Body composition is defined as the relative amounts of the various chemical components of the body, and various methods have been described to provide a quantitative estimate of it. Such methods differ in their applicability to research, referral veterinary practice, and first-opinion practice. Some investigators regard chemical analysis as the most appropriate method for body composition analysis, but this method is laborious and not applicable to clinical practice. Other techniques with reasonable precision and accuracy include total body water measurement and DEXA. Dual-energy x-ray absorptiometry estimates body composition by use of photons of 2 energy levels (70 and 140 kVp), which are impeded differently by bone mineral, lipid, and lean tissue. Algorithms are then used to calculate the quantity and type of tissue in each pixel scanned. Similar to other body composition techniques, DEXA relies on the assumption that lean body mass is uniformly hydrated at 0.73 mL of water/g. Previous studies have validated DEXA for body composition analysis in dogs; results are generally precise, and accuracy is acceptable, although some limitations remain. The technique has also been used as a noninvasive reference method, when validating other (eg, morphometric) methods of composition analysis. However, although DEXA is available at some referral institutions, such methods are still not feasible for use in general practice. Instead, simpler techniques are required and include body condition scoring and electrical conductance methods.

In companion animals, the most widely accepted and practical method of assessing body composition is body condition scoring. All body condition scoring systems assess visual and palpable characteristics, such as subcutaneous fat, abdominal fat, and superficial musculature. These assessments are quick and easy to perform, and when used by trained individuals, scores correlate well with body fat mass determined via DEXA.

**Objective**—To assess performance of a portable bioimpedance monitor for measurement of body composition in dogs.

**Animals**—24 client-owned dogs.

**Procedures**—Percentage body fat was measured via dual-energy x-ray absorptiometry (DEXA) and with a portable bioimpedance monitor, and body condition score (BCS) was measured by use of a 9-integer scale.

**Results**—Although the precision of the bioimpedance monitor was good, this varied among dogs. Body position (standing vs sternal) had no effect on bioimpedance results. There was a significant association between results determined via DEXA and bioimpedance, but this association was weaker than between DEXA and BCS. When agreement was assessed via Bland-Altman plot, the bioimpedance monitor under- and overestimated values at high and low body fat percentages, respectively. In 9 dogs, body fat measurements were taken before and after weight loss to determine the proportional loss of tissue mass during weight management. There was a significant difference in the estimated percentage of weight lost as fat between the DEXA and bioimpedance methods.

**Conclusions and Clinical Relevance**—Although percentage body fat measured by use of a portable bioimpedance monitor correlated well with values determined via DEXA, the imprecision and inaccuracy in dogs with high percentage body fat could make the monitor inappropriate for clinical practice. (Am J Vet Res 2010;71:393–398)
and are repeatable among observers.\textsuperscript{2,6} Even when assessed by inexperienced individuals, BCS correlates well with results of DEXA.\textsuperscript{6} These systems are a valuable means of assessing body composition in epidemiological studies.\textsuperscript{7-10}

Bioelectrical impedance analysis is a safe, noninvasive, rapid, and portable method to estimate body composition in healthy dogs, cats, and humans.\textsuperscript{11-13} This technique assesses body composition by measuring the nature of the conductance of an applied electrical current in the body.\textsuperscript{14} Body fluids and electrolytes are responsible for conductance, and because adipose tissue is less hydrated than lean body tissues, a greater proportion of adipose tissue results in lower conducting volume and hence larger impedance to current passage. A new handheld bioimpedance monitor has recently been validated for dogs, and the manufacturers report good correlation (R\textsuperscript{2} = 0.75) with percentage body fat measured by use of the deuterium oxide dilution method.\textsuperscript{13} Nonetheless, before this method can be widely recommended, there is a need for independent validation. Therefore, on the basis of the hypothesis that bioimpedance provides a useful tool for measuring adiposity in dogs, the purpose of the present study was to assess performance of a bioimpedance monitor, compared with DEXA as a reference method, in dogs, prior to weight loss and after a weight-loss regimen.

Materials and Methods

Study design—All dogs participating in the studies were referred to the Royal Canin Weight Management Clinic, University of Liverpool, for investigation and management of obesity or obesity-related disorders. Dogs were included if there were no clinical signs of systemic disease and they were well hydrated, as judged by use of history, physical examination, CBC, serum biochemical analysis, and urinalysis. For weight loss, all dogs received a high-protein, high-fiber diet.\textsuperscript{6}

In part 1, percentage body fat measured via DEXA, a bioimpedance monitor, and BCS were compared and the precision of the bioimpedance monitor was determined. For this evaluation, results from 24 dogs were included. In 9 of these dogs, both pre- and post-weight loss body fat measurements were available but only 1 data set was included because it would have been statistically inappropriate to include 2 data sets from the same dog. The data set used was randomly selected; pre-weight loss data were used for 4 of the dogs, and post-weight loss data were used for the remaining 5 dogs. Thus, 12 sets of pre-weight loss and 12 sets of post-weight loss data were available for analysis. The median age of the dogs was 78 months (range, 26 to 144 months); 14 dogs were male (13 neutered), and 10 dogs were female (9 neutered). A number of breeds were represented including Labrador Retriever (n = 5), Cavalier King Charles Spaniel (5), crossbred (4), Akita (1), Border Collie (1), Welsh Corgi (1), Dachshund (1), English Bull Terrier (1), Golden Retriever (1), Irish Setter (1), Jack Russell Terrier (1), Schipperke (1), and Yorkshire Terrier (1).

In part 2, changes in body composition during weight loss were evaluated by use of DEXA and a bioimpedance monitor. Only the data from the 9 dogs that had been assessed twice were included; their weight management regimen involved dietary energy restriction and lifestyle changes, as described.\textsuperscript{16} The median age of these dogs was 94 months (range, 26 to 140 months); 6 dogs were male (all neutered), and 3 dogs were female (2 neutered). Breeds represented including Labrador Retriever (n = 2), Cavalier King Charles Spaniel (2), Welsh Corgi (1), Golden Retriever (1), Irish Setter (1), Schipperke (1), and Yorkshire Terrier (1).

In part 3, because a limitation of the first 2 parts of the study was that patient positioning differed from the manufacturer’s recommendations for the bioimpedance monitor, the effect of body position (standing vs sternal recumbency) on bioimpedance-derived percentage body fat was determined. A separate cohort of 9 dogs with a range of body compositions was used. All dogs were referred to the University of Liverpool for various disorders. Dogs were included if there were no clinical signs of systemic disease and the dogs were well hydrated, as judged by use of history, physical examination, CBC, and serum biochemical analysis. All standing measurements were taken while dogs were fully conscious, and this was also the case for 6 of the sternal recumbency body fat measurements; in the remaining 3 dogs, the sternal recumbency measurements were taken while the dogs were sedated for other clinical procedures. The median age of these dogs was 52 months (range, 3 to 128 months); 6 dogs were male (5 neutered), and 6 dogs were female (1 neutered). Breeds represented including Labrador Retriever (n = 3), Springer Spaniel (2), Golden Retriever (1), Irish Setter (1), Jack Russell Terrier (1), and Whippet (1).

The study was performed in adherence to the University of Liverpool Animal Ethics Guidelines and was approved by the WALTHAM Ethical Review Committee. The owners of all participating dogs gave informed written consent.

DEXA—The reference method for body composition in the present study was fan-beam DEXA,\textsuperscript{3} which has high precision for assessment of body composition in dogs.\textsuperscript{4} Dogs were sedated and scanned in dorsal recumbency, as described.\textsuperscript{4} Purpose-designed computer software\textsuperscript{6} was used for data analysis.

BCS—Two experienced observers (AJG and SLH) with high precision for BCS assessments\textsuperscript{6} independently assessed every dog with a 9-integer BCS system.\textsuperscript{2} A final score for each dog was then determined by evaluation of consensus between the scores of the 2 observers. When observers disagreed, the observers would assess the dog together and the final integer score was agreed upon through discussion.

Bioimpedance monitor—A body fat monitor\textsuperscript{4} was used for all bioimpedance measurements. This unit is a handheld device that uses single-frequency (50-MHz) bioimpedance technology.\textsuperscript{15} The conversion from bioimpedance values to percentage body fat is made by use of a canine-specific algorithm developed from comparative studies with the deuterium oxide method of body composition determination.\textsuperscript{15} This monitor has also been used in a preliminary study examining the percentage body fat of a cohort of dogs in Japan.\textsuperscript{6}
A single observer (AJG) performed all bioimpedance measurements. For parts 1 and 2, body fat estimates were taken immediately after the DEXA analysis had been completed in accordance with the manufacturer’s recommendations, except that the dog was sedated and lying in sternal recumbency. Briefly, the site of measurement was 2 cm lateral to the midline, on the left side, with the first electrode just caudal to the last rib. The skin and hair were sprayed with ethanol and then wiped with cotton wool. The hair was then parted with a fine-tooth comb, and the device was held in 2 hands such that all electrodes made contact with and were at right angles to the skin. Five measurements were taken in each dog, with the device being completely removed and repositioned between each measurement. The mean of the 5 values was used as the final result for each dog. The observer had no knowledge of the DEXA results at the time that the assessment was made.

For part 3 of the study, body fat measurements were made with the bioimpedance monitor in dogs in the standing position and dogs in sternal recumbency. Measurements were taken for each position, and the mean of the 5 measurements was used as the final result for each dog. The order of body position (standing vs sternal) was randomized.

**Statistical analysis**—Given that group size was small for parts 2 and 3, nonparametric tests were used. In part 2, the percentage of the weight loss, which was attributable to lost body fat, was calculated and results compared by use of the Wilcoxon signed rank test. In part 3, the Wilcoxon signed rank test and the Kendall rank correlation were used to compare results. As with part 1, a Bland-Altman plot was used to determine agreement and precision was assessed by calculating the CV of the 5 repetitions.

For part 1, the Shapiro-Wilk method was used to confirm that continuous data (DEXA and bioimpedance percentage body fat measurements) had a normal distribution. Subsequently, simple linear regression was used to analyze the association between these variables, and a Bland-Altman plot was used to determine agreement.\(^1\) The Wilcoxon signed rank test was used to compare differences in the percentage body fat measurements made by use of DEXA and bioimpedance. Given that BCSs were categorical data, the Kendall rank correlation and Kendall nonparametric linear regression were used to compare associations between DEXA or bioimpedance percentage fat measurements and BCS. Precision of the bioimpedance monitor was estimated by calculating the CV of the 5 repetitions. A 2-sample t test was used to examine whether differences in precision existed for body fat values obtained before weight loss and after weight loss. The 95% limits for the acceptable difference between bioimpedance and DEXA body fat measurements were determined by use of the method described by Lundorf and Kjelgaard-Hansen.\(^1\) This used the mean CV of bioimpedance results determined in the study and the precision of DEXA (3.8%) as determined in a previous study that used the same DEXA scanner.\(^1\) Statistical analysis was performed with a computer software package.\(^1\) Differences were considered significant at \(P < 0.05\), and 2-sided \(P\) values are reported.

**Results**

Baseline characteristics of the dogs in the 3 study parts were determined as well as body weight, BCS, and percentage body fat (Table 1). Overall, precision for the bioimpedance method was good (median CV, 2.2%), but this varied among dogs (range, 0.0% to 11.2%). When pre–weight loss and post–weight loss values were analyzed separately, the median (range) CV was 2.1% (0.0% to 6.2%) and 4.2% (1.2% to 11.2%), respectively. However, this difference was not significant (\(P = 0.078\)). The 95% limits for the acceptable difference between the results of DEXA and the bioimpedance monitor were 0 ± 8.6%. Mean ± SD percentage body fat for the 24 data sets was 36 ± 12.3% and 33 ± 6.2% for DEXA and the bioimpedance monitor, respectively. The BCS ranged from 4 to 9, with a median of 7.

There was a significant \((R^2 = 0.44; P < 0.001; \text{Figure 1})\) association between percentage body fat measured by use of DEXA and the bioimpedance monitor. However, agreement was poor when assessed by use of a Bland-Altman plot (Figure 2). In this respect, the mean difference between results of DEXA and the bioimpedance monitor was 3%, and the 95% limits of agreement were –16% to 21%. Furthermore, only 4 of 24 (17%) results were within the 95% limits of acceptable difference between the 2 methods. The bioimpedance monitor overestimated at low body fat percentage and underestimated at higher body fat percentages: simple linear regression determined by use of the difference between results as outcome and mean results as predictor confirmed that the slope of the regression line differed significantly \((R^2 = 0.42; P < 0.001)\) from zero.

An association was detected between DEXA-derived values and BCS, which was stronger than the association between values derived via the bioimpedance method. As an example, the difference in the percentage body fat estimated by use of bioimpedance and DEXA was 0.0 ± 12.3% and 0.0 ± 12.3% for dogs in the standing and sternal positions, respectively.

**Table 1**—Variables determined in a 3-part study on the comparison of a bioimpedance monitor with DEXA for noninvasive estimation of percentage body fat in dogs.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Part 1</th>
<th>Part 2 Before weight loss</th>
<th>Part 2 After weight loss</th>
<th>Part 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>BW (kg)</td>
<td>28.2 (6.7–59.2)</td>
<td>31.3 (6.7–53.7)</td>
<td>23.3 (5.0–35.4)</td>
<td>22.5 (7.0–52.2)</td>
</tr>
<tr>
<td>BCS</td>
<td>7 (4–9)</td>
<td>5 (7–9)</td>
<td>5 (5–5)</td>
<td>ND</td>
</tr>
<tr>
<td>BF-DEXA (%)</td>
<td>36 (10–58)</td>
<td>45 (52–51)</td>
<td>28 (11–36)</td>
<td>ND</td>
</tr>
<tr>
<td>BF-BIO-standing (%)</td>
<td>33 (21–43)</td>
<td>40 (30–44)</td>
<td>28 (24–36)</td>
<td>ND</td>
</tr>
<tr>
<td>BF-BIO-standing (%)</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>30 (19–40)</td>
</tr>
</tbody>
</table>

Data are expressed as median (range) values. BF-BIO = Body fat estimated by use of bioimpedance (dogs were standing or in sternal recumbency). BF-DEXA = Body fat estimated by use of DEXA. BW = Body weight. ND = Not done.
monitor versus DEXA ($R^2 = 0.58; P < 0.001$). An association, albeit weaker, was also detected between results obtained by use of the bioimpedance monitor and BCS ($R^2 = 0.22; P = 0.008$).

In part 2, changes in body composition during weight loss were determined. Median (range) duration of weight loss was 210 days (162 to 271 days), percentage of starting weight lost was 30% (24% to 34%), and overall rate of weight loss was 0.9%/wk (0.8% to 1.4%/wk). When assessed by use of DEXA, the median (range) percentage of body weight lost as fat was 85% (65% to 94%). When the bioimpedance monitor was used, the median (range) percentage of body weight lost as fat was 65% (46% to 81%). There was a significant ($P = 0.009$) difference in the estimated percentage weight lost as fat between the 2 methods (median difference, 20%).

In part 3, the effect of positioning on bioimpedance measurements was evaluated. Bioimpedance measurements were taken in standing and sternal recumbency positions from a cohort of 9 dogs. Correlation was good (Kendall’s tau = 0.81; $P < 0.001$; Figure 3), and there was no significant difference in values obtained in ei-
ther position (standing position median, 30% [range, 19% to 40%] vs sternal position median, 27% [range, 21% to 38%]; P = 0.99). There was also no difference in variability between the values obtained in either position (standing position median CV, 3% [range, 2% to 13%] vs sternal position median CV, 3% [range, 1% to 15%]; P = 0.99). When agreement was assessed by use of a Bland-Altman plot (mean difference, –0.2%; 95% limits of agreement, –5.7% to 5.7%; Figure 4), no significant difference was detected between positions.

Discussion

The present study assessed the performance of a handheld bioimpedance monitor for measurement of adiposity in obese dogs prior to weight loss and in dogs at the end of a weight-loss program. Reasonable precision was detected for the repeated measurements for most dogs, although there was imprecision in some individuals. The reason for this imprecision was not clear but may have been caused by operator error, although a single operator with experience in the technique performed all measurements. Given that such errors can exist, the authors recommend that, in a manner similar to that used for indirect blood pressure measurement, the mean value of a number of body fat measurements be used as the final value for a particular dog.

Reasonable correlation was detected between percentage body fat measured via the bioimpedance monitor and DEXA reference method. However, the degree of correlation was worse than that reported by the manufacturers. The reason for this discrepancy was not clear, and further work is required to determine its cause. It is particularly noteworthy that BCS correlated better with DEXA-derived results than with bioimpedance-derived results. In the opinion of the authors, BCS remains the method of choice for evaluating body composition in dogs in first-opinion practice.

Correlation analysis assesses the degree of association between 2 variables but does not prove that values are actually in agreement. Bland-Altman plots compliment tests of association by illustrating the actual agreement between the 2 variables. Despite the reasonable correlation between results, measurements of percentage body fat made by use of DEXA differed markedly from measurements made by use of the bioimpedance monitor in some dogs (mean difference, 3% body fat; 95% limits of agreement, –16% to 21%). Furthermore, the level of agreement was poor, as determined by the fact that only 4 of 24 results were within the designated acceptable level of agreement. Because the range of acceptable agreement was based on the precision of both methods, other factors were likely responsible for the reported difference in results. Upon closer examination of the Bland-Altman plot, it was evident that the degree of discrepancy varied depending on body mass, with the bioimpedance monitor occasionally underestimating the true value when percentage body fat was high and overestimating when percentage body fat was lower. Such a bias could lead to problems if bioimpedance were used for monitoring change in body composition during weight loss because changes in body fat might be underestimated. This concern was supported by the results of part 2 of the study, in which the estimated loss of body fat was lower when measured by use of the bioimpedance method. Given this concern, caution is recommended for use of the handheld bioimpedance device to monitor changes in body composition.

The reason for poor agreement between results obtained by use of the bioimpedance monitor and DEXA is not known. Bioimpedance may be affected by hydration status, skin and air temperature, recent physical activity, conductance of the examination table, and patient characteristics such as age, size, and shape. In this respect, the manufacturers state that variability can occur with prior physical activity or excitement, incorrect device positioning, incorrect angle of electrode contact with the skin, and inadequate contact with the skin. Although all such factors could have been present, a single operator with experience in the technique performed all measurements. Another possibility for the discrepancy in results was that because dogs were sedated, measurements were taken in sternal recumbency rather than standing. The reason that sternal recumbency (under sedation) was chosen was that it enabled the measurements to be taken without concerns over patient compliance. Nonetheless, the manufacturer’s instructions suggest that changes in body position could lead to overestimation of percentage body fat. However, when the effect of body position was assessed in part 3 of the present study, no such systematic difference in results was found. Therefore, it is unlikely that body position caused the inaccuracies seen with the bioimpedance monitor in the present study. Although we did not evaluate in detail how sedation could affect results, some of the dogs in part 3 were conscious for the standing body fat measurements and sedated for sternal recumbency measurements; although the number of observations was small, no difference was observed subjectively in the results. Therefore, it is unlikely that sedation had an effect on results, although further work is required to clarify this. Additional studies are needed to explore the reasons for the inaccuracies and identify ways of improving performance of the monitor.

Although the agreement between body fat percentages determined via DEXA versus the bioimpedance monitor was poor, there may still be potential to recalibrate the monitor by generating a new working algorithm. With only 24 dogs, the data set produced in the present study was too small for such a purpose. Instead, the authors recommend generating a new algorithm based on results of future prospective studies that use larger data sets.

The present study revealed that percentage body fat measured by use of a portable bioimpedance monitor correlated relatively well with percentage body fat measured by use of DEXA, but the correlation was not as good as between BCS and DEXA. Furthermore, imprecision can be seen in some dogs, and there may be under- and overestimation when percentage body fat is high and low, respectively. Errors are also encountered when bioimpedance is used to monitor changes in body fat during weight loss. Such errors may lead to inaccurate estimation of percentage body fat when bioimpedance is used in clinical practice.
References