Comparison of the standard predictive equation for calculation of resting energy expenditure with indirect calorimetry in hospitalized and healthy dogs

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Objective—To determine the level of clinical agreement between 2 methods for the measurement of resting energy expenditure (REE).

Design—Prospective case series.

Animals—77 dogs.

Procedure—Oxygen consumption ($\dot{V}O_2$) and CO_2 production ($\dot{V}CO_2$) were measured with an open-flow indirect calorimeter in healthy (n = 10) and ill (67) dogs. Measurements were collected at 3 time periods on 2 days. The $\dot{V}O_2$ and the $\dot{V}CO_2$ measurements were then used to calculate the REE values.

Results—Mean values of measured (MREE) and predicted (PREE) REEs in healthy dogs and a dog with medical illnesses or trauma were not significantly different. There was a significant difference on day 2 between the MREE and PREE in the group of dogs recovering from major surgery. More importantly, there was significant variation between the PREE and MREE on an individual-dog basis. The PREE only agreed to within ± 20% of the MREE in 51% to 57% of the dogs.

Conclusions and Clinical Relevance—The level of agreement between these two methods for determining the 24-hour REE was poor in individual dogs. The level of disagreement between the 2 methods indicates that these methods may not be used interchangeably in a clinical setting. Measurement of REE by use of indirect calorimetry may be the only reliable method of determining REE in an individual ill or healthy dog. (*J Am Vet Med Assoc* 2004;225:58–64)

Nutritional support plays an integral role in recovery from illnesses or injuries. If adequate caloric intake is not provided during the treatment and recovery phases of illness, the risk of illness and death increases.[1,2] During illness and injury, energy and substrates are mobilized from lean body mass in an attempt to support inflammation, immune function, and tissue repair.[1,3-6] The degree of endogenous nutrient mobilization and the increase in the **energy expenditure (EE)** depend on the nature and severity of illness or injury.[3] Adequate nutritional support may help to reduce the catabolic process and maintain the body's lean mass during this period of altered metabolism.[1,7,8] However, excessive nutrient intake may place additional stress on the respiratory system,[9] cardiovascular system,[10] and liver.[11] Both under- and overfeeding critically ill human patients can have a negative impact on outcome.[1,2,8,12]

It has been assumed that dogs respond to illness and disease in a manner similar to that of humans. Severely ill or injured dogs should have increased EE that is proportional to the severity of the injury. Furthermore, catabolism of endogenous nutrient stores will be increased to meet the energy demands associated with illness, which in turn predisposes the animal to protein-calorie malnutrition. These assumptions are prevalent in the veterinary literature,[13,14] although validation is sparse.[15,16] In veterinary patients, energy requirements are calculated with a commonly used **predictive resting EE (PREE)** equation in an attempt to estimate the daily resting EE. The predictive equation[17] is PREE = 70 × (BW [kg])$^{0.75}$, where BW is body weight and is multiplied by a stress or illness factor. The illness factor is a subjective correction factor that ranges from 1.25 to 2.0 and is meant to take into account the increased EE associated with injury or illness.[13,14] The illness factors have been derived mainly from clinical data in humans,[18] and there are minimal experimental data in dogs.[15] It is unclear from the veterinary literature when or why this equation was adopted, and the equation has never been verified in ill or injured dogs. Recent evidence suggests that this equation is not accurate in healthy dogs.[19,a]

Values obtained from the equations for the estimation of PREE in human medicine, even when corrected for stress and illness factors, differ substantially from the **measured REEs (MREEs)**.[20-23] A more reliable approach to assessing the daily EE in human medicine is to measure the EE via indirect calorimetry under certain conditions. The conditions under which REE is measured may include periods of diet-induced thermogenesis, physiologic or psychological stress, and variations in body and environmental temperature.[24] A clear definition of the conditions under which the metabolic rate is measured should always be provided in the experimental protocol to facilitate comparisons among researchers.[25]

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Table 1—Descriptive statistics (median [range]) of 77 dogs enrolled in a study of the level of clinical agreement between measured and predicted resting energy expenditure (REE).

Group	Age (y)	Weight (kg)	Illness factor	RQ
Control	4 (2–9)	28.1 (21.1–33.5)	1.0 (1)	0.7 (0.7–0.8)
Medicine	5 (0.5–13.0)	24.0 (7.6–57.0)	1.3 (1.2–1.5)	0.7 (0.67–1.03)
Surgery	4 (0.1–9.0)	30.0 (13.4–48.0)	1.3 (1.2–1.5)	0.7 (0.67–1.05)
Trauma	2 (1–8)	29.0 (4.8–41.5)	1.4 (1.3–1.5)	0.7 (0.67–1.0)

Control = Healthy staff-owned dogs (n =10). Medicine = Client-owned dogs with a variety of medical illnesses (n = 34). Surgery = Client-owned dogs recovering from a major surgical procedure (n =17). Trauma = Client-owned dogs in a post-trauma period (n = 16). RQ = Respiratory quotient ($\dot{V}CO_2/\dot{V}O_2$).

Indirect calorimetry is accomplished by measuring the products of oxidative metabolism, **oxygen consumption** ($\dot{V}O_2$), and **CO_2 production** ($\dot{V}CO_2$). Respiratory gas exchange measurements ($\dot{V}O_2$ and $\dot{V}CO_2$), minute volume (expired volume per unit time), and the **respiratory quotient (RQ)** are determined from analysis of expired gas.[26-28] The $\dot{V}O_2$ and $\dot{V}CO_2$ measurements are used to determine the REE by use of the abbreviated Weir formula.[16,29,30] Indirect calorimetry is presently the method of choice for measuring REE in hospitalized humans.[23,29,31,32] The use of indirect calorimetry for assessing REE in dogs has only recently been examined in veterinary medicine.[16,33,34] Examination of the level of agreement between the veterinary standard of care for estimating the daily REE and measurement of REE by indirect calorimetry would provide valuable scientific data in veterinary medicine.

The purpose of the study reported here was to assess the level of clinical agreement between open-flow indirect calorimetry (ie, MREE) and the traditional equation for the 24-hour PREE in a population of healthy dogs and ill dogs in an intensive care unit setting at a veterinary teaching hospital with conditions similar to those reported in human indirect calorimetry studies.[21-23,27,32,35-38] We hypothesized that the PREE would not agree with the MREE measured by use of indirect calorimetry.

Material and Methods

The study population initially consisted of 77 dogs evaluated at the Ontario Veterinary College Teaching Hospital from April to September 1999. The 77 dogs included 10 healthy staff-owned dogs (control dogs), 34 dogs with medical illnesses, 17 dogs recovering from major surgery, and 16 dogs with substantial trauma (**Tables 1 and 2**). The traumatic incident occurred 24 to 72 hours prior to referral.

Case dogs—Dogs with medical, surgical, or traumatic illnesses were enrolled via order of referral and included in the study if they were cooperative, within 10% of ideal body weight (subjective assessment), and remained in the intensive care unit for a minimum of 48 hours (72 hours if they required a general anesthetic). Exclusion criteria included uncooperative patient, entry weight 10% greater than ideal body weight, requirement for supplemental administration of oxygen, facial conformation that would not allow an airtight seal with the face mask, suspected or confirmed diagnosis of neoplasia, and discharge from the intensive care unit or euthanasia prior to completion of at least 3 readings of REE by use of the open-flow indirect calorimeter. Dogs were allocated into 3 groups according to illness or injury. The clinician responsible for each case made decisions regarding treatment and caloric intake entirely independent of the study; however, all ill dogs were fed a similar diet[b] and were on a similar feeding schedule (8:00 AM and 8:00 PM).

Table 2—Sex distribution of 77 dogs enrolled in a study of the level of clinical agreement between measured and predicted REE.

Group	Female	Female spayed	Male	Male neutered	Total No. of dogs
Control	0	5	0	5	10
Medicine	0	17	8	9	34
Surgery	2	9	4	4	17
Trauma	1	7	3	5	16
Total	**3**	**38**	**13**	**23**	**77**

See Table 1 for key.

Control dogs—Control dogs were obtained from staff members. Dogs were judged to be healthy on the basis of results of physical examination, hemogram, serum biochemical profile, and serum free thyroxine concentrations within reference limits. Additional inclusion criteria consisted of no history of a previous medical problem or known exposure to anesthesia or exogenous corticosteroids within the previous month, and all dogs had to be within 10% of ideal body weight (subjective assessment). These dogs were fed a high-quality commercial dog food[c] and were on the same feeding schedule as the case dogs.

Protocols were followed in accordance with the guidelines set by the Canadian Council on Animal Care and approved by the committee concerned with ethical review at the University of Guelph. Informed consent was obtained prior to enrollment in the study.

Determination of the PREE—At the time of study, enrollment PREE was calculated by use of the following equation: PREE = 70 × (BW [kg])$^{0.75}$ × illness factor. The dogs' body weight at entry into the study was used in this calculation, and an illness factor was determined for each dog by the principle author prior to any metabolic measurements. The illness factors were based on the initial clinical signs and results of physical examination performed by the principal author. The following ranges were used as a guideline to assign illness factors: cage rest = 1.25, postsurgery = 1.25 to 1.35, trauma = 1.35 to 1.5, and sepsis = 1.5 to 1.7. The illness factor for all control dogs was considered to be 1.0.

Determination of the MREE—Upon enrollment in the study, blood was collected to perform a CBC, serum biochemical profile, and blood gas analysis. The dogs were provided with a minimum 6-hour period to acclimate to their surroundings prior to the first calorimetric reading. If general anesthetic was required, a full 24-hour recuperation period was provided prior to performing REE measurements or any further measurements of the REE. The measurements during the 24 hours were performed during the following periods on both days: 3:00 AM to 6:00 AM, 11:00 AM to 2:00 PM, and 4:00 PM to 8:00 PM. All metabolic measurements were performed at the cageside in the intensive care unit at least 30 minutes after administration of analgesic medication (if required), 30 to 60 minutes after physical activity or a diagnostic or therapeutic procedure, and 3 to 4 hours after a meal. Dogs enrolled in the study were fed a similar diet[c] twice per day, and the amount was based on the PREE as deter-

mined by the primary clinician. If the dogs were receiving partial parenteral nutrition, the rate of administration was not altered in the 12 hours prior to metabolic measurements or during the 2-day study period.

Measurements in control dogs—Control dogs were hospitalized and cage-rested for REE measurements. All REE measurements were performed during similar daily time periods as the case dogs; however, these measurements were performed in a quiet thermoneutral room within the hospital and not within the intensive care unit. Ten healthy dogs were initially enrolled, but in only 5 of the healthy dogs in the control group were indirect calorimetry readings performed on 2 days.

Indirect calorimetry—The principle author, a research student, or a trained technician performed measurements of $\dot{V}O_2$ and $\dot{V}CO_2$ via a portable, open-flow, indirect calorimeter.[d] The first 2 individuals performed most of the readings (48.5% and 24.2%, respectively). A microprocessor was used to calculate $\dot{V}O_2$, $\dot{V}CO_2$, and RQ by use of standard equations.[39] In this study, $\dot{V}O_2$ and $\dot{V}CO_2$ were calculated every 20 seconds and mean values of these readings were printed at 1-minute intervals. A Haldane transformation was performed at each 20-second interval. The gas analyzers were calibrated on a daily basis with a standard gas of known composition (18.0% O_2 and 2.0% CO_2) that is similar to the composition of expired air in dogs. A 1-L precision syringe[e] was used to calibrate the pneumotachograph on a weekly basis. The MREE (kcal/d) was calculated by use of the abbreviated Weir formula: (3.94 [$\dot{V}O_2$] + 1.1 [$\dot{V}CO_2$]) × 1440, where $\dot{V}O_2$ is oxygen consumption (L/min) and $\dot{V}CO_2$ is carbon dioxide production (L/min).[16,30,40]

A 10-minute adaptation period to the face mask and collection system was performed prior to each measurement. A reading consisted of 15 consecutive 1-minute $\dot{V}O_2$ and $\dot{V}CO_2$ measurements. Steady state was defined as a consecutive 5-minute reading in which the coefficient of variation of the $\dot{V}O_2$ and $\dot{V}CO_2$ measurement was ≤ 10% in the ill dogs and ≤ 15% in the healthy dogs. An additional criterion was that the RQ had to be within the physiologic range of 0.67 to 1.3.[32,35,40] The group MREEs and PREEs were expressed in kilocalories per kilogram per day, whereas each individual dog's REEs were expressed in kilocalories per day.

Statistical analyses—The analyzed data set only included those indirect calorimetry readings in which the RQ in the 5-minute steady-state reading was within the physiologic range (0.67 to 1.3). The individual dog's MREE readings each day (a dog was included in the data analysis if at least 2 readings in a 24-hour period met the above inclusion criteria) were used to calculate a mean MREE measurement. This value was compared with each dog's PREEs. Values obtained for the MREE were assessed for normal distribution by use of a Wilk-Shapiro test. The extent to which the mean MREE and mean PREE differed each day was calculated as a logarithm of the MREE:PREE ratio (ie, log MREE:PREE = log MREE – log PREE). Logarithmic transformation of the data was used to obtain the relative percentage difference per day on a group basis between MREE and PREE. This transformation normalized the data for ANOVA assumptions. A power calculation ($1-\beta = 0.8$) for the sample size of each group was performed so that if a 30% difference was present between the MREE and PREE, it could be detected. A sample size of 30 dogs/group was required to detect a significant difference between the MREE and PREE of 30% at the 0.05 level. A sample size of 80 dogs/group would have been required to detect a significant 20% difference/d between the MREE and PREE at the 0.05 level. Statistical analysis of the MREE:PREE ratio was performed by use of a general linear mixed model that assessed the random effects of the dogs and categoric variables of group, day, sex, and breed. Continuous variables were analyzed by use of regression analysis. The data set was analyzed by use of a software program,[41,f] and an *F* test was used to detect which of the covariates (group, day, age, breed, sex, and any interaction among or between these variables) had an influence on these means. Other covariates, such as body temperature, heart rate, respiratory rate, serum CO_2 concentration, and serum bicarbonate concentration, were also assessed in those dogs for which this information was available (n = 97 readings). Variables were retained in the model at a value of $P = 0.1$. The primary end point of the statistical analysis was to assess whether there was a significant difference between the MREE and PREE via the log ratio of these 2 variables (ie, if MREE and PREE were different, the log ratio was significantly different [$P \leq 0.05$] from 1.0). The logarithm of the ratio gives a relative percentage change between the 2 methods and not the absolute difference. Therefore, if the logarithm of the ratio was positive, the MREE was a relative percentage greater than the PREE, and if the logarithm of the ratio was negative, the MREE was a relative percentage less than the PREE. This statistical analysis examined the means of the logarithm ratio for each group on 2 days and did not examine how well these 2 methods would agree for an individual dog.

A statistical analysis of the level of clinical agreement between the PREE and MREE for each individual dog was also performed.[42] A natural logarithmic transformation of the data was performed. The difference of the natural log of the REE determinations was graphed against the natural log of the mean REE determinations. An antilog function must be performed for the values on figures 2 and 3 to be reported in the original units of kilocalories per day. A level of agreement of ± 20% difference between the 2 methods on a per day basis was deemed significant a priori. This was a subjective cutoff point that was determined prior to the onset of the study by the first and fourth author of this report. In other words, if the 2 methods for the determination of REE differed by more than 20% per day in an individual dog, there would be poor agreement between the 2 methods such that they should not be used interchangeably. A commercial statistical software program[f] was used to perform the data analyses. The adjusted or least square means and SEM are reported. The adjusted means take into account the covariates group, day, age, and group times day. The influence of outlying data points was assessed by removal of these data points and rerunning the model. A value of $P \leq 0.05$ was used to determine significance.

Results

A variety of breeds were enrolled in the study; mixed-breed dogs (19.9%) and Labrador Retrievers (10.2%) were most highly represented. Fifteen of the dogs in the medical illness group had an immune-mediated disease (immune-mediated thrombocytopenia, immune-mediated hemolytic anemia, or poly-arthritis), 9 had an infectious disease, 3 had a toxicosis, 3 had pancreatitis, 2 had renal disease, and the remainder had a fever of unknown origin or encephalitis. Thirteen of the dogs in the surgery group had an exploratory laparotomy, 2 dogs had a neurosurgical procedure, 1 dog had a thoracotomy, and 1 dog had an orthopedic procedure. Fourteen of the dogs in the trauma group had been injured in a motor vehicle accident, and 2 dogs had been injured in a dog fight.

Overall, 384 indirect calorimetry readings were performed in the 77 dogs evaluated initially. Of these observations, only 231 readings from 63 dogs met the inclusion criterion for analysis (**Tables 3 and 4**). The adjusted mean and 95% confidence interval of the mean MREE and mean PREE on a per group basis on days 1 and 2 were determined (**Figure 1**).

There was no main effect of group, sex, breed, or any interaction among or between these variables on

Table 3—Agreement between measured REE (MREE) and predicted REE (PREE) in dogs on day 1 of a study of the level of clinical agreement between measured and predicted REE.

Group	No. of dogs enrolled	No. of REE readings	No. of dogs that met inclusion criteria	No. of REE readings that met inclusion criteria	Agreement between MREE and PREE (%)
Control	10	30	7	12	72
Medicine	34	111	27	67	48
Surgery	17	50	15	35	40
Trauma	16	47	14	28	57
Total	**77**	**238**	**63**	**142**	**51**

See Table 1 for key.

Table 4—Agreement between MREE and PREE in dogs on day 2 of a study of the level of clinical agreement between measured and predicted REE.

Group	No. dogs enrolled	No. of REE readings	No.of dogs that met inclusion criteria	No. of REE readings that met inclusion criteria	Agreement between MREE and PREE (%)
Control	5	15	4	9	50
Medicine	33	73	24	48	62
Surgery	13	29	8	18	50
Trauma	12	28	8	14	50
Total	**63**	**145**	**44**	**89**	**57**

See Table 1 for key.

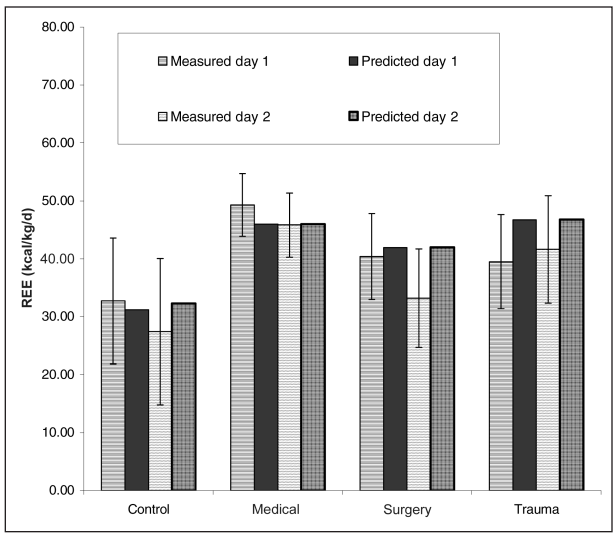

Figure 1—Evaluation of the measured and predicted resting energy expenditure (REE; adjusted mean ± 95% confidence interval) measured on 2 consecutive days in control dogs and dogs with medical illnesses, surgery, or trauma.

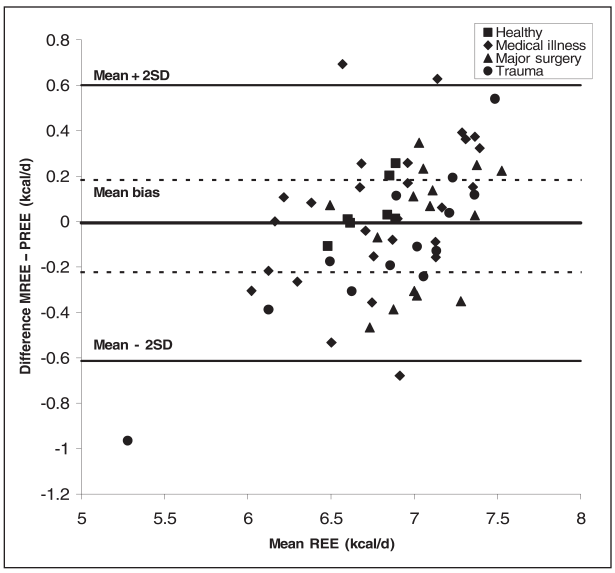

Figure 2—Bland-Altman bias plot comparing the difference in measured and predicted REE (MREE and PREE, respectively [natural logarithm scale]) versus mean REE on the first of 2 consecutive days in control dogs and dogs with medical illnesses, surgery, or trauma. Upper and lower solid lines indicate the 95% confidence interval (mean ± 2 SD) for the mean (center solid line). Dashed lines indicate the predefined target level of clinical agreement (± 20% difference between measured and predicted REE).

the means of the groups' logarithm ratios. However, there was a fixed effect of age (P = 0.043) and day (P = 0.035) and a random effect of the individual performing the test. The MREE declined by 2.58% per year of age and accounted for 10.87% of the total variation observed. The variable day accounted for 14.6% of the total variation observed, and only 1% of the overall variation in the MREE could be attributed to the individual performing the reading. The adjusted mean value of the MREE versus the adjusted mean PREE in healthy dogs, dogs with medical diseases, or dogs with trauma were not significantly different on either day. The difference between the 2 methods on day 1 in the trauma group approached significance (P = 0.06). There was a significant (P = 0.02) difference between the MREE and PREE in dogs recovering from major surgery on the second day. The MREE was 20.95% less than the PREE (Figure 1).

Bland-Altman analysis[42] was performed to compare the difference between the 2 methods (natural log MREE – natural log PREE) versus the mean ([natural log MREE + natural log PREE]/2; **Figures 2 and 3**). For

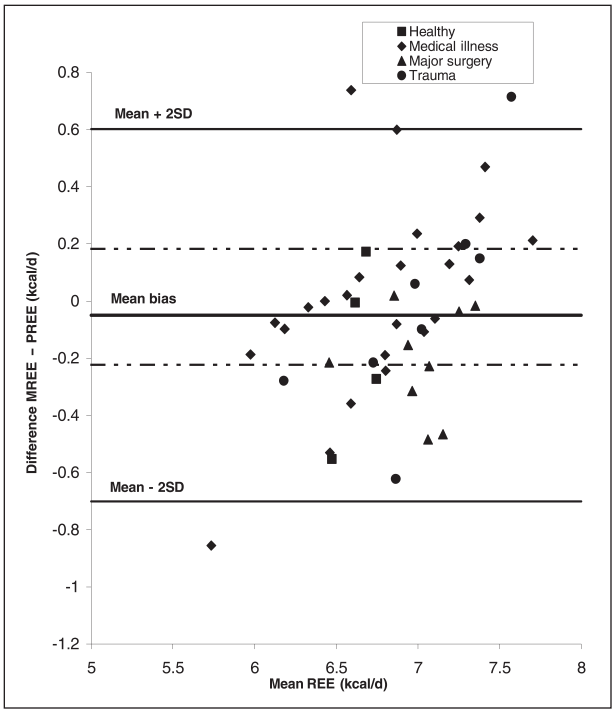

Figure 3—Bland-Altman bias plot comparing the difference in MREE and PREE (natural logarithm scale) versus mean REE on the second of 2 consecutive days in control dogs and dogs with medical illnesses, surgery, or trauma. *See* Figure 2 for key.

agreement between these methods, all the data points must be located between the dashed lines (± 20% difference). Many data points were outside these limits, which indicated poor agreement between the MREE and PREE on an individual dog basis in each of the 4 groups on either day. Moreover, 49% and 43% of the dogs' individual REE determinations differed by ≥ 40% on days 1 and 2, respectively. There was wide variation between the 2 methods on both days and across the 4 groups. The 95% confidence interval of the mean difference on day 1 (calculated from the antilog of the mean ± 2 SD) indicated that the PREE could be less than the MREE by as much as 82.4% or greater than the MREE by as much as 45.8%. These findings were similar on day 2 in which the PREE could be less than the MREE by as much as 82.2% or greater than the MREE by as much as 45.8%. There was no consistent bias (mean difference) on either day, even when the groups were examined individually. Inclusion or exclusion of the outlying data points did not have a significant influence on the overall results and they were therefore retained in the analysis.

Discussion

The study reported here revealed that mean values for MREE and PREE were not significantly different between healthy dogs and dogs with medical illnesses or trauma. The ability to predict the mean 24-hour REE in dogs recovering from major surgery was poor on the second study day. Walton et al[16] reported similar findings in a clinical study; measurement of REE via open-flow indirect calorimetry was performed in 104 dogs after surgery or trauma. Mean MREE (40.2 ± 3.14 kcal/kg/d) was significantly different from the PREE (50 kcal/kg/d). In our study, the combined mean MREE on day 1 for the surgery and trauma groups (39.9 kcal/kg/d) was similar to the findings by Walton et al[16]; the combined mean was slightly less (37.4 kcal/kg/d) on day 2. This difference may reflect the influences of analgesic medication, nutritional support, and repeated indirect calorimetry readings that were performed in our study. In our study, MREE was measured 3 times in a 24-hour period on the 2 study days; the previous study performed only 1 REE measurement on a single day. Several investigators have demonstrated that if the first measurement of the REE was used as an estimate of the 24-hour EE, an overestimation of the nutritional requirements would result.[35,37] However, this observation may not have any clinical importance because the 2 studies compared here had similar results for the mean MREE in dogs with trauma or after surgery despite the methodologic and equipment differences.

Mean values indicate only how the MREE and PREE typically differ each day in a group. In the study by Walton et al,[16] the mean MREE of the surgery or trauma group was 20% less than predicted. This is similar to our findings in which the mean MREE was 20% and 15.5% less than the PREE in the dogs recovering from major surgery (on day 2) and in dogs with trauma (on day 1), respectively. Group means do not provide information for determining REE on an individual dog basis, which is more relevant in a clinical setting. It is important to assess how well the MREE and PREE agree in an individual with a particular illness.[42] An acceptable level of agreement between the MREE and PREE was chosen prior to the start of the study; a difference of ≥ 20% between these 2 methods was chosen as the cutoff point at which agreement was considered poor. The 2 methods agreed in only 51% of the dogs on day 1 and 57% on day 2. No group had an acceptable level of agreement on either day. A consistent bias was not observed; therefore, a simple correction factor cannot be used to account for the difference between the 2 methods of REE determination. The MREE could not be reliably predicted from PREE in this study in the individual dog.

The body reacts to illness and injury in specific ways; however, the magnitude of response is not necessarily similar in each individual. There may be substantial biological variation in an individual's response to illness and injury, and it is these differences that are difficult to quantify and account for when using predictive equations. In our study, the predictive equation was able to estimate the group REE in healthy dogs and those with medical illnesses or trauma on both days. However, we also observed substantial variability in each individual dog's response to similar types of illness; the degree of variation between individual dog's MREE within the groups was so broad that the PREE was not able to accurately assess the energy needs for an individual dog in any of the groups. Substantial variability is observed in MREE of humans with similar diseases or injury, and the ability to precisely estimate the REE in hospitalized humans by use of predictive equations is also poor.[21,32] Predictive equations can estimate the energy requirements within a group of individuals with a similar illness or injury; however, they cannot estimate an individual's needs with any accuracy.

In veterinary medicine, there are further problems associated with the use of the PREE. This equation was derived earlier in the 20th century by measuring the fasting REE in a range of adult animals from as small as a mouse to as large as an elephant.[17] The predictive equation's ability to predict REE is based on the assumption that the body weight in kilograms to the power function of 0.75 reflects the metabolically active portion of the body and assumes a normal body composition.[21] There is compelling evidence that this assumption is incorrect in healthy dogs.[19,a] One can expect that in ill dogs in which the measured weight and body composition are altered because of disease conditions, a catabolic metabolic state, extracellular volume changes, and IV fluid administration, greater imprecision of the predictive equation's ability to estimate the 24-hour REE will be observed. Also, the accuracy of the equation is dependent on the range of weights studied; when the range of weights is narrow, large errors in the PREE may occur.[15,17] Another potential problem with the PREE is in the estimation of the severity of illness or injury-correction factors. The illness factors have been derived from clinical human data and are not based on experimental data in dogs.[14,15,18] They are simply a subjective estimate of the severity of illness or injury in a dog and can vary with the individual assessor.

Discrepancy between the MREE and PREE is inevitable and may be attributable to the inherent variability of MREE, measurement errors, or inherent errors in the predictive equation that is used for dogs. The open-circuit calorimetry method is accurate but requires meticulous calibration of gas sensors and flow meters, strict protocols, and excellent technique.[23,24,26,29,33,43] Some degree of error is inevitable in the collection of metabolic measurements in the clinical setting and is inherent in the equations and assumptions that form the basis of indirect calorimetry.[26] Measured REE must be performed in a metabolic steady state to obtain an accurate assessment of the REE; otherwise, artifact may be introduced into the measurement.[35] A metabolic steady state implies that all oxygen consumed and all CO_2 produced are attributable to metabolic processes. This assumption holds true if the body is at rest and there are no alterations in the body stores of these gases. The body gas stores are influenced by any factor that alters the minute ventilation, such as pain, anxiety, restlessness, hypoventilation, or hyperventilation.[35] In the study reported here, we attempted to minimize any artifact and standardize measurement of the REE by defining a steady state,[44] performing multiple readings,[34,36,37] performing the test after a period of rest for at least 30 minutes,[35,38] allowing at least 30 minutes after administration of analgesic medication,[45] allowing 30 to 60 minutes after a diagnostic or therapeutic procedure or physical activity,[36] and allowing 3 hours after a meal.[21,25,29] Results of a previous study[34] that used this methodology have indicated the reliability and accuracy of this method in healthy dogs. In the study reported here, the variability of the $\dot{V}O_2$ and $\dot{V}CO_2$ measurement (coefficient of variation) used to define the steady state was expanded from 5%, as used in humans, to 10% in the ill dogs and 15% in the healthy dogs.[21,44] The expanded range was adopted because of the variable nature of the conscious dogs' respiratory patterns. There was considerable variation in the MREE that could not be attributed to a single physiologic parameter (ie, body temperature, heart rate, or respiratory rate). However, the variables of day and age did account for approximately 24% of the total variability observed in the MREE. Also, approximately 1% of the overall variation in the MREE could be attributed to the individual performing the reading. A more rigorous training period in the methodology of the system may have decreased or eliminated this random error in our study. However, this random error was likely not an important source of the differences observed between the 2 methods of REE determination.

Both methods have drawbacks associated with determination of the REE. The traditionally used predictive equation for the estimation of REE does not take into account the important biological diversity in individual dogs, even if a correction factor is applied, and the equation itself may not be valid in healthy dogs.[19] Indirect calorimetry does have some inherent variability associated with its measurement of REE; however, if strict adherence to methodology is used, reliable results may be obtained even in critically ill patients. Furthermore, the methodology of indirect calorimetry has been validated in multiple human studies[7,24,25,28,29] in which the reproducibility and accuracy of the technique under a variety of situations have been compared with direct calorimetry, methanol burning, and mass spectrometry. The use of indirect calorimetry is in the initial stages in veterinary medicine; however, results of several studies[33,34] indicate the reliability and accuracy of indirect calorimetry in healthy dogs. Results of a previous study[33] performed by our group also indicate that the equipment is accurate when compared with a traditional gold standard (close-circuit spirometer) and provides reliable results over a 2-day period in healthy dogs. The principles of indirect calorimetry and the theory of measuring REE on the basis of $\dot{V}O_2$ and $\dot{V}CO_2$ and nitrogen excretion have been known for almost a century.[24,29,46] However, until recently, the application of these principles has been hampered by cumbersome gas collection methods. With the advent of newer technology and portable machines, indirect calorimetry has become the clinical gold standard for the measurement of REE at the bedside of hospitalized humans.[29,31,32] With the validation of this technique in healthy animals, it is only a matter of time until indirect calorimetry becomes the clinical gold standard in veterinary medicine as well.

[a]Darmaun D, Maroit S, Martin P, et al. Assessment of the effect of weight loss on energy expenditure by doubly-labeled water method in obese dogs (abstr). *J Vet Intern Med* 2000;14:237.
[b]Eukanuba Low Residue, Iams Co, Dayton, Ohio.
[c]Eukanuba Maintenance, Iams Co, Dayton, Ohio.
[d]TEEM 100 metabolic apparatus, Aerosport Inc, Ann Arbor, Mich.
[e]Hans Rudolph Inc, Kansas City, Mo.
[f]SAS/STAT software, SAS Institute Inc, Cary, NC

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