Effect of crude fiber and total dietary fiber on the calculated nitrogen-free extract and metabolizable energy content of various dog foods fed to client-owned dogs with osteoarthritis

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OBJECTIVE
To compare measurements of crude fiber (CF) and total dietary fiber (TDF) for various dog foods and their effect on the calculated nitrogen-free extract and metabolizable energy (ME) content, and to compare label-guaranteed and laboratory-analyzed macronutrient values.

SAMPLES
51 dog foods fed to client-owned dogs with osteoarthritis.

PROCEDURES
Foods were analyzed for dry matter, ash, crude protein, acid-hydrolyzed fat, CF, and TDF. Metabolizable energy was calculated by use of a formula with modified Atwater factors and formulas recommended by the National Research Council that included both CF and TDF values. Linear regression analysis was performed to determine the correlation between CF and TDF values.

RESULTS
Only a few foods failed to conform to the guaranteed analysis for all macronutrients except for CF, in which approximately 40% of the foods exceeded the guaranteed maximum values. The CF and TDF values were moderately correlated (r = 0.843). Correlations among CF- and TDF-based ME estimations were moderate with use of the modified Atwater formula and strong with use of the National Research Council formulas (r = 0.86 and r = 0.91, respectively).

CONCLUSIONS AND CLINICAL RELEVANCE
Values for CF were the most variable of the macronutrients of the evaluated dog foods and results suggested that CF is an incomplete and inaccurate measurement of dietary fiber content and, thus, its inaccuracy may lead to inaccurate and variable ME values.

Guaranteed analysis is required on pet food labels to advise pet owners about the nutrient composition of the food. In complete and balanced pet foods, GA must report on an as-fed basis (g/100 g food) the maximum percentages of CF and moisture and the minimum percentages of crude protein and crude fat.[1] Failure to meet GA (ie, percentages outside acceptable analytical variation defined by AAFCO) may result in enforcement action if the food is analyzed by AAFCO officials.[2] A previous study[3] reveals that proximate analysis measurements varied slightly from the GA for 1,158 wet and 750 dry pet foods from 204 manufacturers, but the effects on GA inaccuracies on ME could not be measured because of the lack of complete proximate analyses for all but 1 food. If a food with an inaccurate actual GA versus that reported on the label is fed to a pet, its health may be affected. For example, a food with higher soluble dietary fiber content and inaccurate protein content, fat content, or ME estimates than that reported on the label may lead to poor fecal quality and over- or underfeeding of the pet.

Studies[4,5] show that TDF, compared with CF, is an accurate measure of dietary fiber content and therefore is the reason that TDF is reported on the labels of human foods. The definition of dietary fiber set by the FDA[6] is intended to apply to human foods but could be applied to pet foods. The use of TDF rather than CF may lead to accurate and less

ABBREVIATIONS

AAFCO	Association of American Feed Control Officials
AOAC	Association of Official Analytical Chemists
CF	Crude fiber
DM	Dry matter
GA	Guaranteed analysis
LA	Laboratory analysis
ME	Metabolizable energy
ME_{MA}	Metabolizable energy calculated with a formula that incorporated modified Atwater factors
ME_{NRC}	Metabolizable energy calculated with National Research Council formulas
NFE	Nitrogen-free extract
NRC	National Research Council
TDF	Total dietary fiber

variable (ie, more precise) quantification of actual dietary fiber content, which may help distinguish and develop products that may provide health benefits (eg, products that improve quality of feces, manipulate the gastrointestinal microbiota to improve gastrointestinal health, or reduce calories for weight management), specifically associated with different fiber fractions, as well as avoid food intolerance related to underestimated dietary fiber content, particularly soluble fibers.

The objectives of the study presented here were to compare the GA and LA as well as CF and TDF values and estimated ME of commercial dog foods that were fed to client-owned dogs with osteoarthritis. The first hypothesis was that CF would underestimate the actual dietary fiber content and thus the use of CF as a measure of fiber content would inflate estimated NFE content and ME for these diets. The second hypothesis was that the dog foods that were in the popular brand category would have larger differences between GA and LA, compared with the dog foods that were in the premium and therapeutic brand categories, because of greater variability in the ingredient sources for the popular brand foods.

Materials and Methods

Sample preparation and LA

Samples of dog foods (n = 51) that were fed to client-owned dogs with osteoarthritis that were enrolled in a previous unrelated study[7] were used. After dog owners provided written consent for study enrollment, owners provided unopened cans of wet foods (n = 5) and samples of dry foods (46), along with the food labels. Samples were stored at –20 °C until analysis. The foods were divided into 3 categories—popular (n = 11), premium (32), and therapeutic (8)—on the basis of these criteria: the food's brand name and its positioning within each brand, the retail sector in which the food was sold, its GA macronutrient content, and its purported benefits. Foods categorized as therapeutic referred to those available only by veterinary prescription. The study was approved by the University of Illinois Animal Care and Use Committee.

Wet foods were lyophilized in a freeze dryer.[a] All foods were ground in a mill[b] through a 2-mm screen and stored at 4 °C during LA. Samples were analyzed for DM according to the method described by the AOAC[8] and for ash by incinerating the samples at 500 °C in a muffle furnace for 12 hours. Organic matter was calculated as the difference between substrate DM and ash. Crude protein was calculated from total nitrogen values derived from combustion[c] of samples according to the method described by the AOAC.[9] Total lipid content was determined by acid hydrolysis followed by ether extraction according to the methods described by the Cereal & Grains Association (formerly the American Association of Cereal Chemists)[10] and Budde.[11] Acid hydrolysis was used to quantify fat content because it accurately estimates the actual fat content of pet foods, compared with the crude fat method.[12–14] Total dietary fiber content and CF content were determined according to methods described by the AOAC.[15,16] All samples were analyzed in duplicate and an analytical error ≤ 5% was acceptable for all assays.

Calculation of estimates of NFE and ME

Nitrogen-free extract (ie, carbohydrate [digestible starch]) was calculated as the remaining DM after the removal of ash, protein, fat, and fiber. Guaranteed analysis or LA for CF or LA for TDF was used in the NFE calculation. The labels of of 90% (46/51) of the foods did not provide a guaranteed ash content; therefore, those foods were assigned a GA ash content of 5% for dry foods and 1% for wet foods. Nitrogen-free extract was calculated with the following formula:

$$100\% - (\text{moisture [\%]} + \text{ash [\%]} + \text{crude protein [\%]} + \text{crude fat or acid-hydrolyzed fat [\%]} + \text{CF or TDF fiber [\%]})$$

Two ME (kcal/g) values were calculated. The LA data were input into the ME formula that AAFCO required and that included the modified Atwater factors (ME_{MA}).[1] The formula for calculating ME_{MA} was as follows:

$$(3.5 \times \text{crude protein [\%]}) + (8.5 \times \text{fat [\%]}) + (3.5 \times \text{NFE [\%]})$$

The ME_{NRC} value for the LA data was calculated with the use of a set of formulas proposed by the NRC.[17] The formulas were as follows:

$$\text{GE (kcal/g)} = (5.7 \times \text{protein [g]}) + (9.4 \times \text{fat [g]}) + (4.1 \times [\text{NFE \{g\}} + \text{fiber \{g\}}])$$

where GE = gross energy

$$\text{ED (\%)} = 91.2 - (1.43 \times \text{CF in DM [\%]}) \text{ or}$$
$$\text{ED (\%)} = 96.6 - (0.95 \times \text{TDF in DM [\%]})$$

where ED = energy digestibility

$$\text{DE (kcal/g)} = (\text{GE} \times [\text{ED}/100])$$

where DE = digestible energy

$$\text{ME (kcal/g)} = \text{DE} - (1.04 \times \text{protein [g]})$$

Statistical analysis

All GA and LA macronutrient composition values were converted to a DM basis prior to analyses with statistical software.[d] The PROC UNIVARIATE function in the software was used to apply tests of normality (eg, Shapiro-Wilk and Kolmogorov-Smirnov tests). With confirmation of data normality, the PROC MIXED function in the software was used to fit a variety of mixed linear models to the values for ME, NFE, LA, and GA, with a random effect of food. Results are presented as least-squares means ± SD. Values of $P < 0.05$ were considered significant.

Values for the independent variables CF or TDF and values for the dependent variable ME were entered into an electronic spreadsheet[e] and fit to simple linear regression models, and lines of best fit were determined. Correlation coefficients were determined for predicting TDF values from CF values, as well as relationships between predicted ME values. An $r > 0.90$ indicated a strong correlation.

Results

GA versus LA

Laboratory-analyzed moisture content conformed to the guaranteed maximum moisture content for all foods **(Table 1)**. Laboratory-analyzed mean crude protein was 4.1% higher than the GA mean crude protein for all foods. All foods in the premium and therapeutic categories conformed to the minimum crude protein content, whereas 1 of the 11 foods in the popular category failed to conform but remained within the allowable analytical variation ([20/GA for crude protein] + 2) defined by AAFCO. Two of 11 popular, 10 of 32 premium, and 2 of 8 therapeutic foods failed to conform to guaranteed minimum crude fat, compared with LA acid-hydrolyzed fat. Of these nonconformant foods, 2 popular foods and 1 each of premium and therapeutic foods had GA crude fat content that was outside of the AAFCO allowable analytical variation (10%). Similarly, 1 popular, 14 premium, and 6 therapeutic foods failed to conform to the guaranteed maximum CF content. Of these nonconformant foods, 1 popular, 10 premium, and 3 therapeutic foods had GA CF content that was outside of the allowable analytical variation ([30/GA for CF] + 6) defined by AAFCO.

Mean LA crude protein content for popular (crude protein DM, 26.5%), premium (26.3%), and therapeutic (24.4%) categories were significantly ($P < 0.05$) higher than the mean GA crude protein content for each category (crude protein DM: 24.9%, 24.5%, and 22.7%, respectively; Table 1). Mean LA acid-hydrolyzed fat content (DM, 16.3%) was significantly ($P < 0.05$) higher than the GA crude fat content (15.2%) for the premium foods but was not significantly different for the popular and therapeutic foods. The mean difference between GA and LA crude fat content was 1.9%.

Overall, 15 diets exceeded the analytical variation allowed by AAFCO for at least 1 macronutrient; however, only 4 diets exceeded the allowable analyti-

Table 1—Comparison of GA and LA macronutrient composition of samples of dry and wet dog foods (n = 51) that were fed to client-owned dogs with osteoarthritis. Guaranteed analysis values were obtained from the food labels. Foods were assigned to 1 of 3 categories (popular, premium, and therapeutic) on the basis of the food's brand name and its positioning within each brand, the retail sector in which the food was sold, its GA macronutrient content, and its functional properties. Foods assigned to the therapeutic category were those available only by veterinary prescription.

	Popular		Premium		Therapeutic
Macronutrient	Dry (mean ± SD [%])	Wet (mean ± SD [%])	Dry (mean ± SD [%])	Wet (mean ± SD [%])	Dry (mean ± SD [%]
Moisture					
GA	12.4 ± 1.26	78.0	10.6 ± 0.87‡	80.0 ± 2.31‡	10.3 ± 0.82‡
LA	9.0 ± 1.07	75.3	7.2 ± 1.05‡	74.7 ± 2.66‡	8.1 ± 0.77‡
Difference*	3.3 ± 1.20	2.7	3.8 ± 1.36	5.4 ± 0.82	2.5 ± 1.13
Range†	6.6–12.6	—	4.4–9.3	72.3–77.8	6.7–9.1

	DM basis (mean ± SD [%])		
	Popular	Premium	Therapeutic
Organic matter			
GA	NA	NA	NA
LA	92.2 ± 1.94	92.0 ± 1.07	94.4 ± 1.12
Crude protein			
GA	24.9 ± 4.39‡	24.5 ± 5.24‡	22.7 ± 5.50‡
LA	26.5 ± 4.24‡	26.3 ± 6.57‡	24.4 ± 6.26‡
Difference*	4.3 ± 2.03	4.1 ± 2.28	3.8 ± 1.74
Range†	22.8–37.4	20.1–56.0	18.5–35.2
Fat			
GA	13.7 ± 6.75	15.2 ± 4.25‡	10.8 ± 3.45
LA	14.9 ± 7.89	16.3 ± 4.90‡	12.4 ± 3.98
Difference*	2.0 ± 1.37	1.5 ± 1.49	2.1 ± 1.49
Range†	9.5–37.4	7.5–34.9	6.7–17.4
CF			
GA	5.9 ± 2.26	5.6 ± 3.01	8.8 ± 5.52
LA	4.7 ± 2.52	4.7 ± 2.35	9.2 ± 5.31
Difference*	1.8 ± 1.56	1.9 ± 2.48	1.9 ± 1.62
Range†	1.9–9.7	1.8–14.2	4.1–16.7

*Absolute mean ± SD difference between GA and LA data. †Range for LA data. ‡Results within the same column for each macronutrient significantly ($P < 0.05$) differ.

NA = Not available. — = Not applicable.

cal variation for 2 macronutrients. None of the diets exceeded the allowable analytical variation for > 2 macronutrients.

CF versus TDF

Mean (SD) TDF content was 2.0 (0.51) times the corresponding CF content, with mean TDF content 5.2% (2.5%) higher than mean LA CF content and the difference between TDF and CF content ranging from 0.06% to 10.05%. Laboratory-analyzed CF and TDF content were determined and compared with the GA CF content **(Figure 1)**. Mean LA CF content was 4.7% for popular and premium foods and 9.2% for therapeutic foods. Mean TDF content was 9.6% for popular and premium foods, whereas it was 12.5% for therapeutic foods. Mean TDF content was significantly ($P < 0.05$) higher than CF content for popular and premium foods but not for therapeutic foods.

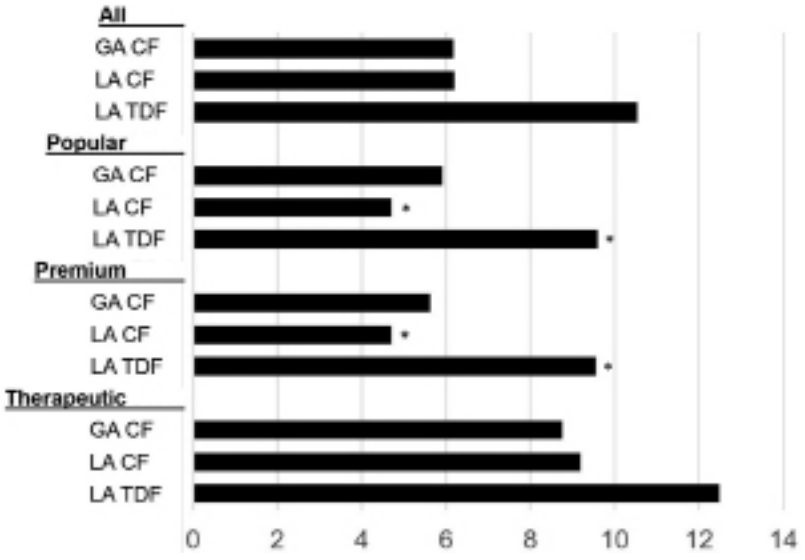

Figure 1—Bar graph of least-squares means for GA CF and LA CF and TDF percentages for samples of dry and wet dog foods (n = 51) that were fed to client-owned dogs with osteoarthritis. Guaranteed analysis values were obtained from the food labels. Foods were assigned to 1 of 3 categories; popular, premium, and therapeutic; on the basis of the food's brand name and its positioning within each brand, the retail sector in which the food was sold, its GA macronutrient content, and its purported benefits. Foods assigned to the therapeutic category were those available only by veterinary prescription. *Means within the same category were significantly ($P < 0.05$) different. Guaranteed analysis and LA CF within each food category were not significantly different, and data for GA CF and LA TDF were not analyzed.

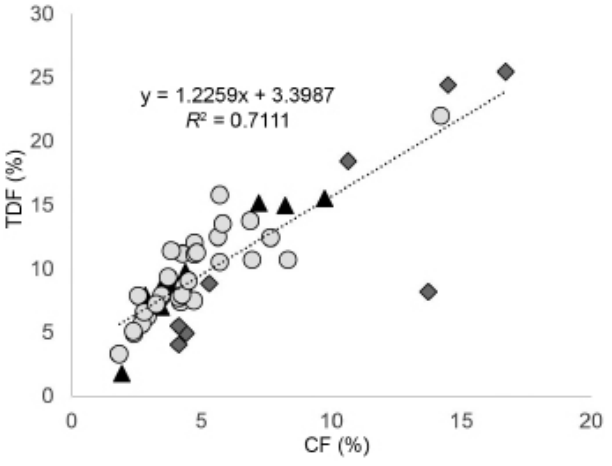

Figure 2—Graphical plot of LA TDF versus LA CF on a DM basis for the foods (popular [triangles], premium [circles], and therapeutic [diamonds]) of Figure 1. A simple linear regression line is denoted by the dotted line. The linear regression equation and coefficient of determination (R^2) are provided.

When LA data for fiber content in all foods were assessed through simple linear regression, correlation between TDF and CF was moderate ($r = 0.84$; **Figure 2**). When LA data for each food category was assessed, r equalled 0.93 for popular foods, 0.87 for premium foods, and 0.84 for therapeutic foods **(Supplementary Figure S1)**.

NFE and ME

For both GA and LA data, mean NFE calculated with CF was significantly ($P < 0.001$) higher than the mean NFE calculated with TDF (data not shown). Mean NFE calculated with GA CF was greater ($P < 0.001$) than the mean NFE calculated with LA CF, and both were significantly ($P < 0.001$) greater than the mean NFE calculated with TDF.

The correlations between LA CF- and TDF-based estimations of ME_{MA} and LA CF-and TDF-based estimations of ME_{NRC} were strong ($r = 0.97$ and $r = 0.95$, respectively; **Figure 3**). Mean ME_{NRC} estimates were significantly ($P < 0.001$) higher, compared with ME_{MA} estimates, for both CF and TDF. Estimations of ME_{MA} were significantly ($P < 0.001$) higher for CF (3.83 kcal/kg) versus TDF (3.66 kcal/kg), whereas estimations of ME_{NRC} were significantly ($P < 0.001$) higher for TDF (4.12 kcal/kg) versus CF (3.97 kcal/kg).

The correlations between LA CF- and GA CF-based estimations of ME_{NRC} overall ($r = 0.92$) and within popular ($r = 0.90$) and premium ($r = 0.96$) categories were stronger than the correlations for their respective CF-based estimations of ME_{MA} ($r = 0.86$, $r = 0.79$, and $r = 0.93$, respectively; **Figure 4; Supplementary Figure S2**). Correlations between LA and GA estimations of ME_{MA} and ME_{NRC} were moderate for the therapeutic foods ($r = 0.85$ and $r = 0.84$, respectively). Crude fiber- and TDF-based estimations of ME_{MA} and CF- and TDF-based estimations of ME_{NRC} were strongly correlated ($r = 0.98$ and $r = 0.99$, respectively; **Figure 5**). No significant differences were observed among food categories for TDF-based estimations of ME_{MA}, TDF-based estimations of ME_{NRC}, or CF-based estimations of ME_{MA}. When all diets were included in the calculation, the TDF-based estimation of ME_{MA} was approximately 95% of the CF-based

estimation of ME_{MA}, with the lowest TDF-based estimation of ME_{MA} approximately 88% of the respective CF-based estimation of ME_{MA}.

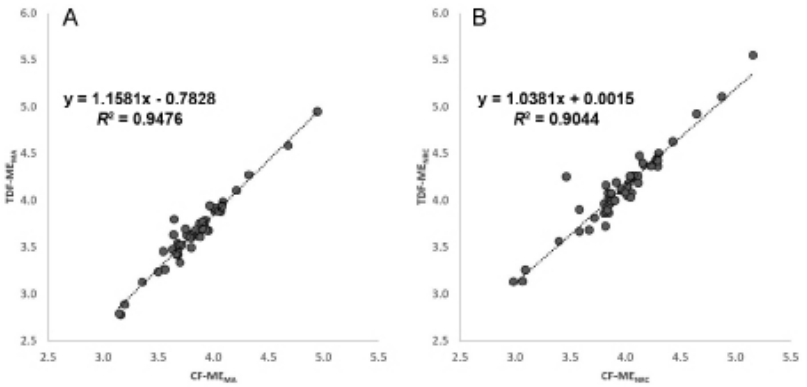

Figure 3—Graphical plots of TDF ME_{MA} estimates (kcal/kg) versus LA CF ME_{MA} estimates (kcal/kg; A) and of TDF ME_{NRC} estimates (kcal/kg) versus LA CF ME_{NRC} estimates (kcal/kg; B) on a DM basis for the foods of Figure 1. A simple linear regression line for each plot is denoted by the dotted line. The linear regression equation and coefficient of determination (R^2) are provided for each plot.

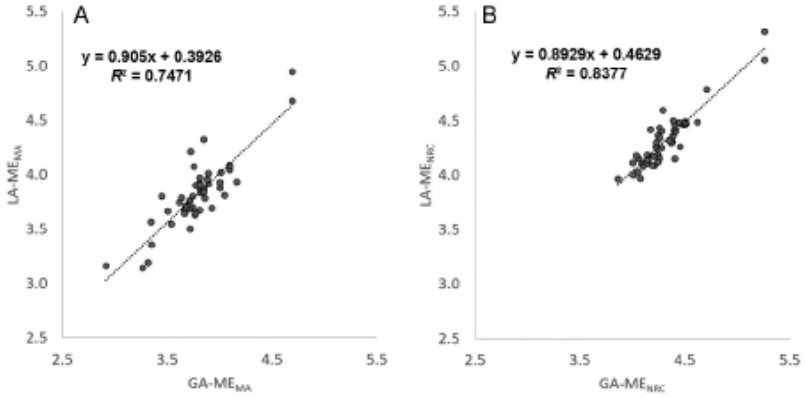

Figure 4—Graphical plots of LA CF ME_{MA} estimates (kcal/kg) versus GA CF ME_{MA} estimates (kcal/kg; A) and of LA CF ME_{NRC} estimates (kcal/kg) versus GA CF ME_{NRC} estimates (kcal/kg; B) on a DM basis for the foods of Figure 1. A simple linear regression line for each plot is denoted by the dotted line. The linear regression equation and coefficient of determination (R^2) are provided for each plot.

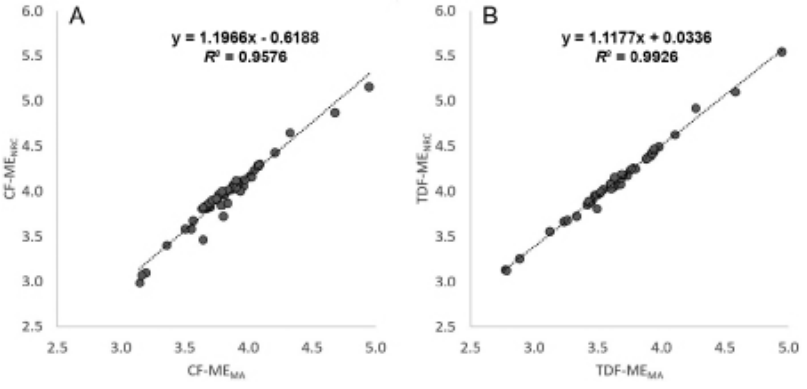

Figure 5—Graphical plots of LA CF ME_{NRC} estimates (kcal/kg) versus LA CF ME_{MA} estimates (kcal/kg; A) and of TDF ME_{NRC} estimates (kcal/kg) versus TDF ME_{MA} estimates (kcal/kg; B) on a DM basis for the foods of Figure 1. A simple linear regression line for each plot is denoted by the dotted line. The linear regression equation and coefficient of determination (R^2) are provided for each plot.

Discussion

All dog foods evaluated in the present study conformed to the maximum moisture content and, as expected, LA moisture was below that for GA. In a previous study,[1] approximately 2,200 commercial pet foods were analyzed for crude protein and the differences between GA and LA for both wet and dry foods (1.3% and 1.6%, respectively) was smaller than for those in the present study (mean, 4.1% for all foods). Differences may be attributed to the smaller sample size for the present study and the dog foods that were analyzed. The previous study[1] included pet foods provided by various manufacturers regardless of the food's market category or therapeutic claims, whereas the present study included dog foods fed specifically to dogs with osteoarthritis by their owners who were each aware of their dog's health status and, in some cases, at the recommendation of a veterinarian because of their dog's health status.

The label of each commercial pet food must state the food's minimum crude fat content. However, the present study analyzed all foods for fat by acid hydrolysis, a method that yields an accurate measurement of total fat content because this method detects phospholipids and sphingolipids that are not detected by the crude fat method.[13,14] This may augment values and make comparisons between LA values and minimum GA values difficult; yet, because GA crude fat is a minimum, interpretation of whether a food is nonconformant by use of the acid hydrolyzed method is acceptable and interpretation is equivalent to that had crude fat been analyzed. Underestimation of dietary fat content may lead to inaccurate determination of caloric density and excessive caloric intake, which may result in positive energy balance and body weight gain.

The AOAC method used to quantify CF in pet foods[16] does not fully account for resistant starches or soluble fibers (eg, pectins, gums, and β-glucans) and uses strong alkaline and acidic reagents that can partially solubilize and dissolve hemicelluloses, celluloses, and lignins (polymers made by cross-linking phenolic precurors), while incompletely remov-

ing some proteins and connective tissues, resulting in values that are typically 30% to 50% of the acutal fiber content.[5,17] Dietary fiber can be categorized on the basis of its chemical and physical properties, including solubility. β-Linkage type between monosaccharides comprising fiber types affects solubility; soluble fibers, such as β-glucans, are typically comprised of mixed linkages and become strongly hydrated in water; whereas insoluble fibers, like cellulose, are comprised of similar linkages that may form ordered crystalline structures.[18] Despite its inaccuracy, the CF method is currently the method that AAFCO requires for GA. The Prosky TDF assay has the capacity to recover β-glucans, pectins and gums, hemicelluloses, cellulose, and lignins and to partially recover resistant starches; however, this assay does not account for low-molecular-weight soluble fibers such as fructo-oligosaccharides and inulin.[19] The TDF analysis also allows for the determination of soluble and insoluble fiber fractions.

Dietary fiber at an appropriate amount is often an ingredient in pet foods to help maintain or restore gastrointestinal health, blunt a postprandial glycemic response, dilute caloric density, and manage body weight.[20–23] These effects are essential in the management of dogs with joint disease such as osteoarthritis,[24–26] with diabetes mellitus or with obesity,[27,28] which are often reported in osteoarthritic[7,25] and old dogs.[29,30] Inaccuracies in dietary fiber content plus in dietary fat content may exacerbate these conditions and therefore are critical when developing therapeutic diets aimed at managing these conditions. Inaccurately reporting dietary fiber content alone may also lead to inappropriate feeding guidelines and greater fiber consumption than anticipated, which may then contribute to intestinal dehydration[31] and increased bloating and flatulence.[32]

Crude fiber was not an accurate predictor of dietary fiber content of the dog foods analyzed in the present study. Similar findings were reported in a previous study[3] that included an evaluation of the CF and TDF contents of dry and canned foods. In general, correlation is poor between analytical methods for CF and TDF, which most likely corresponds to the variety of fiber sources of various dog foods and the amounts of soluble and insoluble fiber that compose each fiber source. The variation between CF and TDF is most likely because the fiber sources of dog foods are high in soluble fibers that escape recovery through CF analysis. Common soluble fiber sources that appeared at the beginning of the ingredient lists of the dog foods analyzed in the present study included beet pulp, oats, and oatmeal.

All dog foods in the present study had a moderate correlation between CF and TDF values, with the TDF values approximately 2 times those of CF values. Possibly a larger sample size would have yielded a better estimate of the inaccuracy of CF. Molina et al[4] report a similar correlation (r = 0.87), with TDF values also approximately 2 times those of CF values for 15 rabbit foods.

The therapeutic foods had the lowest correlation between CF and TDF among the 3 food categories. Although the therapeutic foods analyzed in the present study were fed to dogs with osteoarthritis, all foods were not purported to help dogs with osteoarthritis. Some foods were purported to help dogs with kidney or liver disease or with gastrointestinal health rather than with weight management or joint health. However, various dog foods were expected because they were fed to client-owned dogs that had osteoarthritis and may have been diagnosed with comorbidities. Differences in ingredients and the ratio of soluble to insoluble fiber of these foods may have been the reason for the moderate correlation between CF and TDF. The premium and therapeutic foods included a diversity of fiber-containing ingredients that contributed to a more complex dietary fiber profile than that of the popular foods. Without knowing the exact amount of each ingredient in each food, each food could only be evaluated on the basis of the weight order listed on its label. Nearly all popular foods had whole grain corn as the primary fiber and carbohydrate source, whereas various whole grains, cellulose, oatmeal, and complex fiber blends were the primary fiber and carbohydrate sources for the premium and therapeutic foods.

Nitrogen-free extract is an estimation of the nonfibrous carbohydrates (eg, sugars and starches) within a food sample and is calculated by subtracting the analyzed moisture, protein, fat, and fiber values from the whole (100%). Thus, any analytical error for the quantification of each of those values will be additive in the calculation of NFE. The present study showed that variations in fiber quantification affected the calculations of NFE as well as ME, with an underestimation of dietary fiber content by use of CF rather than TDF that then yielded higher NFE values. The approximately 5% higher CF-based ME values, compared with TDF-based ME values, may lead to overfeeding of 57 kcal/d (15 g/d) or 20,864 kcal/y (6 kg/y). However, feeding guidelines are only a starting point for the amount to feed because the metabolic rate of each dog differs on the basis of age, breed, reproductive status, activity level, environment, etc.[33–36]

The present study also included an evaluation of 2 of the most common methods for estimating ME: a formula proposed by the 1985 NRC that uses modified Atwater values and formulas proposed by the 2006 NRC.[17] When TDF was used to calculate ME, correlation (r = 0.99) between ME_{MA} and ME_{NRC} was strong. The 2006 NRC formulas were more robust because bomb calorimetry is used to determine the gross energy content as well as proposed macronutrient gross energy coefficients prior to subtraction of estimated urinary losses, whereas the modified Atwater formula uses the same macronutrient coefficients (eg, fat, 8.5 kcal/g; crude protein, 3.5 kcal/g; and NFE, 3.5 kcal/g) for all substrates. The NRC

(2006) also acknowledges the differences in CF and TDF analytical methods and their subsequent effects on the calculations for energy digestibility and offers alternative formulas for use with each fiber value.[17] Fiber can provide energy indirectly through the absorption of microbial fermentation products and has been proposed to have an ME coefficient as large as 2 kcal/g.[37] This may help to explain why the use of TDF in the NRC formulas yielded higher estimates of ME. Thus, the increased complexity of the NRC formulas and the allowance of including CF or TDF in the formulas make the NRC formulas more versatile and a beneficial replacement of the modified Atwater formula that has primarily been used.

The large variations between ME estimates may be detrimental, especially in animals suffering from obesity-related or exacerbated conditions such as osteoarthritis. The major limitation to predicting ME continues to be the actual ME discrepancies among animals with use of the same substrate. Without implementing a feeding trial, estimates of ME cannot be directly compared with actual ME to determine the true accuracy of the ME estimates.

Few dogs foods in the present study failed to conform to the GA on the label for all analyzed macronutrients, except for CF, in which approximately 40% exceeded the GA and 27% exceeded the allowable AAFCO analytical variance. However, the CF analytical method greatly underestimated fiber content and was not strongly correlated to TDF. The consequences of the use of the CF method are far-reaching, including inaccurate estimates of NFE and subsequent ME that may affect estimated starch and caloric intake. These inaccuracies may have detrimental effects on a dog's health, especially in conditions for which weight management is of concern.

Acknowledgments

No external funding was used in this study. The authors declare that there were no conflicts of interest.

Footnotes

a. FTS Systems Dura-Dry MP freeze dryer, SP Scientific, Warminster, Pa.
b. Model 4 Wiley Mill, Thomas Scientific, Swedesboro, NJ.
c. TruMac N, Leco Corp, St Joseph, Mich.
d. SAS, version 9.4, SAS Institute Inc, Cary, NC.
e. Excel, Microsoft Corp, Redmond, Wash.

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Supplementary Materials

Supplementary materials are available online at: avmajournals.avma.org/doi/suppl/10.2460/ajvr.82.10.787