorder should be further evaluated.

This review will focus on the canine body composition, how it can be assessed, and the importance of maintaining a healthy, ideal body condition. This review will also describe the risks associated with amounts of BF, muscle, and bone deviating from ideal body condition in the dog. Finally, CCL disease will be explained, outlining currently known risk factors, and examining body composition as a possible risk factor for CCL rupture.

### 1.2 THE METHODS OF ASSESSING BODY COMPOSITION

Since BF, LSTM, bone, and other biological components are dispersed throughout the body in a heterogeneous fashion, it is often challenging to assess body composition accurately (2). The true ex-vivo gold standard for assessing body composition in dogs is chemical analysis, which accurately determines composition by breaking down tissues into fat, proteins, and ash by
carcass analysis (2,20). Since this cannot be used in living dogs, other in-vivo methods are available, some of which have been validated with chemical analysis (20).

In-vivo methods to assess canine body composition can be divided into body weight (BW) measurements, scoring systems, morphometric techniques, imaging techniques, impedance techniques, and dilution techniques (1,2). Use of these latter techniques to determine body composition of dogs can vary on the precision required, cost, invasiveness or other factors (2).

1.2.1. Body Weight

Measuring BW is common in veterinary practice, as an accurate BW is needed to determine drug dosages, the rate of intravenous fluids administration, and caloric requirements. Yet, BW cannot be used alone to assess body composition, and should be used along with another method because BF and LSTM cannot be determined if only using a BW measurement (2,21). A dog’s BW may be compared relative to a breed standard, or its ideal BW, which is an estimated BW for when they are in ideal body condition (4). Yet these are not an accurate assessment of body composition, as body weight can vary based on muscle loss/gain, fat loss/gain, fluid balance, and the fullness of the gastrointestinal tract and bladder (2,21).

1.2.2 Scoring Methods and Morphometry

Body condition scoring (BCS) systems uses visual and palpable characteristics to estimate the amount of adiposity in dogs, where areas of interest include the ribcage, abdomen, and waist (22). While several scoring systems are available, the 5-point scoring system, and the 9-point scoring system which was validated by Laflamme, are commonly used (22,23).
Muscle condition scoring (MCS), while not yet validated in dogs, is recommended as an indicator of muscle wasting (24,25). The validated scoring system in cats evaluates the amount of muscle wasting based on palpation of muscle over the skull, scapulae, lumbar spine and wings of the ilia (26).

Morphometry measures the size, stature, and shape of a being. For animals, this is often termed zoometry (2). This often involves measuring different areas of the body to evaluate changes in dimensions, or to estimate BF and LSTM components, using a tape measure or calipers (2). Only a few morphometric measurement systems have been developed for use in dogs, likely due to the variation in size and stature between dog breeds (27,28).

1.2.3. Imaging and Absorptiometry Techniques

Various imaging and absorptiometric techniques are available which allow for visualization and quantification of BF and LSTM. These include using radiographs, ultrasound, and advanced imaging techniques like computed topography, magnetic resonance imaging, and dual-energy x-ray absorptiometry (DEXA).

Linder and colleagues found that there was a significant association between subcutaneous fat thickness measured on dorsoventral or ventrodorsal thoracic radiographs and BCS, yet there were various study limitations such as possible inclusion of muscle when measuring fat on the ribcage which may influence the results (29). Additionally, other than this
study, there is limited research on this method to assess body composition in companion animals, so further research is warranted.

While ultrasound is used often to assess body composition in large animals like cattle (30), it’s use in companion animals is limited to a few investigations. These studies have found that measuring subcutaneous BF at the level of the lumbar region, was highly correlated with total BF for estimating body composition (31,32). While ultrasound is a rapid method and non-invasive, limitations include the pressure and placement of the probe, and cost of the equipment (2).

Both computed topography (CT) and magnetic resonance imaging (MRI) have been investigated to determine body composition in cats and dogs in comparison to DEXA (33–37). While both are found to correlate well with DEXA, there are limitations to using these devices to assess body composition due to the high cost of the equipment, and need for anesthesia.

Dual-energy x-ray absorptiometry uses photons at two different energy levels to non-invasively and rapidly determine body composition in dogs, by measuring the level of absorbance of the photons in different tissues (20). This measurement then allows for BF, LSTM, and bone mineral density to be determined. Speakman and colleagues found that DEXA estimates were highly correlated against chemical analysis in both cats and dogs (20). This validation study found that there were some discrepancies, although small, between chemical analysis and DEXA, which is due to hydration and inability of DEXA to account for tissue components within other tissue components (ex. mineral in non-bone tissue) (20). The practical
limitations to this method are the cost of the instrument, and that sedation or anesthesia is required to provide immobilization for animals (38).

1.2.4 Impedance and Dilution Techniques

Bioelectrical impedance is a portable and non-invasive method of assessing body composition that is used frequently in humans. It uses an applied electrical current from electrodes to quantify total body water, LSTM and BF (31). While this may be a practical method to be used in veterinary medicine, more research is needed to validate it, and results may be affected by placement of electrodes, temperature, and positioning of the patient (2,39).

Deuterium oxide dilution or isotope dilution measures total body water, by labelling the body’s water pool with deuterium and thus can then be used to quantify BF and LSTM (2). Studies have examined its use in dogs and cats with good results (27,36,37). It has also been compared to DEXA, and validated against chemical analysis in dogs (27,40). However, since deuterium oxide dilution measures total body water, hydration status may influence results (2).

1.3 CURRENT RECOMMENDATIONS IN VETERINARY PRACTICE

In 2008, research in the UK found that body composition was not recorded frequently in the medical records of dogs referred to a teaching hospital (5). In the records of 148 dogs, a BCS was only recorded once for one dog on one occasion, body condition of 29% of dogs was assessed subjectively, and BW was only recorded in 70% of dogs (5). These infrequent
recordings may mean that veterinarians were overlooking abnormal body conditions in their patients. The authors speculate that this may be due to lack of awareness of BCS systems, perception of obesity as a disease, and limited time in consultations (5). It is unclear whether these same results would be found in another population (i.e. in North America).

Rolph and colleagues also sought to determine how much the overweight or obese status of dogs were recorded in the patient medical record (41). In this study, the overweight or obese status was reported in only 1.4% of canine medical records, suggesting that obesity is underreported. This is a concern, as obesity can be very detrimental to pet health, so veterinarians should ensure that they are communicating the importance of appropriate body condition to pet owners.

In 2010, the World Small Animal Veterinary Association (WSAVA) and the American Animal Hospital Association (AAHA) developed nutritional assessment guidelines, which aid veterinary teams in assessing the diet, feeding management, and health of every pet in a veterinary practice (24,25). Along with other key features, nutritional assessments involve an evaluation of the patient’s body composition, which can provide valuable information on the patient’s health, for example if they are becoming ill or being overfed by owners (24,25). The methods recommended by the AAHA and WSAVA nutritional assessment guidelines include BW, MCS, and BCS, which should be performed on every patient at every consultation (24,25). Currently, no method exists that is both accurate, objective, and practical to assess body composition of companion animals in veterinary practice, which identifies a need for continued research in this area (2,3,5).
Both of these studies (5,41) that evaluate how obesity is recorded in the medical record fail to determine the importance of body composition as perceived by veterinary teams. It is also not yet known how many veterinary teams have implemented the AAHA and WSAVA nutritional assessment guidelines in their practice. Further work is needed to determine why an underreporting of obesity exists in the veterinary field.

1.4. IDEAL BODY CONDITION

In human medicine, a normal body composition is typically defined by body mass index (BMI), where adults should have between 18.5–24.9 kg/m² (42). Alternatively, males should have between 12-20% BF, whereas females should have between 20-30% BF (42). Meanwhile, dogs with normal body composition should have roughly 15%-20% BF (4,22). While there are some differences between sexes, with females tending to have more body fat than male animals, neutered dogs will have an increased risk for becoming overweight or obese compared to intact dogs (4,43).

1.4.1 Determining Ideal Body Weight

A dog’s ideal body weight (IBW) is important to calculate if they need to gain or lose weight. There are multiple approaches available to estimate IBW:

a. Obtain an IBW from the patient’s medical record. Ideally, an IBW would be indicated when the record states an BW with an ideal BCS (4). Body weight at one year of age is also
often used, however, this may not be a true indication of IBW if the dog was underfed or overfed during the first year of growth (4).

b. Calculate the IBW using current weight and body fat percentage (%BF) in an equation (4):

\[ IBW = \frac{Current\ Weight \times (100\% - percent\ body\ fat\ [%BF])}{0.80} \]

This equation is based on the estimation that a dog’s body contains roughly 20% BF and 80% LSTM when they are at a normal, healthy body condition (4).

c. Use breed standards (44,45). While this can give an estimate of IBW for a specific breed, it may not provide a truly accurate assessment of IBW considering the variability of purebred individuals. One study reported that 18% of show dogs are overweight, outlining that breed standards may not be the best estimate for IBW (44,45). In these show dogs, breeds such as the Beagle, Newfoundland, Chinese Pug, English Bulldog, and Labrador Retriever, with characteristics like sturdy or muscular, had significantly higher BCS than other breeds (45). Breeds with slender or elegant characteristics were more at risk for being underweight, as seen in breeds such as the Great Dane, Greyhound, Whippet and Borzoi, which had a lower BCS (45). This study shows that by attempting to correspond to the breed standard, dogs may be at risk for being underweight or overweight, instead of the preferred ideal body condition. This likely also would not be applicable for mixed-breed dogs.

d. Estimate the IBW based on current BW and BCS, which is the least accurate method (46).
1.5. THE THREE-COMPARTMENT MODEL

As mentioned previously, the three-compartment model divides the body into a BF compartment, a bone compartment, and a LSTM compartment (1). Each compartment has a specific purpose for storing nutrients and aiding in metabolism, however, insufficient or excess amounts of these tissues can affect overall health.

1.5.1 Body Fat

After eating, fat is broken down into monoglycerides and fatty acids, which are transported by chylomicrons from the digestive tract, through the lymphatic system, and into the circulatory system (47). From there, the fatty acids are taken out of the chylomicrons via lipoprotein lipase, and are stored in adipose or muscle tissue (47). White adipose tissue, a specialized form of connective tissue, is composed of adipocytes which store fat, so that it can be used later as a form of energy (48). Adipose tissue also acts as a storage form for essential fat-soluble vitamins, so dietary fat also allows for improved fat-soluble vitamin absorption (49).

Other than the storage of fat, adipose tissue also has hormonal and thermoregulatory functions (47). Adipocytes release cytokines, hormones, and peptides which contribute to homeostasis, inflammation, and energy balance (50). These compounds, otherwise known as adipokines, also have inflammatory properties, which can contribute to the development of co-morbidities (50).

A certain amount of BF is required for maintenance of essential biological functions, however, when there is insufficient BF, caused by starvation or disease, or if there is excess BF from obesity, there can be detrimental impacts on human and animal health (51).
1.5.1.1 Insufficient Body Fat

An animal can have insufficient amounts of BF due to malnutrition or disease (6). During periods of starvation, after carbohydrate stores are utilized, fat gets broken down for energy (51). During this time, ketosis begins where ketone bodies are produced as an energy source for the brain (51). Ketosis spares protein degradation until almost all of the body’s fat stores are utilized (51). Insufficient amounts of BF allow for this process to occur more rapidly, causing a faster degradation of protein stores, followed by a severe decline in health and potential death (51). This is why many underweight patients, with a loss of both BF and LSTM, have a poor prognosis when affected by disease (6).

1.5.1.2 Excess Body Fat

An overweight or obese body condition is defined as the accumulation of excess BF, which has been shown to cause a low grade inflammatory state and negative health complications in both humans and companion animals (3,4). Multiple studies have estimated that the percentage of overweight and obese adult dogs in the US ranges from 34% to 54% (52,53).

Obesity in humans is mainly linked to excess energy intake, however, genetic, environmental, social, and economic factors also play a role in the complex etiology of this disease (51,54). Similar factors can also be attributed to obesity in dogs (3). The main risk factors of overweight and obese body condition in dogs include breed, overfeeding, activity level, age, neuter status, and existing disease conditions (3,4,55). Certain breeds have been shown to have a genetic predisposition towards obesity, such as Labrador Retrievers, Golden
Retrievers, Cairn Terriers, Cocker Spaniels, Basset Hounds and Beagles (3,4,53). Age has also been shown to have an effect on obesity, where multiple studies reported that the prevalence of excess body fat increases with age in dogs (53). Neutered dogs also have an increased risk of becoming overweight or obese compared to intact dogs, due to decreased energy requirements caused by the loss of hormonal androgens (4,56). There are also diet-related risk factors such as caloric density of food, palatability of the diet, and feeding method (4).

In human medicine, a higher body mass index (BMI) has been found to correlate with increased mortality and increased risk for diseases such as heart disease, stroke and cancer (51,57). Similar observations are seen in dogs, where excess BF can exacerbate a wide variety of diseases, such as metabolic abnormalities, endocrinopathies, orthopedic disorders, cardiorespiratory disease, urogenital disease, and cancer (3,4,55). White adipose tissue has been shown to secrete pro-inflammatory adipokines and increase oxidative stress, which causes a low-grade inflammatory state in obese dogs, therefore exacerbating a variety of disease states (4,50).

An overweight or obese body condition can also impact the lifespan of dogs. This is best depicted in the Canine Lifespan studies which followed 48 Labrador Retrievers from birth until death (10,11,58). Dogs from seven litters were paired at 6 weeks of age into either a control-fed group or restricted-fed group. The restricted-fed group was fed 75% of the amount that the control-fed group was fed. As adults, dogs in the control-fed group had a lower BCS than the dogs in the restricted-fed group (BCS 4.6 ± 0.19 vs. 6.7 ± 0.19), indicating that dogs in the restricted-fed group were maintained at an ideal body condition, while dogs in the control-fed group were overweight (58). Considering that control-fed dogs were overweight and had not
been allowed to become obese, the conclusions of these studies show the large impact that a small amount of excess BF has on canine health (10,11,58). Lean, restricted fed-dogs had a significantly longer median lifespan, 2 years longer, than the control group (58). Lean dogs also had a delayed onset of chronic diseases, such as cancer, osteoarthritis, hepatic disease, and hypothyroidism when compared to their overweight counterparts (58). These ground-breaking studies have shown how much excess BF affects the quality of life, longevity, and overall health in dogs.

1.5.2 Lean Soft Tissue Mass

As described in the three-compartment model of body composition, LSTM includes gut contents, water, muscle, organs, and other non-fat organic matter (1,2). Thus, a major component of LSTM that is subject to change is muscle mass.

After eating, proteins from food are broken into amino acids in the digestive tract, which are then absorbed into the bloodstream (47). Proteinogenic amino acids are then combined to form proteins which enter cells in tissues, like muscle, to replenish protein stores and form specialized muscle contractile proteins (47). These proteins then contribute to the formation of actin, myosin, and actomyosin, which make up muscle fibers in skeletal muscle (47,59).

In dogs, generalized muscle loss can occur as a result of starvation or malnutrition, cachexia, sarcopenia, or caloric restriction (59,60). Alternatively, localized muscle loss can occur due to atrophy from disuse, namely due to orthopedic and neurological disorders (59).
1.5.2.1. Generalized Muscle Loss

After weeks of starvation, when carbohydrate and fat stores are abolished, amino acids will be used to maintain biological functions in the body (47). This loss of protein occurs rapidly, and as such, cellular functions also decreases rapidly without the provision of amino acids, fat, and carbohydrates through the diet (47). Thus, muscle loss will occur due to degradation of skeletal protein in periods of starvation.

In chronic disease states, metabolic changes can occur that cause muscle mass to be metabolized over adipose tissue, which is called cachexia (60). Cachexia describes the loss of muscle, accompanied by weakness, anorexia, and weight loss as a result of disease (7,61). It is important to note that cachexia is different from simple starvation. In a healthy animal undergoing starvation, BF becomes utilized as an energy source to conserve LSTM (7,61). In cachexia, fat utilization is limited and there is a continued loss of LSTM (7). Diseases that typically cause cachexia in dogs include; cancer, congestive heart failure, and chronic kidney disease (7). Multiple studies have linked low BCS to poor prognosis and decreased survival time in these disease states (62–65). For example, one study found that cachexia was significantly associated with heart failure and circulating cytokine concentrations in dogs with heart failure (66). It is important to mention that anorexia and weight loss are two of the most common factors that influence a client’s decision for euthanasia of their chronically diseased pet, as seen in a study on dogs with congestive heart failure (8). Therefore, it is crucial to resolve weight loss by addressing the underlying disease, while ensuring adequate nutritional support for the diseased patient (7,61).
Weight loss that occurs with aging is called sarcopenia (7). Older dogs are prone to sarcopenia due to a decreased appetite, clinical disease, and changes in metabolism with age (67–69). Chronic diseases, such as renal failure or cancer, can cause additional weight loss in geriatric pets, as explained above (67). Therefore, it is important to treat these chronic diseases appropriately, with diets that provide nutritional support to improve health and body composition (67).

Some muscle loss has been also been observed in obese dogs undergoing caloric restriction for weight loss. German and colleagues reported that obese dog undergoing weight loss had a loss of LSTM that was correlated with the percentage of total weight lost (70).

1.5.2.2. Localized Muscle Wasting

Certain orthopedic diseases, such as hip dysplasia, CCL rupture, fractures and OA will cause significant lameness and pain in dogs, leading to decreased mobility (71). Not only does this decreased activity often lead to weight gain if caloric intake is not adjusted, but it also can cause muscle wasting due to disuse (71). For example, muscle atrophy can be seen in the pelvic limb muscles of dogs with hip dysplasia or Legg-Calvé-Perthes disease (71). In CCL rupture, severe muscle atrophy may be present in the quadriceps muscle before surgery, and the amount of atrophy has been shown to correlate to the severity of the injury (71). Although their function is restored after a successful orthopedic surgery, dogs may still have muscle atrophy years after surgery (71). For example, after CCL repair, dogs showed muscle atrophy 2 weeks postoperatively, but muscle mass began to increase after 4 weeks postoperatively (72). Muscle atrophy was also noted in dogs 1 year after surgical repair of the CCL and in 50% of dogs 8 years after femoral head and neck excision to treat hip dysplasia (71). Therefore, it is important
to monitor muscle mass in dogs with orthopedic disease, increasing activity gradually to rebuild muscle mass and muscle strength.

Neurological disorders can also commonly lead to localized muscle wasting. For example, a common neurological disorder in dogs is intervertebral disc disease. Intervertebral disc disease occurs when the intervertebral disc, which rests between vertebrae, protrudes into the spinal cord, causing pain, weakness, and loss of normal ambulation (73,74). Intervertebral disc disease commonly affects chondrodystrophic breeds such as Dachshunds, French Bulldogs, and Cocker Spaniels, however large breed dogs can also be affected by thoracolumbar IVDD, but more commonly cervical IVDD (73,74). In cases of thoracolumbar intervertebral disk disease, there may be mild ataxia of the hindlimbs, and in severe cases, complete paralysis may occur (73,74). This results in limited or no use of the hindlimbs, leading to muscle atrophy from disuse (71,73).

1.5.3. Bone

Bone, a significant mineral store in the body, and integral part of the musculoskeletal system, is formed by osteoblasts, and degraded by osteoclasts (75). In adult dogs, bone mineral content and density have been evaluated in relation to body composition, orthopedic conditions like fractures or implant placements, and hormonal changes (75–78).

In relation to body composition, the bone mineral content of healthy dogs is estimated to be 3-4% of their total body weight, with a strong correlation with the amount of LSTM (79).
After weight loss in dogs, bone mineral content was minimally, but significantly decreased compared to baseline, likely due to its relationship with LSTM, which also decreased significantly in this study (70).

Mechanical load can also affect bone remodelling, as bone will remodel in response to increase force or load (75). In these cases, compact bone will thicken in certain areas where stress is applied and will thin in places where stress is no longer applied (75). Disuse will also impact bone remodelling. One study found that after a CCL repair surgery in dogs, bone mineral density was found to decrease in the surgical leg compared to the non-surgical leg as a result of disuse (72).

Hormonal changes control mineral homeostasis in the body, and thus affect bone mineralization. For example, nutritional secondary hyperparathyroidism (NSHP) can occur in dogs fed a diet that does not contain sufficient calcium, or has an imbalanced calcium-to-phosphorus ratio (60). In NSHP, the lack of dietary calcium, stimulates parathyroid hormone secretion, which then converts 25-hydroxycholecalciferol (a form of Vitamin D3) into its active form 1,25-dihydroxycholecalciferol (80). Parathyroid hormone and 1,25-dihydroxycholecalciferol then act together to stimulate bone resorption, as the body attempts to recover extracellular stores of calcium (60,80). This shows how the intricate balance of vitamins, minerals, and hormones influence bone mineralization.

The changes in bone density affect the structural integrity of the skeletal system (75). Compound fractures and deformities as a consequence of bone remodelling can then occur that
significantly affect a dog’s mobility, pain, and quality of life (60). Thus, ensuring mobility and appropriate nutrition is important for the maintenance of bone mineral density in dogs (72,75).

**1.6 BODY COMPOSITION AND CRANIAL CRUCIATE LIGAMENT DISEASE**

1.6.1 Characteristics of Cranial Cruciate Ligament Disease

Composed of the craniomedial band and the caudolateral band, the CCL works along with the caudal cruciate ligament (CaCL), the collateral ligaments, the menisci, and the patellar ligament to prevent displacement and rotation of the tibia in relation to the femur, in both flexion and extension of the stifle joint (19,81). The CCL originates from the caudomedial aspect of the lateral femoral condyle to the cranial intercondylar notch in a cranial to caudal and medial to lateral direction (see Figure 1.1) (19). Covered by a synovial membrane, this ligament is composed of; collagen bundles arranged into fascicles, connective tissue, and very few blood vessels and nerves (19). Not only does the CCL provide stability to the stifle joint, but it also counteracts cranial tibial thrust (CTT), the shear force of the tibia in the cranial direction that is caused by internal and external forces on the hind limb (19), however, the exact biomechanics behind this are controversial (82). Recent research found that the femur actually may slip caudally relative to the tibia, which may influence how this disease is managed (82–84). This type of motion mainly occurs due to the angle of the tibial plateau, since in the dog, the tibial plateau is not perpendicular to the central line of motion between the hock and stifle (19).
Owners often think that CCL rupture occurs due to a traumatic event; however, it is actually part of a degenerative pathological process (85). Clinical signs of CCL rupture include; a history of weight-bearing pelvic limb lameness, stiffness after activity or rest, an unsymmetrical sitting posture, and audible clicking sound from of the affected limb(s) during walking (19,85). There may also be joint effusion, peri-articular fibrosis, and muscle loss noticed in the affected stifle(s) and pelvic limb(s) (71,85).

In humans, the CCL is called the anterior cruciate ligament (ACL), and has the same anatomy and function in the human knee joint. The current annual incidence of ACL tears in humans is between 0.001-0.01% (86). ACL tears are more often associated with sports injuries and trauma in young, physically active individuals (86). An ACL tear can occur as the result of either contact or non-contact related trauma, however, in dogs, CCL tears most commonly occur due to ligament degeneration (14,19). A retrospective study found that on average, CCL rupture affects roughly 4.87% of dogs in North America (87). However, this study was conducted by analyzing a database of medical records in a veterinary referral hospital, which would not provide the true prevalence for dogs that were not referred (87). Other observational studies have shown that the prevalence ranges from 0.56%-2.55% in dogs (87–90).

Unfortunately, many dogs with a unilateral CCL rupture often develop contralateral CCL rupture, with roughly 35% of dogs developing contralateral rupture at a later time, ranging from 3 weeks to 5 years (14,91). The risk of contralateral rupture increases 10-fold by the presence of severe osteoarthritis and effusion in the contralateral joint (92). Typically, in dogs with unilateral CCL rupture, the progression of osteoarthritis increases in the affected limb(s) due to stifle
instability (91,92). Humans with ruptured ACLs also have an increased risk of rupturing the contralateral ACL, however, the risk of this is between 3-25% in the two years following the first ACL rupture (86). This is a significantly lower risk compared to dogs, and is likely due to the etiological differences of disease in humans and dogs.

1.6.2 Risk Factors for CCL Rupture

In 2003, roughly $1.32 billion was spent on treatment of canine CCL ruptures in the US (18). With this large cost, determining the risk factors is important if the incidence of cruciate disease in the canine population is to be reduced. Currently known risk factors include age, breed, reproductive status, conformation, and body weight (14).

1.6.2.1 Age

Dogs over 4 years of age have been shown to be at an increased risk, with giant breeds showing CCL rupture at earlier ages (13,80,84). The peak incidence of CCL rupture occurs between 7-10 years of age (15,90). However, large breeds have been found to rupture their CCL at a younger age compared to small breed dogs (15,16). With increasing age, the CCL continues to degrade due to histological and biomechanical changes that influence ligament strength (14,15,88).

1.6.2.2 Breed and Genetics

Multiple studies have shown that the most common at-risk breeds for CCL rupture include the Newfoundland, Labrador Retriever, Rottweiler, Boxer, Mastiff, West Highland White Terrier and Yorkshire Terrier (14–17,87,88,93). Breeds not at risk include the Doberman Pinscher, Old
English Sheepdog, Dachshund, Greyhound, and Bassett Hound (14–16,90). In the human literature, studies have shown that there is a familial link towards ACL rupture (94). In dogs, similar studies have been conducted to determine if there is a genetic predisposition for CCL rupture (95,96). One study found that certain genes related to collagen, keratin, extracellular matrix, and elastin may be relevant towards CCL susceptibility in multiple breeds of high-risk dogs (95). The authors believe that mutations (single nucleotide polymorphisms) in these genes may cause an unstable and weak CCL ligament in highly susceptible breeds, such as the Newfoundland dog and Rottweiler (95). Another study has evaluated the heritability of CCL rupture in Newfoundland dogs, and have found that there is an autosomal recessive mode of inheritance, with moderate heritability present (97). In this study, it was found that in Newfoundland dogs, 27% of the phenotypic expression of CCL is attributed to genetics, with 73% of phenotypic expression related to environmental factors (97). Future research is still needed due to contrasting evidence in this area (95–97).

1.6.2.3 Sex and Gonadectomy

In humans, young, active females are 2 to 6 times more likely to have an ACL injury than active males (98,99). This disparity has been attributed to hormones, genetics, age, previous injuries, and neuromuscular differences between males and females (98). There has been a wide variety of evidence on whether a specific sex is more at risk for CCL injury in dogs. Multiple studies have shown that spayed females have an increased prevalence of CCL rupture over neutered males and intact dogs (15,88,90,99). However, other canine studies have not shown any significant differences in CCL risk between the sexes (16,87). Although there are varying
accounts on which sex is more at risk for CCL rupture, studies have shown that gonadectomised dogs are at greater risk for CCL rupture than intact dogs (15,16,87,88,90,91,93,99). Many of these studies have suggested that obesity may play a role in CCL rupture due to the increase in BF after neutering, however, it is important to note that body composition was not assessed in these studies, so a direct link to obesity cannot yet be made (15,16,56,88).

1.6.2.4 Conformation

Canine stifle and pelvic limb morphology have been studied to determine the relationship between conformation and risk of CCL rupture in dogs (100). The amount of flexion is vastly different between the flexed canine stifle (22°) and the straight human knee (<5°), which is inherent in the anatomical differences between biped and quadruped animals (101). This anatomical difference, along with other risk factors, may explain why the etiology behind CCL ruptures in dogs is very different from human ACL tears. In dogs, the major anatomical characteristics that have been studied in its relationship to CCL rupture have been; pelvic limb musculature, CCL morphology, intercondylar notch, tibial plateau angle, and tibial tuberosity width (82,100–106).

1.6.2.5 Body Composition

In humans, very little research has been conducted on how BMI affects the risk of ACL injury, likely because these traumatic injuries occur most often in young, active people. Uhorchak and colleagues found that an increased BMI was a significant risk factor for non-contact ACL injuries in women cadets, but not in men (107,108). Perhaps this area has not been studied frequently in human medicine due to the physical fitness of young athletes and
differences in disease etiology in humans. When discussing the etiology of CCL rupture in dogs, multiple studies quote obesity as a risk factor (3,18,109). However, the majority of these studies reference research that assesses BW, with few assessing body composition in dogs with CCL rupture. A summary of the literature regarding body composition in dogs with CCL rupture is provided in Table 1.1. Whitehair and colleagues have found that dogs with a BW >22kg had a higher prevalence of CCL rupture than those weighing less than 22kg, with similar results found by Duval and colleagues when studying young dogs (15,16). Similarly, a retrospective study used the medical records of Cocker Spaniels, where body weight was recorded for dogs with humeral condylar fractures, CCL rupture, and intervertebral disc disease, as well as a control group (110). Compared to the control group, Cocker Spaniels with CCL rupture weighed more, however this difference was not statistically significant (110). Few retrospective studies have attempted to categorize BW by breed to estimate body condition (88,90). One study estimated body condition by comparing the BW for each animal to the BW range for its breed based on age and sex (88). This study reported that obese dogs were 4 times more likely to sustain a CCL rupture than dogs at a healthy weight (88). Limitations of this study include that in its retrospective nature, body composition was not determined using methods like BCS. These studies examine BW in dogs with CCL rupture, and considering the significant intra-breed differences in BW it is crucial to assess body composition using previously discussed methods. Body weight provides a good indication of if a dog has lost or gained weight, and may be able to determine if a dog is overweight or underweight compared to its ideal body weight or compared to breed standards. However, these studies do not provide an accurate depiction of the bone, muscle and fat contents in dogs that have CCL injury. Additionally, Adams and colleagues did
also not investigate how long these dogs may have been inactive, which may contribute to weight gain, during a period of lameness (88).

Only a few studies on CCL rupture in dogs include BCS or other body composition assessments in their methods. The first study retrospectively assessed gonadectomy on the development of CCL, hip dysplasia, elbow dysplasia, and various cancers in dogs (111). This study collected the BCS from the medical records of dogs with and without CCL, and state that BCS did not differ between these groups (111). However, the authors did not indicate how many medical records provided a BCS, so the sample size of this portion of dogs may be small and inconclusive (111). Secondly, using a questionnaire, BCS was obtained from veterinary practices to establish risk factors for dogs with CCL rupture (83). From this population, dogs that had a BCS > 4/5 had significantly increased odds (OR=2.1) for CCL rupture compared to those at an ideal BCS (3/5) (83). Griffon and colleagues found no significant difference in BCS between purebred Labrador Retrievers with and without CCL rupture in a multi-institution study, but in this study, the scoring system that was used is not known (112). Finally, Wucherer and colleagues also examined the body composition of overweight dogs with CCL rupture using BCS, DEXA and BW (109). However, overweight dogs were only used to examine successful outcomes after weight loss in dogs receiving surgical and nonsurgical treatment versus those obtaining just nonsurgical treatment (109). While these studies use BCS, a more objective and standardized tool would be beneficial to assess the body composition of dogs with CCL rupture.

Excess BF and/or muscle wasting may play a significant role in the development of CCL rupture in dogs. There is a strong clinical impression that overweight or obese dogs may sustain
a CCL injury more commonly than those dogs kept at an ideal weight (113). Since obesity has been linked to osteoarthritis and other joint disorders, there is the potential for obesity to affect the degeneration of ligaments within the joint. The low-grade inflammatory state and joint loading that is a consequence of obesity may impact ligament strength and joint laxity. Two recent abstracts highlight the role that inflammatory adipokines have on the stifle joint and CCL in an ex-vivo study in dogs (114,115). These studies found positive correlations in gene expression between both adipokines and cartilage biomarkers, and between body weight and tumor necrosis factor alpha (TNF-α) in samples of CCL and menisci from dogs undergoing surgical repair (114,115). Because of this, an overweight and obese body condition may have an impact on the development of CCL rupture; however, further work is required (114,115). Muscle wasting and very little activity may also cause a predisposition toward ligament injuries in dogs, as the support and strength of limb musculature is decreased (71). Immobilization and cage rest can lead to CCL damage due to bone resorption, decreased collagen mass, reduced glycosaminoglycans, and water content which significantly decrease ligament strength (71). Therefore, body composition should be further examined as a potential risk factor for dogs with CCL rupture (14).

1.7 CONCLUSION

Underweight, overweight, and obese body conditions have been shown to negatively impact the health and quality of life of dogs (2,3,50,62,65). An underweight body condition caused by loss of BF and LSTM impacts muscle quality, survival, and disease prognosis (6).
Alternatively, excess BF causes a low-grade inflammatory state in dogs, which exacerbates a variety of diseases, such as cancer, urinary tract infections, cardiorespiratory disease, and osteoarthritis (3,11).

Obesity, and likely other body conditions, are underreported in the medical records of dogs in the United Kingdom (5,41). It is unclear why this occurs, but it may be helpful to determine what veterinarians think about the methods available to assess body composition in primary practice, as this may influence their use. Perhaps these results may also be different with the adoption of nutritional assessment guidelines in primary practice. Further work is needed in this area.

Research is also limited on how body composition is associated with CCL rupture (14). Cranial cruciate ligament rupture is a common injury in large breed dogs, requiring surgical and/or medical treatment to achieve stifle stability (15,16,88,90,91). Multiple risk factors are currently known for this degenerative joint disorder, such as age, breed, neutered status and anatomy (14). Some research has been conducted on body weight and BCS in dogs with CCL rupture, however due to limitations in this research more work is needed in this area. Research focused on body composition should be conducted to determine how BF, LSTM, and bone play a role in the degeneration of the CCL in dogs (14–16,90,110).
1.8 – THESIS OBJECTIVES AND HYPOTHESES

Objectives

1. Determine how often veterinary teams in Ontario, Canada assess body composition in cats and dogs.
2. Identify if veterinary teams in Ontario, Canada know of the current nutritional assessment guidelines.
3. Identify what methods veterinary teams use to assess body composition of cats and dogs in Ontario, Canada.
4. Describe the body composition of dogs with cranial cruciate ligament rupture in comparison to a control group free of orthopedic disease.
5. Evaluate body composition of dogs using multiple methods of assessment.

Hypotheses

1. Not all veterinary health care teams always assess body composition in companion animals.
2. Body weight and body condition scoring are used more frequently than other methods.
3. Dogs with cranial cruciate ligament rupture will have a higher BCS, lower muscle condition score (MCS), higher body fat percentage (BF%), lower lean soft tissue mass, and lower bone mineral density (BMD) compared to control dogs.
### 1.9 TABLES AND FIGURES

**Table 1.1:** Summary of literature evaluating body composition in dogs with cranial cruciate ligament rupture.

<table>
<thead>
<tr>
<th>Reference</th>
<th>Study Type</th>
<th>Country</th>
<th>Breed</th>
<th>Sample Size</th>
<th>Method to Determine Body Condition</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Whitehair et al., 1993</td>
<td>Retrospective case-control</td>
<td>USA</td>
<td>Various breeds</td>
<td>CCLR - 10,769 Control - 591,548</td>
<td>BW</td>
<td>Dogs &gt; 22kg had significantly increased risk of CCLR than dogs &lt;22kg</td>
</tr>
<tr>
<td>Moore and Read, 1995</td>
<td>Retrospective case series</td>
<td>Australia</td>
<td>Various breeds</td>
<td>CCLR - 28</td>
<td>Level of overweight / obesity</td>
<td>71% of dogs were considered to be overweight.</td>
</tr>
<tr>
<td>Brown et al., 1996</td>
<td>Prospective case series</td>
<td>USA</td>
<td>Cocker Spaniels</td>
<td>CCLR - 20 Control - 766</td>
<td>BW</td>
<td>Cocker Spaniels with CCLR more likely to weigh more than Control (not significant).</td>
</tr>
<tr>
<td>Duval et al., 1999</td>
<td>Retrospective case control</td>
<td>USA</td>
<td>Various breeds (&lt;2 years of age)</td>
<td>CCLR- 201 Control - 804</td>
<td>BW</td>
<td>Mean body weight was significantly different between groups. CCLR: 35.4 kg Control: not reported</td>
</tr>
<tr>
<td>Marsolais et al., 2002</td>
<td>Prospective clinical trial</td>
<td>USA</td>
<td>Various breeds</td>
<td>CCLR - 51</td>
<td>BCS (9-point)</td>
<td>Mean (± SE) BCS not significantly different between groups. Rehabilitation group: 6.54 ± 0.19 Exercise-restricted group: 6.50 ± 0.22</td>
</tr>
<tr>
<td>Lampman et al., 2003</td>
<td>Prospective case series</td>
<td>USA</td>
<td>Various breeds</td>
<td>CCLR - 755 Control (from NCAS) - 32,055</td>
<td>BCS (5-point)</td>
<td>CCLR group more likely than Control to be overweight or obese. BCS ≥ 4 is a significant risk factor for CCLR: OR (CI) = 2.1 (1.8, 2.5)</td>
</tr>
<tr>
<td>Lund et al., 2006</td>
<td>Cross-Sectional</td>
<td>USA</td>
<td>Various breeds</td>
<td>21,754 dogs from NCAS (~158 had CCLR)</td>
<td>BCS (5-point)</td>
<td>Overweight (OR = 1.7) and obese (OR = 2.1) adult dogs more likely to be diagnosed with CCLR</td>
</tr>
<tr>
<td>Fujita et al., 2006</td>
<td>Prospective clinical trial</td>
<td>Japan / USA</td>
<td>Various breeds</td>
<td>CCLR - 23 Control - 21</td>
<td>BCS (5-point)</td>
<td>Mean BCS not different between groups: CCLR: 3.9 (1-5) Control: Not reported.</td>
</tr>
<tr>
<td>Study</td>
<td>Design</td>
<td>Country</td>
<td>Breeds/Animals</td>
<td>CCLR/Control</td>
<td>Condition estimated (BW vs. breed standard)</td>
<td>Significant differences in body condition categories between CCLR group and Control. “Obese” dogs were more likely (OR = 3.756) to sustain CCLR than control.</td>
</tr>
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<tr>
<td>Adams et al., 2011</td>
<td>Retrospective case-control</td>
<td>UK</td>
<td>Various breeds</td>
<td>CCLR - 68</td>
<td>Control - 223</td>
<td></td>
</tr>
<tr>
<td>Grierson et al., 2011</td>
<td>Retrospective case series</td>
<td>UK</td>
<td>Various breeds</td>
<td>CCLR - 511</td>
<td>Overweight classification in medical record</td>
<td>Overweight dogs more likely to have bilateral CCLR (OR = 1.77, CI 1.05-3.00, p=0.033)</td>
</tr>
<tr>
<td>Gordon-Evans et al., 2013</td>
<td>Randomized blinded controlled clinical trial</td>
<td>USA</td>
<td>Various breeds</td>
<td>CCLR - 80</td>
<td>BCS (9-point)</td>
<td>Median (range) BCS not significantly different between groups. LFS: 7 (3-9) TPLO: 7 (5-9)</td>
</tr>
<tr>
<td>Torres de la Riva et al., 2013</td>
<td>Retrospective case-control</td>
<td>USA</td>
<td>Golden Retrievers</td>
<td>CCLR - 751</td>
<td>BCS (9-point) (not available for all dogs)</td>
<td>No significant difference in mean BCS between sexes of dogs with and without CCLR. CCLR Males: 5.8 Control Males: 5.8 CCLR Females: 5.8 Control Females: 5.8</td>
</tr>
<tr>
<td>Wucherer et al., 2013</td>
<td>Prospective randomized clinical trial</td>
<td>USA</td>
<td>Various breeds</td>
<td>CCLR - 40</td>
<td>BCS (9-point) DEXA</td>
<td>Mean BCS not significantly different between groups. Surgical group: 6.97 ± 0.14 Non-surgical group: 6.74 ± 0.16 Baseline DEXA BF% for both groups = ~30%</td>
</tr>
<tr>
<td>Christopher et al., 2013</td>
<td>Retrospective clinical cohort</td>
<td>USA</td>
<td>Various breeds</td>
<td>CCLR - 162</td>
<td>BCS (9-point)</td>
<td>Median (range) BCS not significantly different between groups. TPLO: 6 (4-9) TTA: 6 (4-8) TR: 6 (4-8)</td>
</tr>
<tr>
<td>Griffon et al., 2016</td>
<td>Cross-sectional</td>
<td>USA</td>
<td>Labrador Retrievers</td>
<td>CCLR – 57</td>
<td>Control – 97</td>
<td>Mean (SD) BCS not significantly different between groups. CCLR: 5.6 (1) Control: 5.5 (0.9)</td>
</tr>
</tbody>
</table>
Abbreviations: BCS, body condition score; BF%, body fat percentage; BW, body weight; CCLR, cranial cruciate ligament rupture; CI, confidence interval; DEXA, dual energy x-ray absorptiometry; LFS, lateral fabellar suture stabilization; NCAS, National Companion Animal Study; OR, odds ratio; TPLO, tibial plateau levelling osteotomy; TR, Tight-Rope surgical technique; TTA, tibial tuberosity advancement; UK, United Kingdom; USA, United States of America
**Figure 1.1**: Cranial view of stifle with patellar fat pad removed. 1a: caudolateral bundle of CCL, 1b: craniomedial bundle of CCL, 2: CaCl, 3: medial meniscus, 4: lateral meniscus. (81)
1.10 REFERENCES


CHAPTER 2:

ASSESSMENT OF CANINE AND FELINE BODY COMPOSITION BY VETERINARY HEALTH CARE TEAMS IN ONTARIO, CANADA

A Santarossa¹, JM Parr¹,², A Verbrugghe¹

¹ Department of Clinical Studies, Ontario Veterinary College, University of Guelph, 50 Stone Road, Guelph, Ontario N1G 2W1, Canada
² Royal Canin Canada, 100 Bieber Road, Puslinch, Ontario N0B 2J0, Canada
2.1 ABSTRACT

Nutritional assessment guidelines recommend that veterinary teams assess the body composition of pets at every visit. The objective of this study was to determine how veterinary teams in Ontario, Canada assess body composition in cats and dogs. An online survey was distributed to veterinary teams, with questions on; how often body composition is assessed, what methods are used, and demographics. Results demonstrated that 66.7% of respondents reported always assessing body composition. Body condition scoring (99.4%) and body weight (99.4%) are used most often, with muscle condition scoring (33.9%) and morphometry (41.2%) used less frequently. Veterinary technicians were less likely to assess body composition compared to veterinarians. These results indicate that veterinary teams use body condition scoring and body weight measurements used most often to assess body composition. However, education of veterinary teams is needed, as body composition should be assessed for every patient as part of a complete nutritional assessment.
2.2 INTRODUCTION

The prevalence of overweight and obese body conditions, caused by the accumulation of excess body fat (BF), is typically between 20% and 60% for adult cats and dogs, depending on the study population (1–3). This accumulation can be caused by excess energy intake or decreased energy expenditure, which lowers quality of life by exacerbating disease and shortening lifespan (2–7). Alternatively, underweight pets displaying a loss of subcutaneous BF, palpable skeletal structure, and muscle wasting; have poor prognosis and survival (8–13). Weight loss and muscle loss can be attributed to: physiological changes, dietary inadequacies, presence of disease, or increasing age (12).

Veterinarians are a trusted resource for pet owners who want to manage their pets body weight (BW) (14). However, owners tend to underestimate the body condition of their pet, so veterinarians must continue to educate pet owners on nutrition and body composition (14–16). In 2010, nutritional assessment guidelines were developed by the American Animal Hospital Association (AAHA) and the World Small Animal Veterinary Association (WSAVA) (17,18). Their purpose is to guide veterinary health care teams (VHTs) through a nutritional evaluation, where a body composition assessment is recommended for every patient (18,17). The question still remains if these nutritional assessment guidelines have made their way into examination rooms in primary care practice, and how VHTs are assessing body composition in their patients.

Body composition is generally ranked on a relative scale, from underweight to obese, with an ideal body condition estimated at 15-20% BF (19,20). In veterinary practice, multiple
methods are available to assess body composition in pets; however, they vary in their accuracy, practicality, and cost (21). Currently, the established nutritional assessment guidelines recommend that all veterinarians and veterinary technicians consistently use body condition scoring (BCS), muscle condition scoring (MCS), and BW measurements for every patient (18,17). Body condition scoring uses both visual and palpable characteristics to estimate subcutaneous BF in pets, while MCS similarly evaluates muscle quality (19,20,22). Body weight is frequently used; however, it cannot differentiate between BF and lean soft tissue mass (LSTM), and should be used along with BCS and MCS to assess body composition. Body weight can also be used to estimate a pet’s condition in comparison to a previous BW measurement, breed standard, or ideal body weight (IBW) calculation (3,21). Morphometric measurements, which use various anatomic lengths and circumferences measured with a tape measure to determine a BF percentage (BF%) or other indexed system (3,23,24) are also used in veterinary practice. Other advanced, uncommon methods like dual-energy x-ray absorptiometry (DEXA) and bioelectrical impedance analysis (BIA), are available to assess body composition in companion animals, however, these may not be applicable to clinical practice because of cost, time required, or increased invasiveness (21).

In two studies from the United Kingdom, BCS and BW measurements to assess body composition were found to be recorded infrequently in the medical records of dogs, and the overweight status of dogs seemed to be underdiagnosed in primary practices (25,26). While veterinary practices have been shown to use BCS and BW to assess body composition, there is no data on the use of MCS or other methods in veterinary practice, and there is limited data on how often body composition is assessed by VHTs in both cats and dogs (3,15,21). While there
are recommendations on developing weight management plans in pets, there is limited data on what occurs in veterinary practice (27).

The present study investigated the use of different body composition assessment methods as reported by VHTs in Ontario, Canada. It was hypothesized that not all VHTs always assess body composition in companion animals, and that BCS and BW are used more frequently than other methods (25,26).

2.3 MATERIALS AND METHODS

2.3.1 Data Collection

Ethical approval for this study was obtained by the institutional Research Ethics Board (REB# 14OC041) prior to survey distribution. The survey was created and distributed online using the Qualtrics Research Suite (Qualtrics©, Provo, Utah, USA). The survey was open from November 2014 to June 2015; and was distributed via social media, postcard distribution at local veterinary conferences, provincial veterinary association websites or newsletters, and by email to veterinary practices in Ontario. Reminder e-mails were sent twice during the study period. Completed responses from veterinarians, registered veterinary technicians, and veterinary assistants that examine cats and dogs in Ontario, Canada, were included in this study.

2.3.2 Survey Design

The survey consisted of fifty-one questions in multiple choice, multiple response, Likert, close-ended, and open-ended format. Eight questions were based on how often body composition
is assessed, VHT’s knowledge of AAHA and WSAVA nutritional assessment guidelines, and VHT’s knowledge, use and opinions on the various methods available to assess body composition in companion animals. These methods include scoring systems, weight measurements, morphometric measurements, and advanced methods. Twenty-three questions in total were included on the system used, the accuracy, ease of use and frequency of BCS, MCS, BW and morphometric measurements in companion animals. Ten questions were included on how respondents assess body composition and determine IBW for pets on a weight management plan. Finally, ten questions were included to determine demographic data of respondents.

2.3.2 Statistical Analysis

Descriptive statistics were used to analyze the data. Frequencies were reported for the following categorical data: body composition assessment, use of body condition scoring, use of muscle condition scoring, use of body weight, use of morphometric measurements, how body composition is assessed in weight management plans, and demographics. Binomial logistic regressions were performed to determine the likelihood that demographics (role in veterinary practice, graduating year, practice type, practice size, species examined in practice, and geographical location) influenced the odds of how respondents assess body composition (how often they use methods, if they have heard of the AAHA/WSAVA nutritional guidelines, what methods they heard of, and their use of BCS, MCS, BW, and morphometric measurements). Significance was set at $\alpha = 0.05$. Data were analyzed using SPSS (IBM© SPSS Statistics for Macintosh, Version 23.0).
2.4 RESULTS

2.4.1 Study Population

When the online survey was closed, 285 online responses were recorded. Survey responses were excluded from data if they were incomplete (93 responses), if the respondent was not from Ontario, Canada (12 responses), and if they do not see cats and dogs in their practice (3 responses). This left 177 responses on which statistical analysis was performed. Since the survey was circulated through social media and various other forms, it is not possible to determine a response rate. The study population consisted of practicing veterinarians, veterinary technicians, and veterinary assistants from Ontario, Canada. Demographic data are summarized (Table 2.1).

2.4.2 Nutritional Assessment and Body Composition Assessment

Although 19.2% of the respondents (34/177) have not heard of AAHA and WSAVA nutritional assessment guidelines, 80.8% (143/177) have heard of these guidelines, of which 25.2% (36/143) have implemented them in their practice. Still, less than half of the respondents that implemented the guidelines (44.4%, 16/36) indicated that they used all three methods together (BCS, MCS, and BW) to assess body condition. Only 66.7% (118/177) of respondents noted they always assess body composition, with the remaining selecting often (24.3%, 43/177) sometimes (7.9%, 14/177), rarely (0.6%, 1/177) or never (0.6%, 1/177). Logistic regression analysis also showed that technicians are 2.7 (95% CI = 1.4 - 5.3) times more likely to not always assess body composition, 2.3 (95% CI = 1.3 - 4.5) times more likely to not always assign body condition scores, and 2.2 (95% CI = 1.1 - 4.3) times more likely to not use muscle
condition scoring compared to veterinarians, but body weight and morphometric measurements are used as often by technicians as by veterinarians.

2.4.2 Common Methods and Uncommon Methods

Respondents were asked different questions about common and uncommon methods. In this survey, common methods include BCS, BFI, MCS, Morphometric measurements, and BW, which have been evaluated in more detail below. Uncommon methods to assess body composition include BIA, deuterium oxide dilution, and different forms of imaging, which include: computed topography (CT), magnetic resonance imaging (MRI), ultrasound, quantitative magnetic resonance (QMR), and DEXA. This is due to their increased cost and decreased practicality in primary practice (21). Respondents were asked which methods they had heard of, which ones they found most applicable to practice, which they found were easiest to use, and which they found were most accurate. A summary of these results are available (Table 2.2). They also were asked which method they would use if the cost associated with this method was not a factor in their decision. Almost all of the respondents (94.4%, 167/177) indicated that they would use an alternative, more accurate method, than the method they are currently using.

2.4.3 Body Weight

The majority of respondents reported measuring body weight on patients in their practice (99.4%, 175/176). Body weight was reported as being either measured always (96.0%, 169/176), or often (4.0%, 7/176). Most (97.2%, 171/176) indicated that measuring body weight was easy or very easy. Roughly 42.6% (75/176) of respondents indicated that measuring body weight was either accurate or very accurate for determining body composition. The remaining selected
neither accurate nor inaccurate (36.4%, 64/176), inaccurate (15.9%, 28/176) or very inaccurate (5.1%, 9/176). Some respondents (16.4%, 29/176) provided additional comments including; that BW cannot determine body composition when used alone, concerns with accuracy due to patient cooperation or scale calibration, and that BW can be useful to communicate to clients if a pet needs to gain/lose weight.

2.4.4 Body Condition Scoring

Similar to BW, BCS is used by 99.4% (176/177) of respondents, of which 68.8% (121/176) use the 5-point scoring system, 38.1% (67/176) use the 9-point scoring system, 2.3% (4/176) use the body fat index (BFI) system, and 0.6% (1/176) use the S.H.A.P.E system. Of the respondents that use BCS, 63.1% (111/176) reported always assigning a BCS to patients, while 28.4% (50/176) selected often, 8.0% (14/176) selected sometimes, 0.6% (1/176) selected rarely. Most respondents (89.8%, 158/177) ranked BCS as being easy or very easy to use, and most (74.4%, 131/176) ranked BCS as accurate or very accurate for assessing body composition. Some of these respondents (29%, 51/176) provided additional comments including concerns about accuracy, subjectivity, positive comments (e.g. fast, easy to use, non-invasive), and negative comments (e.g. difficult for clients to understand, difficult depending on dog breed).

2.4.5 Muscle Condition Scoring

Muscle condition scoring is used by 33.9% (60/177) of respondents. Of those, 68.3% (41/60) indicated that they use a 4-point MCS system, with the remaining respondents indicating that they use an alternative system or subjective assessment of muscle (31.7%, 19/60). Of the respondents that use MCS, 8.5% (5/59) reported always assigning a MCS to patients, while
33.9% (20/59) selected often, 37.3% (22/59) selected sometimes, 20.3% (12/59) selected rarely. Over half of the respondents using MCS, ranked it as being easy or very easy to use (53.3%, 32/60). Most respondents (65.0%, 39/60) ranked MCS as accurate. Some respondents (18.3%, 11/60) provided additional comments on using MCS to assess body composition including positive comments (e.g. fast, easy to use, good for sick/geriatric patients) and negative comments (e.g. concerns about subjectivity, difficult in obese patients, how much loss is normal in geriatric pets?).

2.4.6 Morphometric Measurements

Morphometric measurements are used by 41.2% (73/177) of respondents. Of these respondents, 16.7% (12/72) use a body mass index (BMI) system, 45.8% (33/72) use girth measurements, and 58.3% (42/72) use a BFI system. These respondents used morphometric measurement systems often (5.6%, 10/72), sometimes (20.3%, 36/72), and rarely (14.1%, 25/72). Most respondents that use morphometric measurements said that it had neutral difficulty (45.2%, 33/73) or was easy to use (31.5%, 23/73). According to respondents, morphometry is accurate (21.5%, 38/73) or neutral in accuracy (13.0%, 23/73). Respondents (21.9%, 16/73) provided additional comments including concerns about accuracy, concerns about increased time required, and that this system is used for a specific condition (e.g. obesity, muscle atrophy).

2.4.7 Weight Management Plans

To assess the body composition of patients requiring a weight management plan (weight loss or weight gain), respondents use BW and BCS most frequently. Other methods used include the BFI system, MCS, and morphometric measurements. The majority of respondents indicated
that they assess the body composition of patients on a weight management plan every month. Most respondents indicated that they calculate a patient’s IBW based on BCS or by estimation when developing a weight management plan. These results have been summarized in Table 2.3.

2.5 DISCUSSION

The current study reports the use and opinions of methods of assessing body composition among VHTs in Ontario, Canada. The current study found that VHTs had concerns with the methods they are currently using, and would use a more accurate method to assess body composition than is what is currently available. Veterinary healthcare teams also did not always assess body composition, with most VHTs using BCS and BW to assess body composition, which seems to be an improvement from previous research (25,26). Before the AAHA and WSAVA guidelines were developed, two studies found that canine body composition was not assessed frequently by primary care veterinarians in the United Kingdom. German and Morgan (25) found that out of 148 dogs visiting a referral hospital, only one dog had a BCS recorded in the medical record, and only 29% of patients had their body condition assessed subjectively (e.g. described as overweight or obese). Body weight was recorded in 70% of dogs, with a median of one BW measurement recorded per dog (25). Furthermore, Rolph and colleagues reported that the overweight or obese status of dogs was only recorded in 1.4% of medical records (26). These authors could not determine the overweight status of the population, because BCS was recorded <25% of the time (26). Given the low numbers of body composition assessments by VHTs in the United Kingdom, it has been suggested that obesity is underdiagnosed in companion animals (25,26). Still veterinarians reported that obesity is a common disease, and acknowledge the
profession should do more to combat this disease (28). Given the many negative health consequences that come with a pet not being at an ideal body condition, it is important for veterinarians to convey to owners that their pet is underweight, overweight or obese. Multiple studies have shown that pet owners underestimate the body condition of their pets, again highlighting the importance for veterinarians to effectively communicate the importance of keeping pets at an ideal body condition (14–16,29).

The AAHA and WSAVA nutritional assessment guidelines recommend that body condition is assessed in every patient using BW, BCS, and MCS measurements (18,17). The current study found that the majority of respondents have heard of the AAHA and WSAVA nutritional assessment guidelines, but only one fourth of these respondents have implemented them in their practice. The reasoning behind this is unclear, yet it may demonstrate a greater need for education of VHTs on performing nutritional assessments. The current study reports that VHTs use BCS and BW most often to assess body composition, as demonstrated previously (25). Yet, MCS and morphometric measurements were not used as often, which may be due to unfamiliarity of these methods by VHTs.

When demographic data (role in veterinary practice, year of graduation etc.) was compared to body composition data (how often body composition is assessed, which methods are used), only role in veterinary practice showed significance. Overall, veterinary technicians were less likely to assess body condition compared to veterinarians. The reason for this is unclear, however, the authors speculate that this may be due to each position’s role in veterinary practice. A veterinarian would be more likely to perform a physical examination, and in doing so, will be
more likely to assess body composition and discuss dietary history than a veterinary technician. While this may be practice-dependent, guidelines suggest that the entire VHT should work together to follow-up and provide support to clients with pets requiring weight management (27).

Most respondents indicated that BW was always measured. Almost half of the respondents in the current study thought that BW was either accurate or very accurate for assessing body composition. This is paradoxical, as BW does not differentiate between BF and LSTM. This may indicate that body composition is being elucidated based on the difference in body weight to the breed standard, which may not be appropriate for mixed breed animals, or even purebred animals, as certain breeds of dogs and cats were found to be either overconditioned or underconditioned when attending breed competitions (30,31). Some comments indicated that respondents were aware that measuring BW alone could not determine body composition, and another method should be used, like BCS, which is also recommended in the AAHA and WSAVA guidelines (18,17).

Body condition scoring was used to assess body composition as much as BW. While the 5-point scale is used predominantly, it is the 9-point scale that has been validated by DEXA for both cats and dogs (19,20). A BCS was always assigned by over half of the respondents, with most respondents indicating it was accurate and easy to use. Yet, when asked to comment on body condition scoring, there were concerns about subjectivity, accuracy, and that it was difficult for clients to understand. Although high reproducibility has been found when comparing body condition scores assigned from both trained and untrained evaluators, there are still concerns about subjectivity and accuracy when using this scoring system (32). Additionally, respondents
indicated that it is difficult for clients to understand, which is not surprising, as owners have been found to underestimate the body condition of their dog despite using a body condition scoring chart (15). Since BCS charts were difficult for clients to understand, additional techniques or resources should be used to educate pet owners on body condition and optimal body shape. Respondents also indicated that assigning a BCS was difficult depending on the patient’s breed. While the stature of different dog breeds may make this difficult, and a breed effect will be present when evaluating canine body composition, and the optimal body condition for that breed should be considered when assigning a BCS (33). Since most BCS systems use photographs of a medium-sized dog, like a Labrador Retriever, it may be beneficial to develop BCS systems based on specific breeds or breed group (15,33).

Most of the respondents that use a MCS system use a 4-point subjective system (normal, mild loss, moderate loss, severe loss), or used other subjective methods to evaluate muscle quality. However, muscle condition scoring was only used by a third of the respondents, even though it is recommended to be used in every patient (18,17). Since less than half of all respondents heard of muscle condition scoring, this may be due to a lack of knowledge on this method. Alternatively, MCS may only be used in a select population of canine and feline patients. Some respondents indicated that MCS is “good to use in sick or geriatric patients”, which may indicate that respondents are evaluating muscle quality more in patients with cachexia or sarcopenia, but not in healthy animals. Additionally, MCS may not be assigned often by VHTs because, thus far, it has been validated for use in cats, but not in dogs, despite canine MCS systems being readily available to practitioners (22). For these reasons, MCS may not be used as commonly as BCS or BW to assess body composition. However, the AAHA and
WSAVA guidelines stress that MCS should be used alongside BCS, since BCS evaluates BF, while MCS evaluates muscle mass. Since these two systems are complementary, they should both be used together in every patient, healthy or ill (18,27).

Morphometric measurements were reported to be used by almost half of the respondents, with different systems being used in practice. Respondents indicated that these methods were less accurate and difficult to use, and mentioned concerns relating to accuracy and time required. A few respondents also indicated that morphometry was only used for specific conditions, such as obesity and muscle atrophy, which may indicate why morphometric measurements are not used frequently. The system used the most was a BFI system, one of which was recently validated in overweight and obese cats and dogs, and is available for use in veterinary practices (23,24). These studies found that the BFI system was more accurate at predicting BF% than BCS when they were both compared to DEXA (23,24). The authors also noted that dogs and cats in these studies had up to 65% BF, so the BFI system may be beneficial for morbidly obese animals at accurately determining BF%, however, this has yet to be validated. It is also important to note that this system is not intended to be used in pets with ideal body condition or underweight body condition (23,24).

When asked if VHT members know about advanced, uncommon methods of assessing body composition, such as DEXA, BIA, radiographic imaging, or QMR; many respondents did not know of these methods. This is expected, as many methods are used mainly in research settings, as they may be too costly or time consuming for use in clinical practice (21). While many respondents indicated they were unfamiliar with some of the methods listed, many would
still use BCS and BW to assess body composition in their patients if cost was not a factor. This shows that VHT members are comfortable with these methods, even though there are inherent limitations to both. Interestingly, almost all respondents would use a more accurate method if there were one available. While VHT members are comfortable with using BCS and BW to assess body composition, there is a desire for a more accurate, practical method to use in veterinary practice.

For assessing body composition for weight management plans (weight loss and weight gain), respondents used mostly BW and BCS. Body weight is mostly rechecked every month for both weight loss and weight gain plans. This is in line with what is recommended for weight management, however, assigning a MCS would be beneficial to include when developing a weight management plan to account for any current muscle wasting, or for any muscle loss during periods of weight loss (18,27,34). More respondents calculated an ideal body weight for patients requiring weight loss than for those requiring weight gain. This may be due to the low prevalence of underweight pets and high prevalence of overweight pets in veterinary practice (12,35). Most respondents assigned ideal body weight by calculating it with a BCS or by estimation. When an ideal BCS and associated BW is not available from the patient’s medical history, it is recommended to calculate a patient’s ideal body weight instead of estimating the ideal body weight (27). The following equation can be used: ideal BW = current BW X (100% – BF percentage)/0.80 (27). BF percentage can be determined using BCS, morphometric measurement systems, or other methods. This equation assumes that a healthy cat or dog with an ideal body weight has approximately 20% BF and 80% LSTM (27).
This study has several limitations that may influence the interpretation of these results. Since data were obtained using a survey, there may be selection, participation, and self-reporting biases. Members of a VHT with an interest in body composition or nutrition may have been more inclined to answer the survey than those not interested these topics. They may also have indicated that they assess body composition in a way they think the researchers would like to see, but not what is actually true. A review of patient medical records at different veterinary practices would have likely provided more accurate data on how often body composition is assessed, as done previously (25,26). However, the current study allowed practicing VHT members to voice their opinions about certain methods, which can be beneficial in future development of methods to assess body composition. In spite of these limitations, the current study identifies how practicing VHTs assess body composition in companion animals, along with concerns they have regarding the methods currently available.

2.6 CONCLUSION

To determine how body composition is assessed by VHTs in Ontario, Canada, the current study asked respondents to indicate what methods they use and how often they use them in practice. In this current study, we can see that VHTs rely heavily on BCS and BW to assess body composition in cats and dogs, with a few implementing additional methods such as MCS and morphometric measurements into their practice. The current study also shows that over half of the VHTs in Ontario, Canada reported that they always assess body composition. While this result seems to be an improvement from previous research, the present study’s limitations and difference in study design may influence the interpretation of these results. Nonetheless, the
veterinary profession should continue to perform nutritional assessments in every patient, no matter if they are in an underweight, ideal, or overweight body condition, at every consultation. This will allow veterinarians to obtain a thorough dietary history, evaluate for changes in body composition in relation to age or disease, and educate pet owners about appropriate nutrition and body composition for their pet.
2.7 TABLES AND FIGURES

Table 2.1: Demographic characteristics of veterinary healthcare teams (N=177).

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>n (respondents)</th>
<th>Proportion (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Job Title</strong></td>
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<td></td>
</tr>
<tr>
<td>Veterinarian</td>
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<td>51.4</td>
</tr>
<tr>
<td>Registered Veterinary Technician</td>
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<td>45.2</td>
</tr>
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<td>Veterinary Assistant</td>
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<td>4.5</td>
</tr>
<tr>
<td><strong>Type of Practice</strong></td>
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<td></td>
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<td>General Practice</td>
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<td>83.5</td>
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<tr>
<td>Specialty Hospital</td>
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</tr>
<tr>
<td>Emergency Clinic</td>
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<td>2.3</td>
</tr>
<tr>
<td>Other(^a)</td>
<td>16</td>
<td>9.1</td>
</tr>
<tr>
<td><strong>Number of Veterinarians In Practice</strong></td>
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<td></td>
</tr>
<tr>
<td>1-5</td>
<td>147</td>
<td>86.5</td>
</tr>
<tr>
<td>6-10</td>
<td>15</td>
<td>8.8</td>
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<tr>
<td>11-30</td>
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<td>2.4</td>
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<tr>
<td>30+</td>
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<td>2.4</td>
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<td><strong>Number of Veterinary Technicians In Practice</strong></td>
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<td></td>
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</tr>
<tr>
<td>6-10</td>
<td>19</td>
<td>11.3</td>
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<td>30+</td>
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<td><strong>Animal Species Treated In Practice</strong></td>
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<tr>
<td>Pocket pets</td>
<td>59</td>
<td>33.3</td>
</tr>
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</table>

\(^a\)Other includes: rehabilitation practices, teaching hospitals, multiple practice types, and animal shelters.
Table 2.2: Veterinary team members opinions of different body composition assessment methods (N=177).

<table>
<thead>
<tr>
<th>Methods that respondents...</th>
<th>have heard of</th>
<th>think are the most applicable to practice</th>
<th>think are the easiest to use</th>
<th>think are the most accurate</th>
<th>would use if cost was not a factor</th>
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<tr>
<td>Methods</td>
<td>N</td>
<td>%</td>
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<td>N</td>
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<td>147</td>
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<td>9</td>
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<td>MCS</td>
<td>83</td>
<td>47.2</td>
<td>49</td>
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<tr>
<td>Other&lt;sup&gt;b&lt;/sup&gt;</td>
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<td>2</td>
<td>1.1</td>
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<tr>
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<tr>
<td>Radiographic imaging (MRI, CT, Ultrasound)</td>
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<sup>a</sup> Abbreviations: Body weight, BW; Body condition scoring, BCS; Body fat index, BFI; bioelectrical impedance, BIA; deuterium oxide dilution, DOD; dual energy x-ray absorptiometry, DEXA; muscle condition scoring, MCS; quantitative magnetic resonance, QMR; magnetic resonance imaging, MRI; computed topography, CT

<sup>b</sup> Other includes nonsense responses, additional comments on a specific method, or a respondent indicating that they are not familiar with all methods listed.
Table 2.3: How veterinary team members assess body composition for weight management (N=177).

<table>
<thead>
<tr>
<th>Methods Used</th>
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<th>Weight Gain</th>
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<tr>
<td></td>
<td>n</td>
<td>%</td>
<td>n</td>
<td>%</td>
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<tr>
<td>BCS</td>
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<td>155</td>
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<th>How often body composition is assessed</th>
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<tr>
<td></td>
<td>n</td>
<td>%</td>
<td>n</td>
<td>%</td>
</tr>
<tr>
<td>Every week</td>
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<td>2.8</td>
<td>13</td>
<td>7.6</td>
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<tr>
<td>Every 2 weeks</td>
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<td>Every month</td>
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<td>Every 6 months</td>
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<td>Range of time (ex. 2-4 weeks)</td>
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<th>Calculate IBW for weight management</th>
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<td></td>
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<td>Yes</td>
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<table>
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<tr>
<td></td>
<td>n</td>
<td>%</td>
<td>n</td>
<td>%</td>
</tr>
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<td>17.2</td>
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<tr>
<td>Calculated based on BCS</td>
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<td>57.6</td>
<td>104</td>
<td>61.5</td>
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<td>Calculated based on BFI</td>
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<td>11.9</td>
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<td>Web-based program</td>
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<td>31.0</td>
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<td>Estimate</td>
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<td>72</td>
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<td>15.3</td>
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<td>8.9</td>
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<td>Simultaneous ideal BCS and BW in record</td>
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<td>31.2</td>
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<td>I don’t determine IBW</td>
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<td>2.3</td>
<td>3</td>
<td>1.8</td>
</tr>
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</table>

<sup>a</sup> Abbreviations: Body condition scoring, BCS; body fat index, BFI; body weight, BW; muscle condition scoring, MCS; ideal body weight, IBW.

<sup>b</sup> Other includes that time is dependent on owner compliance, that follow up is not applicable in the given practice type (ex. emergency practice), or that body composition is assessed as needed.
2.8 REFERENCES


CHAPTER 3:

ASSESSMENT OF BODY COMPOSITION IN DOGS WITH AND WITHOUT CRANIAL CRUCIATE LIGAMENT RUPTURE

A Santarossa¹, TWG Gibson¹, C Kerr¹, T Durzi², S Gowland², A Verbrugghe¹

¹ Department of Clinical Studies, Ontario Veterinary College, University of Guelph, 50 Stone Road, Guelph, Ontario N1G 2W1, Canada.

² Smith Lane Animal Hospital, Hill’s Pet Nutrition Primary Healthcare Centre, Ontario Veterinary College, 48 Smith Lane, Guelph, Ontario N1G 4S7, Canada.
3.1 ABSTRACT

A case-control study was conducted to compare body composition of dogs with and without cranial cruciate ligament rupture (CCLR). Thirty adult dogs with CCLR (cruciate group), and thirty adult dogs without CCLR (control group) were included. Body composition was assessed using body weight, scoring systems, and dual-energy x-ray absorptiometry. Results demonstrate that the cruciate group had higher amounts of body fat and bone tissue when accounting for sex, age, and body weight. The cruciate group also had lower muscle condition scores, but total tissue mass and lean soft tissue mass were not different compared to the control group. The cruciate group is overconditioned, but it is unclear if these findings are cause or consequence of CCLR, so further research is warranted.
3.2 INTRODUCTION

One of the most common causes of lameness in the dog is cranial cruciate ligament rupture (CCLR), a musculoskeletal disorder which results from the degeneration of the cranial cruciate ligament (CCL) (1–3). Located in the canine stifle, rupture of the CCL leads to joint instability, pain and secondary osteoarthritis (1,2). While this disorder typically presents unilaterally, the risk of developing CCLR bilaterally is quite high (4). In less than 2.5 years after initial presentation with unilateral CCLR between 38.7% - 61.3% of dogs presented with CCLR in the contralateral hind limb (4–6). From a multi-breed population of over 1 million dogs throughout North America, prevalence of this disorder was estimated at 2.55% (7), with pet owners in the United States spending about $1.32 billion for surgical and non-surgical treatment options (8).

The etiology of CCLR, while controversial and complex, has been thoroughly researched (1,7,9–15). Multiple studies have indicated that medium, large, and giant breed dogs are overrepresented, which include Labrador Retrievers, Newfoundlands, Rottweilers, Mastiffs, and Bulldogs (7,9,11–13). Gonadectomised dogs are also predisposed, with spayed females at an increased risk compared to neutered males (7,9,11,13,16,17). Peak incidence of CCLR occurs between 2-10 years of age, with large and giant breed dogs more prone to rupture at a younger age (7,11,13). Pelvic limb conformation, musculature, tibial tuberosity width, and tibial plateau angle have also been evaluated extensively, with controversial results (1,3,14,16,18–21).
To date, few studies have investigated the relationship between body composition and CCLR. In the early 90’s, it was noted that dogs with higher body weight (BW) were at an increased risk for CCLR (9,13). Body weight has also been used to estimate body condition within breed in some studies evaluating dogs with CCLR, however, BW is not ideal for determining body condition, as it is not a true indicator of fat mass and lean soft tissue mass (LSTM), as a higher BW compared to the breed standard may not necessarily indicate that a dog is overconditioned (11,22). Body condition score (BCS) has also been used to determine body composition of dogs with CCLR, where dogs with CCLR were reported to have a mean BCS larger than 5/9, but there were no comparisons to a control population (23–27). When BCS was compared between dogs with CCLR to those without, the results are variable, with two studies indicating that dogs with CCLR were overconditioned (10,28), while one did not indicate any differences (19). In most of these studies, BCS was obtained from the medical record (19,23,26,27,29), which can be unreliable, as BCS is not assigned frequently in the medical record of dogs (30). Few studies evaluating dogs with CCLR specifically indicated that they did not record BCS because it was not reported frequently in the medical records of dogs (31–33). Due to the variability in these results, and since BCS is a subjective measure of body condition, a more objective method, such as dual-energy x-ray absorptiometry (DEXA); which uses low dose radiation to quantify bone, fat, and soft tissue mass, may be beneficial (34). One study used DEXA to evaluate body condition of dogs with CCLR, where dogs had a mean body fat percentage (BF%) of 30%, but this was not compared to a control group and was done to quantify changes in body condition after weight loss (25). Thus, further research is needed to determine the relationship between body composition and CCLR.
The objective of this study was to comprehensively compare the body composition of dogs affected with CCLR to dogs without CCLR using BCS and muscle condition score (MCS) performed by a single trained assessor, and DEXA technology. It is hypothesized that dogs with CCLR have a higher BCS and a lower MCS; and that DEXA scans will reveal, higher body fat percentage (BF%), lower lean soft tissue mass, and lower bone mineral density (BMD) compared to the dogs without CCLR.

3.3 MATERIALS AND METHODS

3.3.1 Animals

A case-control study design was used. Thirty client-owned dogs with hind-limb lameness consistent with unilateral CCLR were included in the study (Cruciate Group). These dogs had been admitted to the Ontario Veterinary College’s Health Sciences Centre (OVC-HSC) for unilateral surgical repair, with CCLR confirmed at the time of surgery. The affected limb and type of surgery were recorded. The date of initial presentation for lameness at the referring veterinary clinic and recorded BW on that date, were recorded from the medical history. Thirty healthy client-owned dogs without orthopedic disease, from the Guelph, Ontario area, were also enrolled (Control group). All animals were determined to be clinically healthy based on medical history, physical examination, complete blood count, and serum biochemistry profile. All dogs were determined to be free of orthopedic disease, with the exception of CCLR in cruciate group, based on medical history, orthopedic exam and gait analysis. Dogs were included if they were between 1-12 years of age and were medium, large, or giant breed dogs with an ideal BW greater than 15 kg. Dogs were categorized into medium (15-20kg), large (21-40kg), and giant (>41kg)
breed categories based on their ideal BW and BW ranges for purebreds (35). Dogs were not included if they were receiving medications that may influence body composition, such as corticosteroids or epilepsy medications. Additional exclusion criteria were a recent history of hospitalization and previous orthopedic condition or surgery. Informed consent was obtained from owners prior to enrollment. All study procedures were approved by the University of Guelph Animal Care and Use Committee (AUP #3499) in accordance with institutional and national guidelines for care and use of animals.

3.3.2 Body Composition Assessment

Signalment was recorded and BW was obtained using a weigh scale. Body condition score was assigned by a single trained assessor (AS) using a 9-point scoring system as developed by Laflamme (36). Muscle condition score was also assigned by the same assessor using a canine MCS system, assigning a score of 3 for no muscle loss, 2 for mild muscle loss, 1 for moderate muscle loss, and 0 for severe muscle loss, if loss was noted in the skull, scapulae, spine, or pelvis (37). Body condition score and MCS were assigned before DEXA scans were completed for all dogs.

Dogs were sedated, after a 12-hour fast, with dexmedetomidine hydrochloride 2.0 – 5.0 µg/kg (Dexdomitor; Zoetis, Kirkland, QC, Canada) and butorphanol tartrate 0.2 mg/kg (Torbugesic; Zoetis, Kirkland, QC, Canada) or hydromorphone 0.05 mg/kg (Hydromorphone Injection USP; Sandoz, Boucherville, QC, Canada) administered intravenously. If needed, an additional dose was given between scans to maintain adequate sedation. Dogs were positioned in dorsal recumbency (Figure 3.1) on the scanning surface, with limbs extended caudally. The forelimbs were placed laterally to the thorax and held off from the body using foam blocks. All
limbs were secured in position using ropes attached to sand bags, and the spine was straightened dorsoventrally, with adhesive tape applied over the chest and head if needed. Free flow oxygen was provided at all times unless the head was being scanned.

Body composition analysis was completed using a fan-beam DEXA (Prodigy® Advance, GE Healthcare, Madison, WI, USA) by a trained investigator (AS). Scans were completed in duplicate with repositioning performed between scans if needed. Scanning time was between 10 and 30 minutes in length. In the scanner’s software (enCORE Version 16; GE Healthcare, Madison, WI, USA), the Total Body Mode was used, with the software selecting the Thick, Standard, or Thin settings based on the dog’s BW. Estimates of whole-body body fat percentage (BF%), total tissue mass (g) (the sum of lean soft tissue mass and fat mass), lean soft tissue mass (g), fat mass (g), bone mineral content (BMC) (g), and BMD (g/cm$^2$) were obtained based on the software’s analysis. These estimates for both scans were averaged prior to statistical analysis. Following the DEXA scans, dogs were administered atipamezole hydrochloride 0.17 – 0.11 mg/kg (Antisedan; Zoetis, Kirkland, QC, Canada).

3.3.3 Statistical Analysis

Statistical analysis was performed using SAS version 9.3 (SAS Institute Inc., Cary, NC, USA). Residuals were examined and tested for normality using a Shapiro-Wilk test. All variables were normally distributed except for BW, BMC, and Tissue Mass, so a logarithmic transformation was used. General linear mixed model ANOVAs were used to look at the effect of age, sex (male/female), BW and group on BCS, BF%, tissue mass, fat mass, LSTM, BMC, and BMD, with all possible interactions explored and quadratics for explanatory variables included. Non-significant terms were subsequently removed from the model. A Mann-Whitney
U test was used to compare MCS between groups. A p-value < 0.05 was considered statistically significant. Results are expressed as mean ± standard error (S.E.).

### 3.4 RESULTS

3.4.1 Animals

Population characteristics (age, sex, breeds) for both groups are described (Table 3.1). Eighteen dogs in the cruciate group had a left limb affected and twelve dogs had right limb affected by CCLR. The CCL was confirmed to be either partially (n=5) or completely (n=25) ruptured at the time of surgery, and all dogs underwent a tibial plateau levelling osteotomy.

3.4.2 Body Weight

Body weight was significantly higher in the cruciate group compared to the control group when age and sex were included in the model (p<0.0001) (Table 3.2, Figure 3.2). Age was not significant, but there was a significant effect of sex on BW (p=0.0430), with males (33.1 ± 1.8 kg) having a higher BW than females (32.3 ± 2.1 kg) (Figure 3.2).

For the cruciate group, medical history from the referring veterinarian including the date of initial presentation with lameness and BW on that date was available for 83% of the dogs (25/30). The average number of weeks from initial lameness to consultation at OVC-HSC for surgery was 16.3 weeks (range: 0.5 weeks to 63 weeks). At the time of initial noted lameness, the mean BW of dogs in the cruciate group was 39.6 ± 1.8 kg, which is not significantly different (p=0.1975) from the BW recorded on entrance into the study at OVC-HSC (38.8 ± 1.6 kg).
3.4.3 Body Condition Score and Muscle Condition Score

The cruciate group had a significantly higher mean BCS compared to the control group (p<0.0001) (Table 3.2, Figure 3.3). Sex was not significant, but there was a significant age (p=0.0093) effect where BCS increased as age increased, until approximately 6 years of age, where the rate of increase slowed, indicated by a significant age*age interaction (p=0.0212).

There was a lower MCS in the cruciate group compared to the control group (p<0.0001) (Table 3.2, Figure 3.4).

3.4.4 Dual Energy X-ray Absorptiometry

Results of the body composition analysis by DEXA are summarized (Table 3.2, Figure 3.5).

The cruciate group had a higher BF% compared to the control group (p < 0.0001). Sex was not significant, but age significantly influenced BF% (p=0.0055), with BF% increasing as age increases in both groups.

Fat mass was significantly different between groups (p=0.0010), with the cruciate group having a higher fat mass than the control group. Fat mass significantly increases with increasing age (p=0.0142) and BW (p<0.0001), however there was no effect of sex.

There were no significant effects of group and sex on lean soft tissue mass. However, there were significant effects for age, age*group, BW, and BW*BW. Age (p<0.0001) had an effect, where lean soft tissue mass decreases with increasing age, with the cruciate group having a greater rate of loss of lean soft tissue mass compared to the control group. A significant age*group (p=0.0140) interaction indicated that there were only significant differences between the groups when age is approximately ≥ 3.5 years old (p=0.0445). Lean soft tissue mass
increases as BW (p<0.001) increases and then the rate the increase slows at approximately 50 kg, as shown by a BW*BW interaction (p=0.0467).

Total tissue mass was not significantly different between groups or by sex, but there were significant effects of age, BW, and BW*BW interaction. As age increased, there was a small decrease in tissue mass (p = 0.0416). Also, there was an increase in tissue mass as BW increased (p<0.0001), and the rate of increased slowed at approximately 50 kg, indicated by a BW*BW interaction (p<0.0001).

Bone mineral content was significantly higher in the cruciate group compared to the control group (p=0.0003). Age was not a significant factor, but there was also a significant effect of sex (p=0.0468), with males having a higher bone mineral content (1,034.4 ± 53.5 g) than females (873.7 ± 43.0 g). Bone mineral content increased with increasing BW (p<0.0001), and the rate of increase slows as BW rises, as shown by a BW*BW interaction effect (p<0.0001). Additionally, there was a BW*group interaction (p=0.0017), where the control group had a significantly higher BMC than the cruciate group when BW was approximately ≤ 36 kg (p=0.04279).

Finally, BMD was significantly higher in the cruciate group than the control group (p=0.0312). Like BMC, age was not a significant factor. However, there was a significant effect of sex (p=0.0272), where males have a higher BMD (0.95 ± 0.02 g/cm²) compared to females (0.89 ± 0.02 g/cm²). There was also a significant effect of BW (p=0.0002) and a BW*BW interaction (p=0.0334), where BMD increased as BW increased, but the rate of the increase slowed after approximately 36kg.
3.5 DISCUSSION

The results of this study indicate that dogs with CCLR had significantly higher BW, BCS, BF%, fat mass, BMC, and BMD than control dogs when accounting for sex, age, and BW in the statistical models. Dogs in the cruciate group also had significantly lower MCS compared to control group, however, total tissue mass and lean soft tissue mass were not different between groups. These results support a portion of the authors’ hypothesis, where dogs with CCLR had a higher BCS, lower MCS and higher BF% compared to those without. Yet, a portion of the author’s hypothesis is rejected, because lean soft tissue mass had no effect, and BMD was higher in the cruciate group compared to the control group.

Body weight was higher in the cruciate group, which this was likely due to differences in dog breeds, as the cruciate group had more large breed dogs (ex. Mastiffs, Labradors) compared to the control group. Fat mass, BCS, and BF% were also higher in the cruciate group compared to the controls. Although fat mass was likely higher due to the higher BW in the cruciate group, the BF% and BCS indicate that dogs with CCLR were more overconditioned compared to the control group. Previous case-control studies have suggested that overconditioned dogs may have an increased risk of developing CCLR (10,11,29). In humans, obesity (higher body mass index) seemed to be a risk factor for anterior cruciate ligament rupture in female cadets, but not male cadets (38). Excess adipose tissue would increase mechanical load on joints; but it also releases hormones, like leptin and adiponectin, and cytokines like interleukin-6, which may act to influence joint inflammation and tissue breakdown (10,11,15,39–41). These factors have been found to contribute to osteoarthritis in overweight and obese dogs (41–43). The findings of the
current study would support ongoing investigations in this area. A longitudinal study, similar to
the work conducted by Kealy and colleagues (42), would provide stronger evidence on the
association between adiposity and CCLR.

While the data from the present study found that dogs with CCLR are overconditioned, it
is important to consider that other factors like muscle quality and activity level can also influence
the progression of CCLR in dogs. In the present study, MCS was lower in dogs with CCLR. This
is likely due to localized muscle atrophy in the affected hindlimb. However, total tissue mass and
lean soft tissue mass were not different in the cruciate group compared to controls. From these
results, it is difficult to determine what influence muscle and lean soft tissue mass has on CCLR.
Nonetheless, immobilization has been found to contribute to ligament failure, and exercise has
been associated with improving tensile strength of collateral ligaments in various animal models
(44). Thus, further research should focus on muscle condition, lean soft tissue mass and activity
in dogs with CCL.

Finally, the mean BMC and BMD were elevated the cruciate group compared to the
control group. This could be due to the higher BW in the cruciate group, but obesity has also
been associated with elevated BMC and BMD in humans (45). In dogs, BMC was found to be
higher in overweight dogs compared to those in ideal body condition from 6 to 9 years of age
(46). Our results also indicated that BMC was significantly higher in the control group compared
to the cruciate group when BW was < 36 kg, however the reason for this is unclear.
Possible explanatory variables that might influence body composition in the present study included age, sex, and BW. The results indicated that BCS, BF%, and fat mass increased with increasing age. Meanwhile, total tissue mass, MCS, and lean soft tissue mass decreased as age increased. These age effects on MCS, BCS, soft tissues mass, and fat mass are likely due to decreases in energy requirements with increasing age, which results in fat gain and loss of LSTM (47). This is in line with previous research, where the level of adiposity seems to increase with increasing age, as the prevalence of overweight and obese body conditions is greatest when dogs are between 6 and 10 years of age (29,46,48). Previous research has also noted an association between LSTM loss and increasing age in dogs (46,48), with one study finding that LSTM increased with age in female Beagles (49). The results of the present study did not find a significant effect of age on BMC or BMD, however, these variables decreased with increasing age in a study on overweight Labrador Retrievers, in parallel with LSTM decline (48). Sex was also evaluated as an explanatory variable in the present study, where males weighed more, and had higher BMC and BMD than females. This may be due to differences in body size and LSTM between the sexes, as these are highly correlated with BMC in humans (50), however differences in lean soft tissue mass between the sexes was not seen in the present study. In dogs, Lauten and colleagues found that BMC, BMD and BW were greater in males compared to females for Rottweilers, but not other purebreds or mixed breeds (49). More research should be conducted on bone mineral content in dogs. Finally, higher BW was associated with increased total tissue mass, lean soft tissue mass, fat mass, and BMC, as amounts of these biological components would rise with increasing BW.
In this study, dogs with CCLR presented for surgical repair to a referral hospital, so the authors evaluated the time frame of lameness between when the dog was initially seen by a referring veterinarian to their surgical consult. This was done to determine if there was potential weight gain associated with decreased activity before surgery, as restricted exercise is often recommended to manage CCLR (51). While the length and severity of lameness varied, the authors determined that dogs’ BW did not change significantly, indicating that they may have been in similar body condition compared to when lameness began. However, even though there was no significant change in BW, there may have been changes in BF, lean soft tissue mass, or BMD that cannot be evaluated with this study design.

The present study is subject to further limitations. Compared to other studies (10,11,19) that evaluate BW or BCS in dogs with CCL, this study has a small sample size. There may have been selection bias with patient enrollment, as owners concerned with the body composition of their dog may have been more inclined to participate, for example, owners of sport dogs or dogs with a non-ideal body condition. Additionally, the same investigator assigned BCS, MCS, and subsequently analyzed the DEXA results. Although BCS and MCS were assigned before determining the DEXA results for each dog, there may have been scoring bias over time. The present study did not evaluate factors like energy intake and activity level that may also influence body composition.
3.6 CONCLUSION

In conclusion, the present study found that dogs with CCLR were overconditioned compared to dogs without CCLR. However, although BW remained unchanged between initial presentation with lameness and consultation for surgery, further research is warranted to determine if overconditioning is a cause or consequence of CCLR. It is also important to consider that etiology behind canine CCLR is multifactorial and complex, and that other aspects of body composition such as muscle and bone density could also affect CCLR.
3.7 TABLES AND FIGURES

Table 3.1: Population characteristics of dogs with (n=30) and without (n=30) cranial cruciate ligament rupture. Data reported as mean ± S.E.

<table>
<thead>
<tr>
<th></th>
<th>Control Group (n=30)</th>
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</thead>
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<tr>
<td>Age (years)</td>
<td>5.3 ± 0.4</td>
<td>4.7 ± 0.4</td>
</tr>
<tr>
<td>Sex</td>
<td>19 males</td>
<td>13 males</td>
</tr>
<tr>
<td></td>
<td>(all gonadectomised)</td>
<td>(12 gonadectomised, 1 intact)</td>
</tr>
<tr>
<td></td>
<td>11 females</td>
<td>17 females</td>
</tr>
<tr>
<td></td>
<td>(10 gonadectomised)</td>
<td>(all gonadectomised)</td>
</tr>
<tr>
<td>Breeds</td>
<td>Mixed Breed (n=15)</td>
<td>Mixed Breed (n=10)</td>
</tr>
<tr>
<td></td>
<td>Golden Retriever (n=5)</td>
<td>Labrador Retriever (n=4)</td>
</tr>
<tr>
<td></td>
<td>Australian Shepherd (n=2)</td>
<td>Bullmastiff (n=3)</td>
</tr>
<tr>
<td></td>
<td>Belgian Malinois (n=1)</td>
<td>Golden Retriever (n=3)</td>
</tr>
<tr>
<td></td>
<td>Boxer (n=1)</td>
<td>German Shepherd (n=3)</td>
</tr>
<tr>
<td></td>
<td>English Mastiff (n=1)</td>
<td>English Bulldog (n=2)</td>
</tr>
<tr>
<td></td>
<td>English Springer Spaniel (n=1)</td>
<td>American Bulldog (n=1)</td>
</tr>
<tr>
<td></td>
<td>German Shepherd (n=1)</td>
<td>Black Russian Terrier (n=1)</td>
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<tr>
<td></td>
<td>Nova Scotia Duck Toller Retriever (n=1)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Viszla (n=1)</td>
<td>Boxer (n=1)</td>
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<tr>
<td></td>
<td>Weimaraner (n=1)</td>
<td>Doberman Pinscher (n=1)</td>
</tr>
<tr>
<td>Breed Sizes</td>
<td>Medium (n=14)</td>
<td>Medium (n=5)</td>
</tr>
<tr>
<td></td>
<td>Large (n=15)</td>
<td>Large (n=21)</td>
</tr>
<tr>
<td></td>
<td>Giant (n=1)</td>
<td>Giant (n=4)</td>
</tr>
</tbody>
</table>
Table 3.2: Body composition characteristics (mean ± S.E.) of dogs with (n=30) and without (n=30) cranial cruciate ligament rupture.

<table>
<thead>
<tr>
<th></th>
<th>Control Group</th>
<th></th>
<th>Cruciate Group</th>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean S.E.</td>
<td>Mean S.E.</td>
<td></td>
<td>P-value</td>
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</tr>
<tr>
<td>BW (kg)</td>
<td>26.69 1.50</td>
<td>38.78 1.63</td>
<td></td>
<td>&lt; 0.0001</td>
<td></td>
</tr>
<tr>
<td>BCS (1-9)</td>
<td>5.87 0.23</td>
<td>7.50 0.20</td>
<td></td>
<td>&lt; 0.0001</td>
<td></td>
</tr>
<tr>
<td>MCS (0-3)</td>
<td>2.77 0.08</td>
<td>1.90 0.13</td>
<td></td>
<td>&lt; 0.0001</td>
<td></td>
</tr>
<tr>
<td>DEXA</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BF% (%)</td>
<td>27.49 1.24</td>
<td>38.78 1.40</td>
<td></td>
<td>&lt; 0.0001</td>
<td></td>
</tr>
<tr>
<td>Total Tissue</td>
<td>25,964.70 1,463.48</td>
<td>37,987.18 1,589.86</td>
<td>0.2854</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mass (g)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lean Soft</td>
<td>18,722.28 1,051.04</td>
<td>23,268.68 1,108.17</td>
<td>0.6850</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tissue Mass (g)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fat Mass (g)</td>
<td>7,242.38 578.35</td>
<td>14,718.50 833.50</td>
<td>0.0010</td>
<td></td>
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</tr>
<tr>
<td>BMC (g)</td>
<td>872.18 47.93</td>
<td>1,046.64 50.00</td>
<td>0.0003</td>
<td></td>
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</tr>
<tr>
<td>BMD (g/cm²)</td>
<td>0.8943 0.02</td>
<td>0.9508 0.02</td>
<td>0.0312</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Abbreviations: BW, body weight; BCS, body condition score; MCS, muscle condition score; DEXA, dual-energy x-ray absorptiometry; BMC, bone mineral content; BMD, bone mineral density.
Figure 3.1: Image of dog in dorsal recumbency positioning for dual-energy x-ray absorptiometry scan to assess body composition.
Figure 3.2: (a) There was no significant effect of age on body weight for dogs with (n=30) or without (n=30) cranial cruciate ligament rupture. (b) Mean (± 1 S.E.) body weight for male (n=32) dogs is higher than female (n=28) dogs.
Figure 3.3: (a) Body condition score increases with increasing age in dogs with (n=30) and without (n=30) cranial cruciate ligament rupture. (b) No significant effect of sex on mean (± 1 S.E.) body condition score for dogs with (n=30) and without (n=30) cranial cruciate ligament rupture.
**Figure 3.4:** Muscle condition score significantly lower in control dogs (n=30) compared to dogs with (n=30) cranial cruciate ligament rupture.
Figure 3.5: Body composition results from dual-energy x-ray absorptiometry by group (Mean ± 1 S.E.) for dogs with (n=30) and without (n=30) cranial cruciate ligament rupture (* = p<0.005).
3.8 REFERENCES


26. Christopher SA, Beetem J, Cook JL. Comparison of long-term outcomes associated with three surgical techniques for treatment of cranial cruciate ligament disease in dogs: Long-


CHAPTER 4:
GENERAL DISCUSSION

A Santarossa

Department of Clinical Studies, Ontario Veterinary College, University of Guelph, 50 Stone Road, Guelph, Ontario N1G 2W1, Canada
4.1 GENERAL DISCUSSION

The results of this thesis have supported the need for further research into companion animal body composition, specifically, how it is assessed in Canadian veterinary practices, and how body composition is associated with canine cranial cruciate ligament rupture. The conclusions from this work have been highlighted in the discussions for Chapter 2 and Chapter 3.

This thesis reports the use and opinions on methods of assessing body composition among VHTs in Ontario, Canada. Almost all of the VHTs use BCS and BW to assess body composition, with less than 50% using MCS and morphometric measurements. Only 66.7% of VHTs reported that they always assess body composition, which seems to be an improvement from previous research (1,2), yet various study limitations would influence how these results are interpreted. Veterinary healthcare teams had concerns with the methods they are currently using, and almost all would use a more accurate method to assess body composition than is what is currently available. This could be a reason why previous research has demonstrated that overweight and obesity is underreported in veterinary medical records for dogs (1,2). However, further research is needed to understand VHTs attitudes on body composition methods.

This thesis also reports that dogs with CCLR had significantly higher BW, BCS, BF%, fat mass, BMC, and BMD than control dogs when accounting for sex, age, and BW. Dogs in the CCL group also had significantly lower MCS compared to control dogs, however, total tissue mass and lean soft tissue mass were not different between groups. This study also found that dogs with CCLR were likely in the same body condition at the time of initial diagnosis at their referring veterinarian. These results indicate the dogs with CCLR are more overconditioned
compared to dogs free of orthopedic disease. Previous work has come to the similar conclusions (3), but a longitudinal cohort study, similar to the work conducted by Kealy and colleagues (4), would provide stronger evidence regarding the relationship between overconditioning and CCLR in the dog.

This research was developed to address gaps in the literature regarding how body composition is assessed in veterinary medicine, and how body composition affects health of companion animals. Further research in this area is needed to determine changes that could be made in the veterinary field to ensure that body composition is assessed accurately and regularly, so that the negative health consequences of abnormal body conditions is minimized in the companion animal population.
4.2 REFERENCES


